IoT-Based Controlled Environment System for Optimized Mushroom Production

Nina Korlina Madzhi*, Mohamad Mukhmin Bin Ridzuan

Abstract—**Most mushroom farming in Malaysia is carried out on a small scale and depends largely on manual labour. Any changes in temperature, humidity, air quality and light often affect mushroom growth. The temperature must not be too hot or too cold. Humidity must be high enough to keep the growing blocks moist and the light exposure to the mushrooms block must be appropriate to support the formation of mushroom caps. It all these conditions are not within the suitable ranges, it will slow down the mushroom growth, uneven yield among blocks or no yield at all. This study presents the design, implementation, and evaluation of a low-cost Internet of Things (IoT)–based controlled environment system to enhance mushroom cultivation. It integrates environmental sensors with an ESP32 microcontroller to enable real-time monitoring and regulation of temperature, humidity, and CO_2 levels. Experiments were conducted under four conditions: automated controlled environment, manual spraying, dark enclosure, and natural open condition. Results demonstrate that the IoT-controlled environment consistently produced the highest mushroom yield and the most stable growth conditions, outperforming manual and uncontrolled setups. Dark and minimally regulated environments resulted in negligible or zero yield. The findings confirm that automated environmental control improves productivity, reduces variability, and minimizes crop loss, particularly for resource-limited small-scale farmers. This study highlights the potential of affordable IoT solutions in supporting sustainable agricultural practices and smart farming adoption in developing contexts.**

Index Terms—**Agriculture, Internet of Thing (IoT), Mushroom farming.**

I. INTRODUCTION

Mushroom cultivation is increasingly recognised as a viable agro-based activity due to its short production cycle, low land requirement, and high economic and nutritional value. In Malaysia, mushroom industry remains largely small-scale, with productivity often limited by inadequate environmental control, manual farm management practice which leads to inconsistent environmental control and variable yields[1]. Compared to conventional crops grown in open fields, mushroom cultivation requires precise control of microclimatic factors, including temperature, relative humidity, carbon dioxide concentration, and light exposure. Maintaining these parameters within suitable limits is critical to ensure optimal yield and quality.

Mushroom cultivation farm needs a good monitoring particularly the temperature, humidity, carbon dioxide level and light intensity[2]. Without automated environmental control, mushroom farms are highly dependent on external climatic conditions, resulting in fluctuating temperature and humidity levels that must be manually regulated by farmers, often leading to inconsistent growing environments[3]. To overcome these limitations, a controlled environment system is proposed to maintain stable growing conditions within the mushroom farm.

Environmental sensors are used to monitor temperature, humidity, carbon dioxide concentration, and light intensity, allowing timely detection of environmental changes and automated regulation to enhance mushroom growth, reduce crop losses, and improve production consistency[4]. Based on the sensor readings, the system continuously compares the measured values with predefined optimal ranges. When a deviation is detected, the controller automatically activates the appropriate actuators, such as ventilation fans, humidifiers, or lighting systems, to restore suitable growing conditions. In addition, real-time environmental data are displayed on a smartphone interface, allowing users to monitor conditions and receive alerts when values fall outside acceptable limits.

II. METHODOLOGY

A. Overall System Block Diagram

Fig. 1. illustrates the block diagram of the proposed controlled environment system with smartphone-based monitoring. The SCD40 sensor is used as the input device to measure temperature, relative humidity, and carbon dioxide (CO_2) concentration within the cultivation area. The measured data are processed by an ESP32 microcontroller, which enables real-time data transmission and notification delivery to the user via a Telegram-based smartphone interface. To control the humidity in the mushroom farm, humidifier will be turn on or turn off according to the set desired value that detect by the SDC40 sensor. Fan will be turn on to control the CO_2 level and temperature in the project environment.

This manuscript is submitted on January 23, 2026, revised on March 22, 2026, accepted on March 27, 2026 and published on April 30, 2026.

