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Design and implementation of an IoT-based microclimate control system for oyster mushroom cultivation

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Abstract Oyster mushrooms are renowned for their outstanding nutritional content and medicinal attributes that have grown in popularity due to their cholesterol-free, protein-rich nature. However, the current demand surpasses the available production capacity and necessitates implementing an Internet of Things (IoT) enabled microclimate control system for cultivating oyster mushrooms. The ESP32 microcontroller powers the central processing unit of this system, working in conjunction with a DHT22 temperature and humidity sensor. The main actuators in the system include a 12 V DC water pump sprinkler and an AC exhaust fan. The system centrally controls the LED tube lighting within the mushroom house. It achieves temperature and humidity regulation within the mushroom house using fuzzy logic algorithms. The Arduino Cloud platform monitors microclimate parameters and enables remote lighting control via IoT switches. The DHT22 temperature and humidity sensor has demonstrated remarkable precision, featuring an R-squared value of 0.998 for temperature and 0.992 for humidity. Furthermore, it maintains minimal Mean Absolute Percentage Error (MAPE) values, recording only 0.49 % for temperature and 1.09 % for humidity. Data on temperature, humidity, fan and sprinkler operation times, and LED status is logged every minute in a Google sheet connected through internet service, ensuring data accuracy and integrity. This IoT-based microclimate control system effectively maintains a consistent temperature and humidity environment conducive to the optimal growth of oyster mushrooms within the mushroom house. This innovative solution holds great promise in addressing the production deficit and enhancing the quality of oyster mushroom cultivation.

Keywords: Oyster mushroom, IoT-enabled, ESP32, Fuzzy logic, DHT22 sensor, Microclimate control system

Introduction

Oyster mushrooms represent a distinctive fungal variety characterized by their unique oyster-shaped caps and truncated stems. Classified within the *Agaricaceae* family and the *Basidiomycetes* class, these fungi are notable for their lack of chlorophyll and reliance on organic matter decomposition in

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their substrate for nutrient acquisition. This metabolic strategy endows them with the remarkable ability to convert agricultural, agro-industrial, and forest waste into high-protein, nutrient-dense food resources (Nongthombam *et al.*, 2021; Sánchez, 2010; Singh *et al.*, 2022). The nutritional profile of oyster mushrooms is noteworthy, offering a rich content of fat, protein, iron, phosphorus, riboflavin, thiamine, and a complement of 18 essential amino acids while remaining devoid of cholesterol (Setiawati *et al.*, 2021). This unique blend of nutritive value and a distinctive flavour has earned them the epithet "boneless vegetarian meat" (Panjikkaran and Mathew, 2013).

In addition to their culinary allure, oyster mushrooms exhibit medicinal properties (Gundoshmian *et al.*, 2022). Their consumption has proven advantageous for individuals with cardiac and diabetic conditions. Consequently, the demand for oyster mushrooms has been on the ascent, attributable to their combined nutritional and therapeutic benefits.

The burgeoning global population and challenges posed by climate change have imposed limitations on conventional crop cultivation (FAO, 2015), necessitating innovative approaches to augment agricultural productivity. Reducing these constraints involves providing favourable climate conditions during cultivation, which is often contingent on the availability of agricultural labour, an aspect that has experienced a decline in recent years (Srivastava *et al.*, 2020). This decline in labour issue can be mitigated by the adoption of microcontrollers and IoT (Internet of things), which provide more yield than the conventional manual temperature and humidity control system in oyster mushroom cultivation (Setiawati *et al.*, 2021; Hendrawan *et al.*, 2019). Ariffin *et al.*, (2020) introduced an automated climate control system for mushroom cultivation, utilizing an Internet of Things (IoT) approach. This innovative system incorporates ESP8266, two DHT22 sensors, an exhaust fan, water pump, and other components. This system effectively regulated temperature and humidity within the desired range, substantially reducing the need for human intervention. The evaluation of fuzzy logic's efficiency in controlling the temperature and humidity within a mushroom cultivation chamber demonstrated a substantial water-saving potential of up to 40 %. Moreover, this application of fuzzy logic also led to a remarkable increase in mushroom yield, achieving an impressive growth of up to 226 % (Ariffin *et al.*, 2021). A comprehensive comparison of manual control, threshold control, and fuzzy logic in regulating temperature and humidity in a mushroom cultivation chamber revealed distinct outcomes. The average oyster mushroom mass was 83.00 g with manual control, 104.00 g with threshold control, and significantly increased to 132.33 g with fuzzy logic control. Additionally, the average oyster mushroom stem length was 57.2 mm under manual control, 60.5 mm under threshold control, and improved to 62.3 mm with fuzzy logic control. These results highlight the superior performance of fuzzy logic in enhancing mushroom growth (Hendrawan *et al.*, 2019). In the comparison between fuzzy logic and feed-forward neural networks, it was observed that fuzzy logic required more time to stabilize or reach the desired temperature range, particularly when the temperature exceeded 36 °C. However, there was relatively little difference in the time required for temperature control when the temperature remained below 36 °C (Adhitya *et al.*, 2016).

The objective of the present study was to develop a fuzzy logic-based IoT control system to monitor and control the environmental parameters such as temperature and humidity with the provision of storing data in Google sheet.

Materials and methods

The IoT-based environmental parameters monitoring and controlling system of the oyster mushroom cultivation chamber was developed and evaluated in the agricultural engineering section of the division of system research and engineering, ICAR Research Complex for North Eastern Hill Region, Umiam, Meghalaya, India. The evaluations were conducted from July to November 2023.

Oyster mushroom

The selection of the oyster mushroom (*Pleurotus pulmonarius*) variety as the planting material for evaluating the developed system is attributed to the climatic suitability of Umiam, Meghalaya. The preparation involved the utilization of paddy straws, which were initially chopped using a chaff cutter and subsequently soaked in water overnight. Following this overnight immersion, the soaked straw underwent a 1 hour autoclave treatment and was then allowed to cool under shading on trays. Approximately 4 kg of the cooled straw was subsequently packed in a polyethene bag in five stratified layers, each interspersed with 25 g of mushroom spawn. A visual representation of this process is provided in Figure 1. To facilitate aeration, random perforations with a diameter of approximately 10 mm were introduced at intervals of about 50 mm on the surface of the packed bag as illustrated in Figure 2. These prepared bags were placed within the mushroom cultivation chamber as shown in Figure 3.

Mushroom cultivation chamber

The evaluation took place within a chamber constructed with steel and insulated with Polyisocyanurate Sandwich Panels. The chamber's dimensions measured 3500 mm in length, 2500 mm in width, and 3000 mm in height as illustrated in Figure 4.

Figure 1. Layer filling of straw in the bag

Figure 2. Aeration hole on the surface of the bag

Figure 3. Bag inside the mushroom cultivation room

Figure 4. Mushroom cultivation chamber

Figure 5. Air circulation arrangement provided in the chamber

The chamber's doors remained open, with cloth curtains affixed, to facilitate air circulation with the aid of an electric fan while concurrently shielding the interior from direct sunlight, as depicted in Figure 5. Oyster mushrooms require darkness during the mycelium growth phase and necessitate light exposure during the fruiting stage. This requisite lighting was fulfilled by incorporating LED (Light Emitting Diode) tube light fixtures within the chamber, controllable via an Internet of Things (IoT) system. Additionally, racks were installed inside the mushroom chamber to accommodate the mushroom bags.

IoT-based Mushroom chamber environmental control system

The system primarily regulates temperature and humidity in accordance with the specific needs of oyster mushrooms. Light exposure is synchronized with the fruiting stage via an IoT mechanism. The developed system comprises an ESP32 microcontroller serving as the central computing unit. This microcontroller unit is equipped with integrated Wi-Fi capability. The electronic circuit diagram of this developed system is illustrated in Figure 6. In order to establish a connection to the internet, the control system is connected to the web using a portable broadband device as illustrated in Figure 7.