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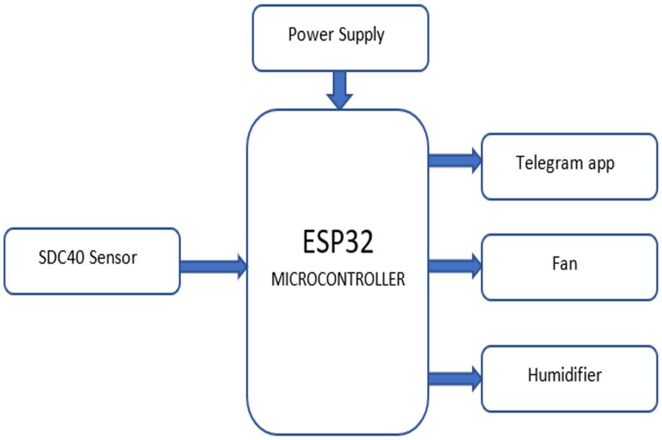

Fig. 1. Block diagram

B. System Circuit Configuration and Integration

Fig. 2 presents the circuit diagram of the proposed IoT-based environmental control system. The system continuously monitors temperature, relative humidity, and carbon dioxide (CO_2) concentration and regulates these parameters by controlling actuators such as ventilation fans and a humidifier based on sensor feedback. An ESP32 microcontroller serves as the central processing and communication unit, enabling real-time control and wireless data transmission. Two SCD40 sensors are interfaced through a TCA9548A I²C multiplexer to support simultaneous data acquisition from multiple locations. A relay module is incorporated to control the humidifier, ensuring safe and reliable operation. The circuit diagram illustrates the complete electrical connections among the microcontroller, sensors, actuators, and power supply components used in the prototype system.

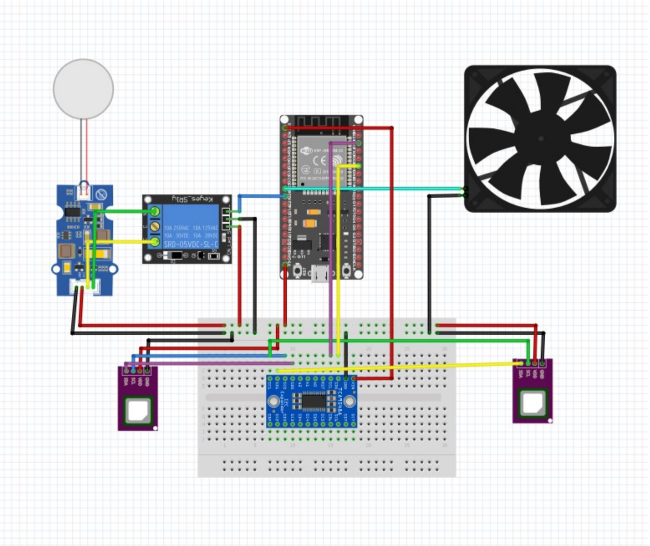

Fig. 1. Circuit Diagram

Fig.3 illustrates the operational flow of the proposed controlled environment system for mushroom cultivation. The process begins with system initialization, during which the microcontroller configures all input–output interfaces with the environmental sensors. Once the sensor data are obtained, the system executes a series of conditional control routines to evaluate whether each parameter falls within predefined optimal thresholds for mushroom growth. The first control routine assesses the temperature condition. If the measured temperature deviates from the specified range, the controller generates a control signal to activate the appropriate actuator, such as ventilation or cooling mechanisms, in order to restore thermal stability within the cultivation chamber.