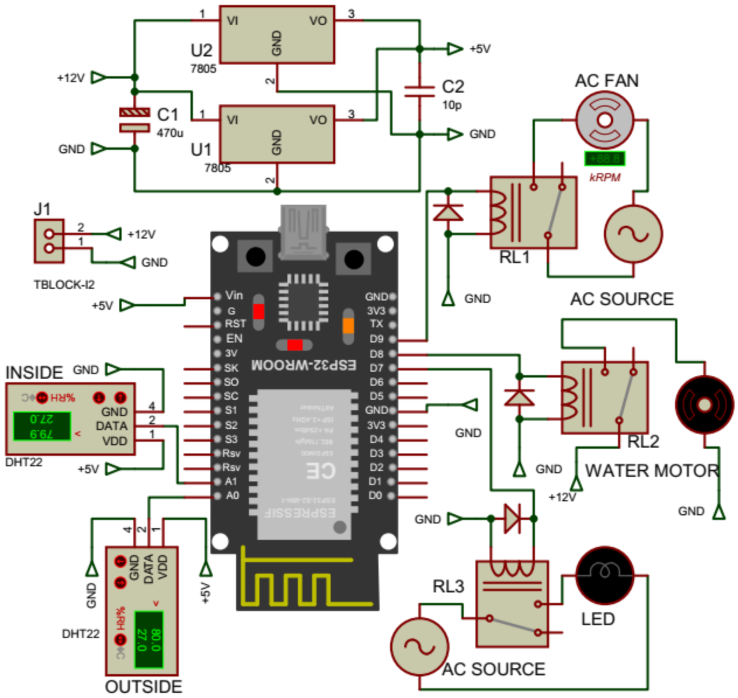


Figure 6. Circuit diagram of IoT-based temperature and humidity control system

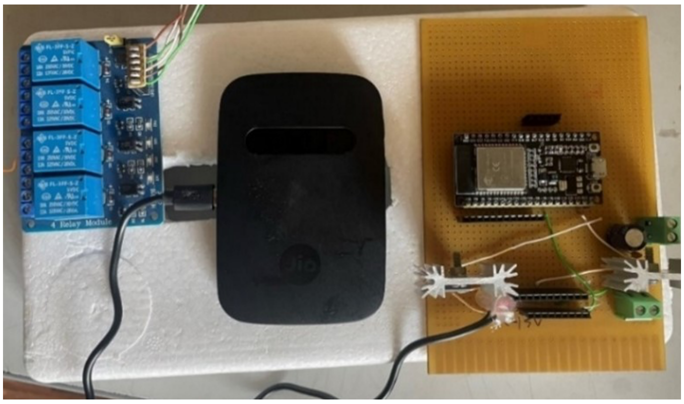


Figure 7. The developed IoT-based temperature and humidity control system

Figure 8. DHT22 sensor

The system incorporates two DHT22 sensors (https://www.kuongshun-ks.com/uno/uno-sensor/dht22-am2302-digital-temperature-humidity-sensor.html) as shown in Figure 8, for temperature and humidity measurements. These sensors are strategically positioned to monitor both the internal conditions within the mushroom chamber and the uncontrolled external environment. Additionally, a 65 W AC fan with a diameter of 230 mm, illustrated in Figure 9 which was employed to facilitate efficient air circulation within the mushroom chamber. This fan serves the dual purpose of homogenizing the air inside the chamber and expelling stale air while introducing fresh external air into the chamber.

Figure 9. AC Fan

Figure 10. DC Water pump with sprinkler

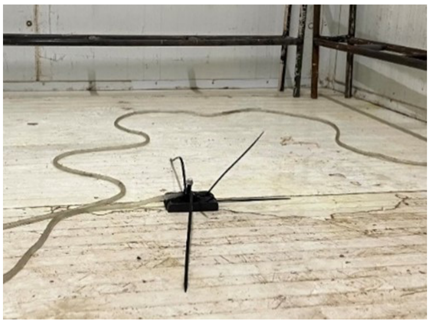


Figure 11. Water sprinkler

Figure 12. LED tube light

The optimal environmental conditions for oyster mushroom cultivation include a 16 to 30 °C temperature range and humidity levels exceeding 80 %. It is important to note that during the mycelium growth phase, the absence of light is required, while during the fruiting period, the mushroom benefits from light exposure with an intensity falling between 200 to 300 lux (Saraswati *et al.*, 2022).

Humidity inside the mushroom chamber is maintained by sprinkling water as needed by the system through a 12 V DC-powered water pump as in Figure 10 and a sprinkler in Figure 11. The discharge from the water sprinkler was measured with the help of a measuring cylinder and stopwatch after operating the pump for 20 seconds. The mushroom cultivation chamber needs to be protected from light during the incubation period (from planting to full mycelium run). Once the mycelium run is completed, it requires light for fruiting. The LED light inside the mushroom chamber supplies this light requirement. The LED light switch is controlled through the relay with the help of an IoT switch, i.e., the operator controls the switch as and when required remotely through IoT. Light intensity inside the mushroom chamber is measured with the help of line quantum sensors and determines the number of LED tubes to provide the desired light intensity. The developed system required 12 V DC power, which was fulfilled with the help of a 12 V 40 Ah battery and 220V AC grid power. The 12 V DC battery was charged using a 12 V, 5 A DC charger for 8 hours once every 3 days. The consumption of DC power was quantified with a high-precision 150 A DC-wattmeter.

Temperature and humidity inside the mushroom chamber are controlled by using fuzzy logic. The temperature and humidity from the DHT22 inside the mushroom chamber are provided as input to the fuzzy logic and the duration of operation of the fan and water sprinkler pump as output of fuzzy logic. The triangular membership function plot for the input variable temperature and humidity are illustrated in Figures. 13 and 14, respectively. The five membership values of the temperature membership function are tooCold, cold, normal, hot and tooHot, whereas tooDry, dry, normal, humid and tooHumid are the five membership values of the humidity membership function.

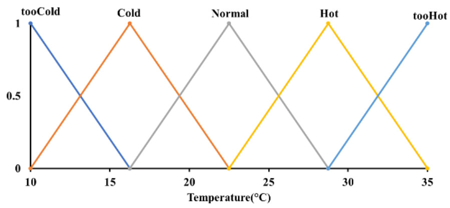


Figure 13. Membership function plot for temperature

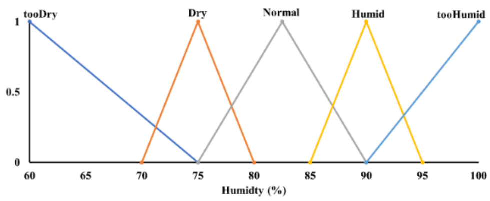


Figure 14. Membership function plot for humidity

The membership function plot for the output variable duration of the active period of the fan and water sprinkler pump are shown in Figures 15 and 16, respectively.

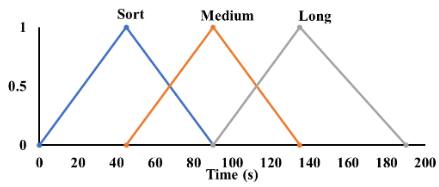


Figure 15. Membership function plot for fan

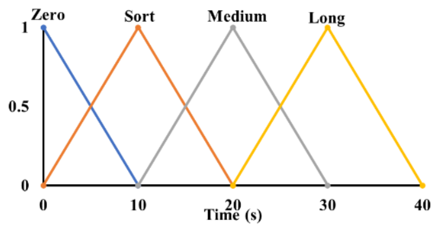


Figure 16. Membership function plot for sprinkler

The fuzzy logic rules for the input and output parameters are given in Table 1. These rules dictate the behaviour of the system based on input conditions. For instance, if the temperature is categorized as “Cold” and the humidity is labelled as “Dry”, then the fan is adjusted to “Short” and the sprinkler to “Medium”.