C. *Flow Chart How to Create a PostScript File*

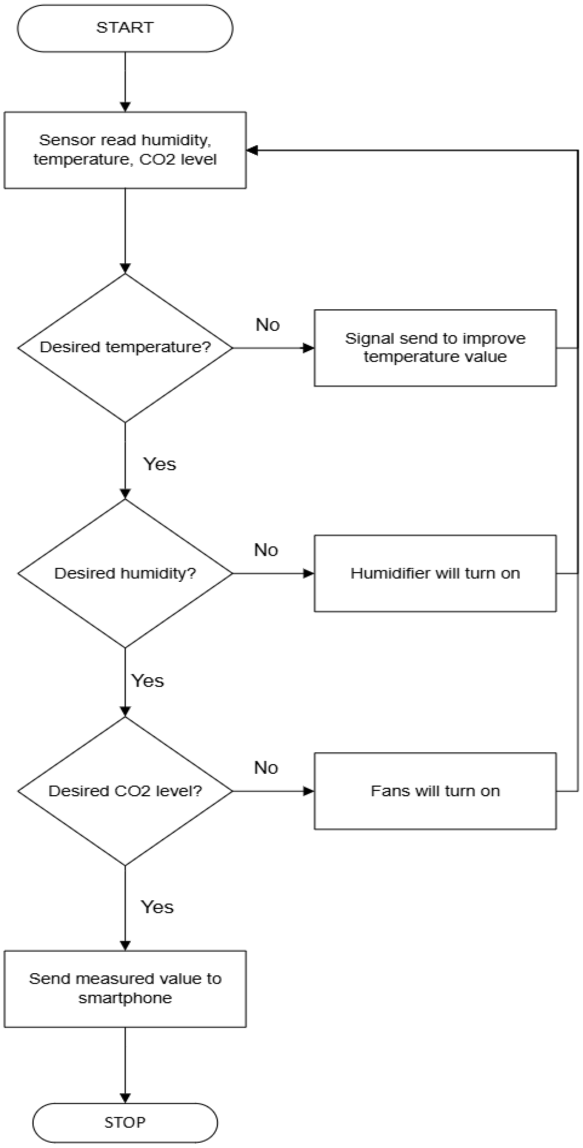

Fig. 3. Flowchart

Next, the system evaluates the relative humidity level. When the humidity reading falls below the predefined threshold of 80%, the humidifier is automatically activated to increase moisture content and maintain suitable conditions for mycelial growth and fruiting development [5]. Similarly, the CO_2 concentration is continuously monitored, and when the measured value exceeds 600 ppm, ventilation fans are triggered to enhance air circulation and reduce CO_2 accumulation within the enclosure.

The system then transmits the real-time sensor readings to a smartphone through a wireless communication interface, such as Wi-Fi or Bluetooth. This enables remote monitoring and provides users with up-to-date information on the environmental status of the mushroom farm. The control loop then repeats continuously, allowing the system to dynamically adapt to environmental changes and maintain stable growth conditions throughout the cultivation period.

D. Experimental Setup and System Implementation

The experimental setup was designed to replicate common mushroom farming practices under different environmental conditions in order to evaluate the effectiveness of the proposed controlled environment system. A hardware prototype was deployed across four distinct cultivation environments, representing controlled, manually managed, enclosed dark, and natural open conditions. Each environment contained two mushroom blocks, labelled NA1–NA2, NB1–NB2, NC1–NC2, and ND1–ND2, respectively, to account for variability between cultivation substrates and to allow meaningful comparison of mushroom growth performance, yield, and environmental stability across different farming conditions.The first condition, referred to as Box 1, represents the controlled environment setup, as illustrated in Fig. 4.

Fig. 4. Controlled environment condition

This configuration employs sensors and actuators to maintain predefined environmental thresholds. An SCD40 sensor continuously measures temperature, relative humidity, and carbon dioxide (CO_2) concentration inside the enclosure. When the temperature exceeds 30 °C, a ventilation fan is automatically activated, while a humidifier is triggered when relative humidity falls below 80%. A moist towel is placed above the mushroom blocks to assist in moisture retention, and the enclosure is covered with a plastic net to allow limited light penetration and ventilation.

Fig.5. Manually control condition

The second experimental condition (Box 2), as shown in Fig. 5 represents a manually managed cultivation environment that reflects common mushroom farming practices. In this setup, relative humidity was maintained through manual water misting conducted twice daily, while temperature and carbon dioxide (CO_2) concentration were not actively controlled and were allowed to fluctuate with ambient conditions. The mushroom blocks labelled NB1 and NB2 were used to examine the impact of manual environmental management on mushroom growth and yield consistency. The absence of automated regulation in this condition resulted in variable environmental parameters, which contributed to inconsistent mushroom development when compared with the controlled environment setup.