Table 1. Fuzzy logic rule set for temperature and humidity control system

Humidity / Temperature	tooDry	Dry	Normal	Humid	tooHumid
tooCold	Fan = Sort Sprinkler = Long	Fan = Sort Sprinkler = Medium	Fan = Medium Sprinkler = Sort	Fan = Long Sprinkler = Zero	Fan = Long Sprinkler = Zero
Cold	Fan = Sort Sprinkler = Long	Fan = Sort Sprinkler = Medium	Fan = Sort Sprinkler = Medium	Fan = Medium Sprinkler = Zero	Fan = Long Sprinkler = Zero
Normal	Fan = Sort Sprinkler = Long	Fan = Sort Sprinkler = Medium	Fan = Sort Sprinkler = Sort	Fan = Sort Sprinkler = Zero	Fan = Medium Sprinkler = Zero
Hot	Fan = Long Sprinkler = Long	Fan = Long Sprinkler = Long	Fan = Long Sprinkler = Medium	Fan = Medium Sprinkler = Sort	Fan = Medium Sprinkler = Sort
tooHot	Fan = Long Sprinkler = Long	Fan = Long Sprinkler = Long	Fan = Long Sprinkler = Medium	Fan = Long Sprinkler = Short	Fan = Long Sprinkler = Short

The flow chart of the algorithm for the developed control system is illustrated in Figure 17. The temperature and humidity readings from the inside and outside environments of the oyster mushroom cultivation chamber were collected and stored in the microcontroller for every minute. These data points were transmitted and updated in the Arduino clouds and Google sheet at one-minute intervals. Over 15 minutes, the average values of the inside temperature and humidity within the cultivation chamber were computed. These average values served as inputs for the fuzzy logic system to determine the activation time for the sprinkler and fan. Subsequently, the sprinkler and fan were activated at the times specified by the fuzzy logic. The sprinkler and fan activation times were updated in the Arduino clouds and Google sheet. Furthermore, whenever the operator activated the LED light switch via the Arduino clouds app, the microcontroller triggered the LED tube light inside the cultivation chamber, maintaining its activation until the operator deactivated the switch via the Arduino clouds app.

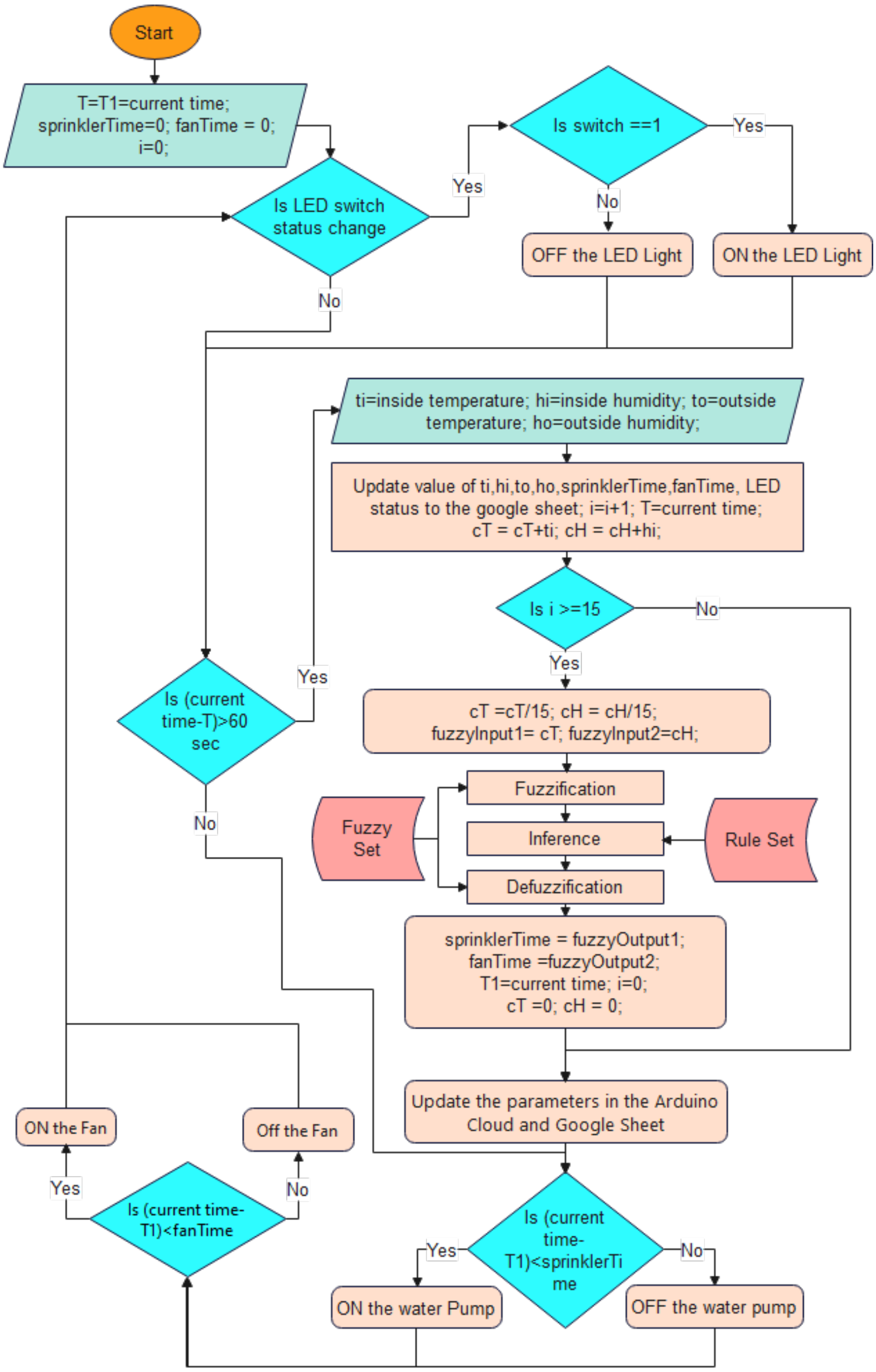


Figure 17. Flowchart for the algorithm used in the IoT-based control system

Mobile and web application

The microcontroller was responsible for acquiring temperature and humidity data, which were subsequently transmitted to the cloud for comprehensive monitoring alongside additional activity-related information. To facilitate the monitoring and control of environmental parameters within the mushroom cultivation chamber, mobile and web applications were developed within the Arduino cloud platform, accessible at https://www.arduino.cc. A graphical user interface (GUI) was meticulously designed for both the web page and mobile applications hosted on the Arduino cloud, as illustrated in Figures 18 and 19, respectively.

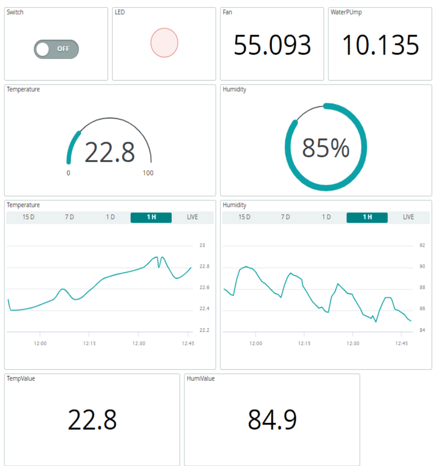


Figure 18. GUI for web page application

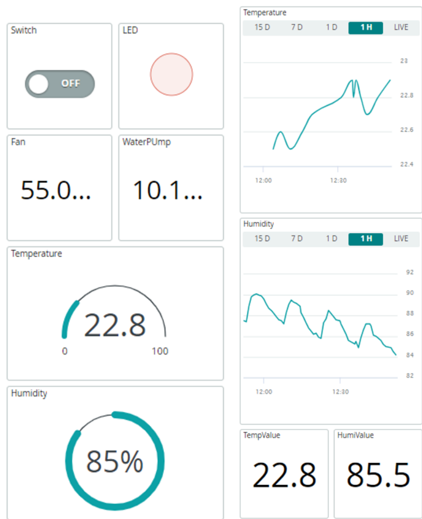
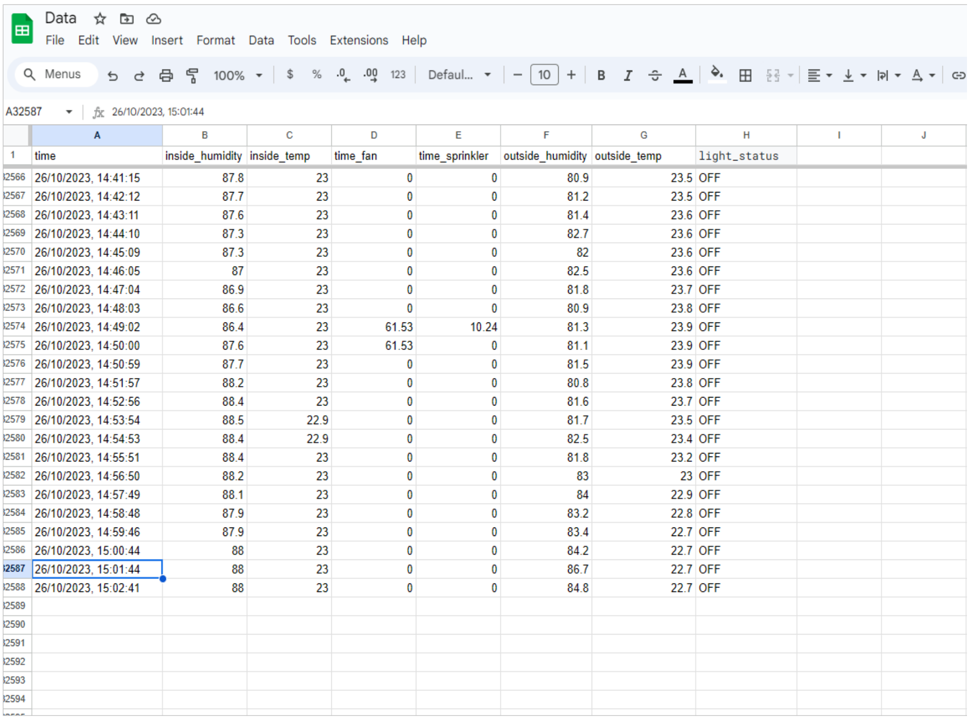