Fig. 6. Dark condition (Box3)

The third experimental condition (Box 3), as illustrated in Fig.6, represents a dark and fully enclosed cultivation environment with no active environmental regulation. In this configuration, the mushroom blocks labelled NC1 and NC2 were placed inside a closed container without any form of misting, ventilation, or automated control. The enclosure was opened only once per day for visual inspection and environmental data recording. As a result, temperature, relative humidity, and carbon dioxide (CO_2) concentration were allowed to fluctuate naturally within the confined space, leading to limited air exchange and reduced moisture availability.

This condition was designed to evaluate mushroom growth performance under extreme environmental constraints, where the absence of humidity control and airflow restricts the formation of a favourable microclimate. The enclosed nature of the setup promotes CO_2 accumulation and moisture depletion over time, conditions that are generally unfavourable for mushroom fruiting. Observations from this condition provide a baseline for assessing the minimum environmental requirements for mushroom cultivation and highlight the critical role of controlled humidity and ventilation in supporting successful mushroom development.

Fig. 7. Normal condition

The fourth condition, referred to as the normal environment (Fig.7.), involves placing the mushroom blocks in an open setting without enclosure or environmental regulation. While similar to the dark condition in terms of control, this setup allows exposure to ambient environmental conditions. Storage boxes with net coverings are used for Box 1 and Box 2, whereas the normal condition remains fully open. Environmental measurements across all conditions are obtained using two SCD40 sensors. One sensor is permanently installed in the controlled environment, while the second sensor is sequentially placed in the remaining conditions, allowing a stabilisation period of five minutes before data acquisition.

The software component of the proposed system is developed using the Arduino IDE platform. Control algorithms are implemented to compare sensor-derived temperature, humidity, and CO_2 values against predefined optimal thresholds and to initiate appropriate control actions based on real-time feedback. For remote accessibility, the system is integrated with a Telegram bot, allowing users to interact with the system via a smartphone interface. Environmental parameters can be queried through predefined commands, with real-time sensor readings returned to the user for continuous monitoring.

III. RESULTS AND DISCUSSIONS

The results obtained from the experimental evaluation are presented in terms of environmental parameters and mushroom yield performance across four different cultivation conditions. Measurements of CO_2 concentration, temperature, and relative humidity were recorded over a 10-day observation period and analysed to assess the influence of environmental regulation on mushroom development. The discussion focuses on comparing controlled and non-controlled environments to determine how variations in microclimatic conditions affect mushroom productivity and growth reliability.

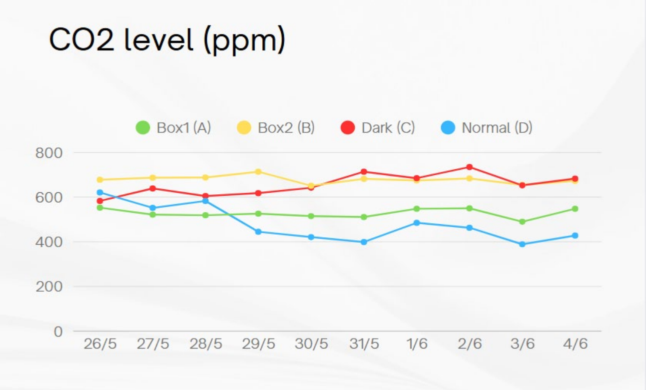

Fig. 8. CO_2 concentration level graph

Fig.8 presents the CO_2 concentration profiles for all four experimental conditions. The Dark (C) condition consistently recorded the highest CO_2 levels, reaching a peak of 735 ppm, primarily due to limited ventilation and restricted air circulation, which promoted CO_2 accumulation within the enclosed environment[8]. The Box 2 (B) condition recorded the second-highest CO_2 level, slightly below that of the Dark (C) condition. This suggests that although Box 2 may offer some ventilation or light exposure compared to the dark condition, it still restricts airflow to a degree that results in noticeable CO_2 accumulation. This intermediate level of CO_2 may be attributed to semi-closed spatial characteristics that limit gas diffusion[9].