Figure 19. GUI for mobile application

The application features a switch for LED light control and an LED indicator to reflect the current light status. Additionally, it offers numerical and graphical displays for the inside temperature and humidity of the oyster mushroom cultivation chamber and a section for presenting the active duration of the AC fan and the DC water sprinkler pump.

Data acquisition

The microcontroller's sensor data, encompassing temperature and humidity, were transmitted to the Arduino cloud platform. Concurrently, these data points were synchronized with a Google sheet, including the duration of activity for the AC fan and DC water pump, recorded per minute, leveraging internet connectivity. This data logging process into the Google sheet was facilitated through the utilization of Google apps script, and a representation of the Google sheet for data recording is illustrated in Figure 20.



time	inside_humidity	inside_temp	time_fan	time_sprinkler	outside_humidity	outside_temp	light_status
26/10/2023, 14:41:15	87.8	23	0	0	80.9	23.5	OFF
26/10/2023, 14:42:12	87.7	23	0	0	81.2	23.5	OFF
26/10/2023, 14:43:11	87.6	23	0	0	81.4	23.6	OFF
26/10/2023, 14:44:10	87.3	23	0	0	82.7	23.6	OFF
26/10/2023, 14:45:09	87.3	23	0	0	82	23.6	OFF
26/10/2023, 14:46:05	87	23	0	0	82.5	23.6	OFF
26/10/2023, 14:47:04	86.9	23	0	0	81.8	23.7	OFF
26/10/2023, 14:48:03	86.6	23	0	0	80.9	23.8	OFF
26/10/2023, 14:49:02	86.4	23	61.53	10.24	81.3	23.9	OFF
26/10/2023, 14:50:00	87.6	23	61.53	0	81.1	23.9	OFF
26/10/2023, 14:50:59	87.7	23	0	0	81.5	23.9	OFF
26/10/2023, 14:51:57	88.2	23	0	0	80.8	23.8	OFF
26/10/2023, 14:52:56	88.4	23	0	0	81.6	23.7	OFF
26/10/2023, 14:53:54	88.5	22.9	0	0	81.7	23.5	OFF
26/10/2023, 14:54:53	88.4	22.9	0	0	82.5	23.4	OFF
26/10/2023, 14:55:51	88.4	23	0	0	81.8	23.2	OFF
26/10/2023, 14:56:50	88.2	23	0	0	83	23	OFF
26/10/2023, 14:57:49	88.1	23	0	0	84	22.9	OFF
26/10/2023, 14:58:48	87.9	23	0	0	83.2	22.8	OFF
26/10/2023, 14:59:46	87.9	23	0	0	83.4	22.7	OFF
26/10/2023, 15:00:44	88	23	0	0	84.2	22.7	OFF
26/10/2023, 15:01:44	88	23	0	0	86.7	22.7	OFF
26/10/2023, 15:02:41	88	23	0	0	84.8	22.7	OFF

Figure 20. Google sheet used for recording the data through IoT

Analysis

The system underwent multiple operational cycles after installing the hardware and software components of the IoT-based environmental parameters monitoring and control system within the oyster mushroom cultivation chamber. This was carried out with the primary objective of evaluating the performance and behaviour of the DHT22 sensor in conjunction with the entire system.

To assess the accuracy of the data obtained from the DHT22 sensor a comparative analysis was conducted. The data received from the DHT22 sensor was compared with the data supplied by a digital thermo-hygrometer. This comparative evaluation involved the computation of the R-squared (R^2) value and the Mean Absolute Percentage Error (MAPE) specifically for the DHT22 sensor. The R^2 value, as computed using Eq. (1), served as an indicator of the degree of correlation between the actual data produced by the hygrometer and the data recorded by the sensors.

$$R^2 = 1 - \frac{\sum_1^n (V_a - V_r)^2}{\sum_1^n (V_a - V_{ma})^2} \tag{1}$$

Where V_a is the actual value, V_r is the value read by the system sensor (DHT22), V_{ma} is the mean of the actual value, and n is the number of observed data. Moreover, the disparities between the data obtained from the system sensors and the real-world data were examined by calculating the Mean Absolute Percentage Error (MAPE), as defined in Eq. (2).

$$MAPE = \frac{100}{n} \times \sum_{i=1}^{n} \left[\frac{|V_a - V_r|}{|V_a|} \right] \tag{2}$$

where V_a is the actual value, V_r is the value read by the system sensor (DHT22) and n is the number of observed data.