In contrast, the Normal (D) condition, which represents an open and naturally ventilated environment, exhibited lower CO_2 concentrations due to increased airflow and natural gas diffusion with the surrounding environment [10]. The controlled environment (Box 1, A) recorded the lowest CO_2 levels among all conditions, indicating effective air exchange and stable environmental regulation. This condition serves as a baseline for comparing the influence of different cultivation environments on CO_2 accumulation. Overall, the results demonstrate that ventilation and environmental control play a significant role in regulating CO_2 concentration, which is a critical factor affecting mushroom growth and cultivation performance [11].

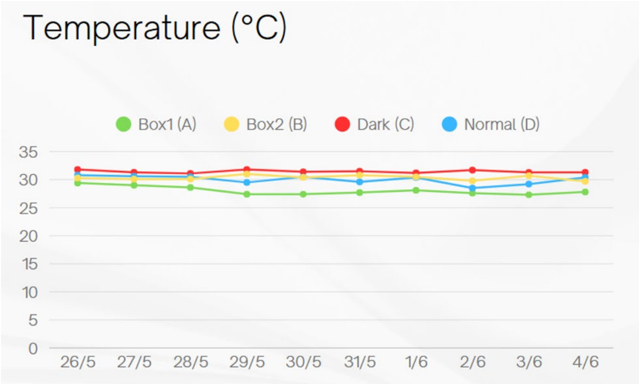

Fig. 9. Temperature graph

Fig. 9 presents the temperature profiles recorded under the four experimental conditions. The Dark (C) condition consistently exhibited the highest temperatures, primarily due to the enclosed structure and lack of ventilation, which limited heat dissipation and promoted heat accumulation [12]. The manual condition (Box 2, B) recorded the second-highest temperatures. Although occasional manual ventilation was possible, the semi-enclosed configuration restricted effective heat removal, resulting in elevated but lower temperatures compared to the dark condition [13]. In contrast, the controlled environment (Box 1, A) maintained the lowest temperature levels among all conditions, reflecting effective ventilation and environmental regulation. This stable thermal environment is favourable for mushroom growth, as excessive temperature fluctuations can negatively affect fungal development [14].

Overall, the findings suggest that degree of enclosure and ventilation significantly affects temperature retention within the mushroom growing environments. Higher temperatures in enclosed or poorly ventilated conditions can impact fungal development by affecting moisture retention and metabolic activity[16]. Therefore, selecting an appropriate environmental setup is essential to maintain the thermal conditions suitable for optimal mushroom cultivation.

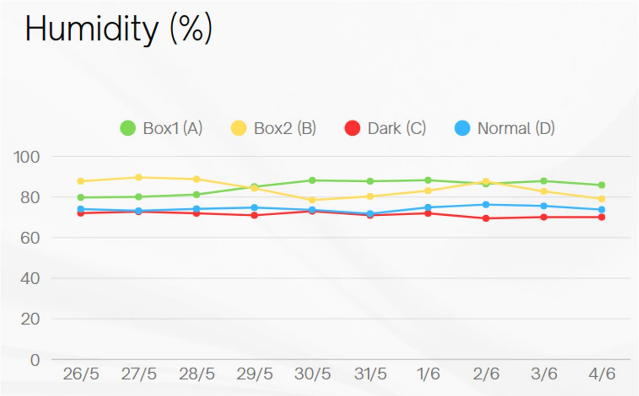

Fig. 10. Humidity graph

Fig. 10 presents the relative humidity levels measured across the four experimental conditions during the 10-day observation period. Among all conditions, the manual setup (Box 2, B) recorded the highest humidity levels, with average values ranging from 82% to 85%. This indicates effective moisture retention due to regular manual misting, which is essential for supporting mushroom colonisation and fruiting processes [17]. The controlled environment (Box 1, A) maintained slightly lower but more stable humidity levels, ranging between 78% and 82%. This stability reflects effective environmental regulation through controlled misting and ventilation, providing conditions suitable for consistent mushroom growth and serving as a reference baseline for comparison.