Results

Sprinkler nozzle

The discharge from the sprinkler nozzle was collected in a beaker for 20 seconds as shown in Figure 21. The discharge values were given in Table 2. Its average flow rate was measured and found to be 5.89 ml/s.

Table 2. Discharge rates from the water sprinkler

Particular	Discharge volume (ml)	Discharge average volume (ml)	Flow rate (ml/s)
Sample 1	118.50		
Sample 2	117.00		
Sample 3	119.00	117.80	5.89
Sample 4	116.50		
Sample 5	118.00		

LED tube light

One 20 W LED tube light was provided inside the mushroom chamber, and its intensity was measured using the line quantum sensor as in Figure 22.

Figure 21. Collection of discharge from the sprinkler nozzle

Figure 22. Measuring the intensity of light inside the chamber

During the measurement phase, it was ascertained that employing a single 20 W LED light source resulted in an average light intensity of 3 µmol m^{-2} s^{-1} (162 lux) and 2 µmol m^{-2} s^{-1} (108 lux) for the upper and middle racks, respectively. In contrast, the lower rack registered a null light intensity of 0 µmol m^{-2} s^{-1} (0 lux). The apparent cause of this null reading may be attributed to the limited sensitivity of the line quantum sensor, which cannot detect light levels below 54 lux.

To meet the specific requirements of the experiment, two 20 W LED lights were installed within the mushroom cultivation chamber. Consequently, light intensity increased to 5 µmol m^{-2} s^{-1} (270 lux) for the upper rack, 4 µmol m^{-2} s^{-1} (216 lux) for the middle rack, and 2 µmol m^{-2} s^{-1} (108 lux) for the lower rack. Consequently, the upper and middle racks were designated as suitable locations for housing the mushroom bags.

Furthermore, the airflow velocity within the experimental setup was quantified utilizing an anemometer. The measured average air velocity provided by the AC fan was determined to be 5.47 m/s.

Temperature and humidity sensor

The performance of the DHT22 sensor against the digital thermo-hygrometer is presented in Table 3 and 4. The absolute error for temperature varies from 0.07 to 0.39 °C, with an average of 0.1 °C. The mean absolute percentage error (MAPE) for temperature is 0.49 %, with the minimum absolute percentage error value at 0.17 % and the maximum at 0.59 %. The R^2 value for temperature between the DHT22 and thermo-hygrometer readings is 0.998. On the other hand, for relative humidity, the absolute error ranges from 0.07 to 1.71 %, with an average absolute error of 0.91 %. The maximum absolute percentage error for relative humidity is 1.82 %, while the minimum is 0.09 %. The MAPE for relative humidity between the DHT22 and digital hygrometer is 1.09 %. The R^2 value for relative humidity between the DHT22 and thermo-hygrometer is 0.992. These results highlight the precision and accuracy of the DHT22 sensor in temperature and relative humidity measurements, as evidenced by the high R^2 values and relatively low error metrics.

Performance of the system

The variations in the inside and outside temperature of the mushroom cultivation chamber and the variations of the inside and outside humidity on a particular day are given in Figures 23 and 24, respectively.

Table 3. Comparison of temperature data obtained from DHT22 sensor and digital thermo hygrometer

Digital Thermo hygrometer (°C)	DHT22 (°C)	Absolute error (°C)	Absolute error (%)
16.7	16.63	0.07	0.42
16.9	17.00	0.10	0.59
17.6	17.57	0.03	0.17
17.5	17.53	0.03	0.17
18.9	18.86	0.04	0.21
19.1	19.05	0.05	0.26
20.4	20.01	0.39	1.91
22.1	22.14	0.04	0.18
23.7	23.56	0.14	0.59
25.7	25.80	0.10	0.39

Table 4. Comparison of relative humidity data obtained from DHT22 sensor and digital thermo hygrometer

Digital thermo hygrometer (%)	DHT22 (%)	Absolute error (%)	Absolute error (%)
68.9	68.40	0.50	0.73
73.4	72.20	1.20	1.63
75.9	76.61	0.71	0.94
79.6	79.53	0.07	0.09
82.7	81.46	1.24	1.50
84.1	83.76	0.34	0.40
86.2	87.81	1.61	1.87
88.3	89.01	0.71	0.80
93.4	95.10	1.70	1.82
97.8	98.87	1.07	1.09

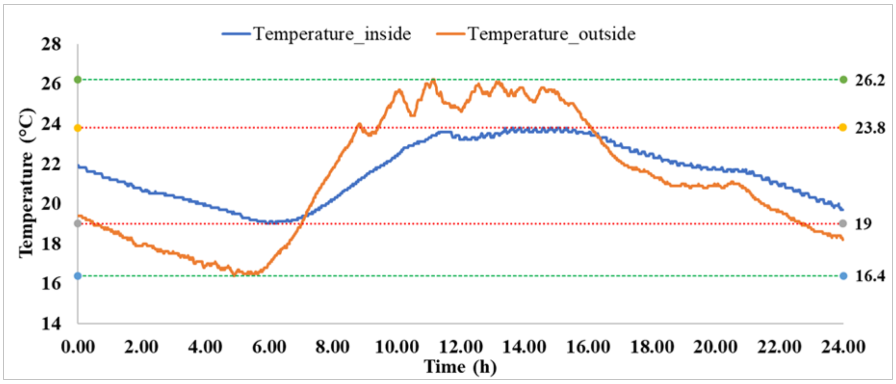


Figure 23. Variation of temperature inside and outside of the mushroom cultivation chamber