In contrast, the dark and enclosed condition (Box 3, C) exhibited the lowest humidity levels, averaging between 65% and 68%. The absence of misting and limited air exchange contributed to gradual moisture loss, resulting in conditions that are less favourable for mushroom development. Similar trends have been reported in enclosed cultivation environments without active humidity control [18]. The normal condition (D), representing a naturally ventilated environment, recorded moderate humidity levels of approximately 68% to 70%. While airflow supported ventilation, it also promoted moisture dissipation, limiting the ability to maintain high humidity.

Overall, these results highlight the importance of effective humidity management, particularly misting and enclosure design, in sustaining suitable growing conditions for mushroom cultivation, as humidity directly influences pinhead formation and fruiting body development.

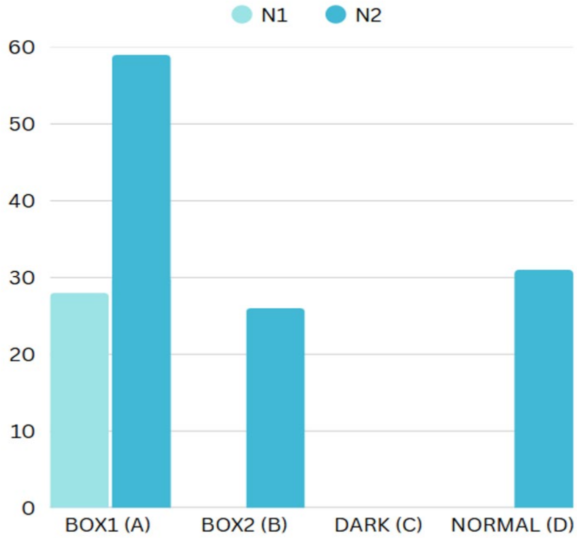

Fig. 11. Weight of each block mushroom produced

Fig. 11 presents the total mushroom yield obtained from each experimental condition based on two replicates per setup. The results indicate that environmental management had a significant effect on mushroom productivity.The controlled environment (Box 1, A) produced the highest yields, with sample A2 yielding 59 g and sample A1 yielding 28 g. This outcome reflects the effectiveness of automated humidity and airflow control in maintaining a stable microclimate that supports mushroom growth and fruiting. Similar findings have been reported in studies highlighting the advantages of controlled environments in enhancing yield consistency [19].The normal condition (D) produced the second-highest yield; however, only one replicate (D2) yielded mushrooms (31 g), while the other showed no growth.

This variation suggests that environmental fluctuations in open conditions can limit yield consistency [20].Under the manual condition (Box 2, B), mushroom production was limited, with only one replicate (B2) yielding 26 g. The reliance on periodic manual misting likely resulted in inconsistent moisture levels, which are insufficient to support uniform mushroom development [21].No mushroom growth was observed in the dark enclosed condition (Box 3, C). The absence of misting, ventilation, and light created unfavourable conditions for fruiting, highlighting the importance of adequate environmental control for successful mushroom cultivation [22].

Overall, the yield results demonstrate that stable and automated environmental control, particularly of humidity and ventilation, is critical for achieving consistent and high mushroom production. In contrast, manual and uncontrolled cultivation methods are less reliable and prone to variable outcomes.

IV. CONCLUSION

This project successfully developed an IoT-based system to improve mushroom cultivation by automatically controlling key environmental factors such as temperature, humidity, and CO_2 using sensors and an ESP32 microcontroller. The system also allowed real-time monitoring through the Telegram app. Four environmental setups were tested: controlled (Box 1), manual spray (Box 2), dark condition (Box 3), and natural condition (Box 4). The controlled environment (Box 1) produced the highest and most consistent yields, with NA2 reaching 59 grams and NA1 at 28 grams. In comparison, other conditions showed poor or no yield due to unstable growing environments.

ACKNOWLEDGMENT

The authors would like to express their sincere appreciation to the Faculty of Electrical Engineering, Universiti Teknologi MARA, for providing the facilities, technical support, and conducive research environment that made this study possible.

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