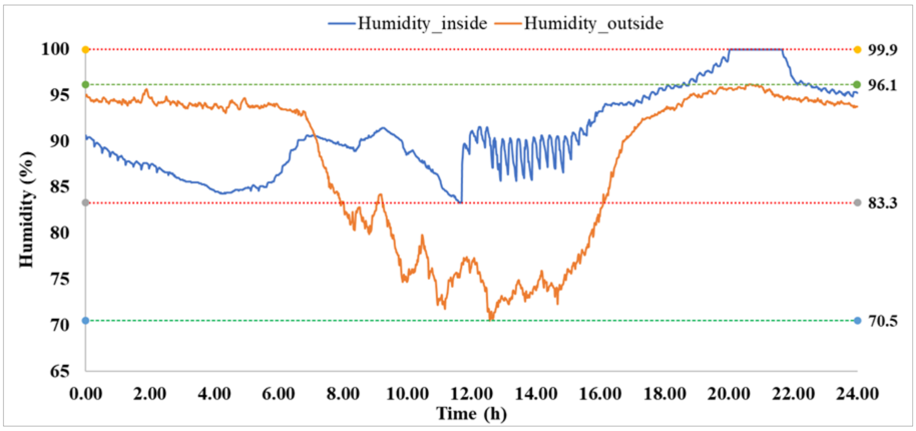


Figure 24. Variation of humidity inside and outside of the mushroom cultivation chamber

The inside temperature varies from 19 to 23.8 °C (marked by a red dotted line), whereas the outside temperature varies from 16.4 to 26.2 °C (marked by a green dashed line). This shows that the developed system maintains the temperature within the favourable temperature range more uniformly. The control system maintains the humidity inside the mushroom chamber in the range from 83.3 to 99.9 %, whereas the humidity variation during the period was from 70.5 to 96.1 %. This provides the ability of the developed system to maintain the humidity level suitable for the growth of oyster mushrooms. DC power consumption was measured with a wattmeter by connection in series with the system. The wattmeter readings during the normal and active periods of the water pump are provided in Figures 25 and 26.

Figure 25. Reading of wattmeter during the normal period

Figure 26. Reading of wattmeter during the active period of DC water pump

It was observed that during the normal operation period, DC consumed by the system varies from 0.15 to 0.43 A with an average of 0.26 A. In contrast, the average consumption of DC current during the active period of the system was found to be 2.87 A with a maximum of 3.26 A and a minimum of 2.59 A. The oyster mushroom at the different stages of their growth is shown in Figure 27.

(a) Introduction inside the cultivation chamber

(b) Mycelium running

(c) Pinhead formation

(d) Mature oyster mushroom

Figure 27. Growth stages of oyster mushrooms in the cultivation chamber

Discussion

In this study, a system for monitoring and controlling temperature and humidity in oyster mushroom cultivation was successfully implemented. This system offers mushroom cultivators a means to oversea and manage temperature, humidity, and lighting conditions through web and mobile applications. The developed system employed ESP32 as the main computing unit. A similar control unit is reportedly developed using ESP and Arduino microcontroller (Adhitya *et al*., 2016; Cikarge and Arifin, 2018; Islam *et al*., 2022). There is also a report on using an Intel Galileo- microprocessor and programmable logic controller for developing such kind of control unit (Fuady *et al*., 2017; Thong-un and Wongsaroj, 2022).

The temperature and humidity inside the oyster mushroom cultivation chamber were maintained in the desired range by sprinkling water inside the cultivation chamber and providing an air circulation fan. Temperature and humidity management success by providing water and air flow has already been reported (Adhitya *et al.*, 2016; Ariffin *et al*., 2021; Ariffin *et al*., 2020). However, there is a report for controlling temperature and humidity for the small volume cultivation chamber (0.00594 cubic meters plastic box) using airflow (Islam *et al*., 2022). As the DHT sensor is already pre-calibrated by the manufacturer, the researchers used the DHT sensor directly without calibrating in their work (Islam *et al.*, 2022). However, some researchers recalibrated it by comparing it with the laboratory instrument (Hakim *et al*., 2022). The mean average temperature error of the DHT22 was 1.24 %, whereas the average humidity error of the DHT22 was reported as 0.611 % (Hakim *et al*., 2022). The calibrated DHT22 sensor used in the present study has MAPE of 0.49 % and 1.09 % for temperature and humidity, respectively.

The light requirement during the fruiting period was fulfilled by two 20 W LED tube light units. It has already been reported that oyster mushrooms can be cultivated using artificial light (Mohammed *et al*., 2018). Fuzzy logic algorithms for controlling temperature and humidity inside the mushroom cultivation chamber are superior to the threshold and manual control (Ariffin *et al*., 2021; Hendrawan *et al*., 2019). The developed control system in the present reported work also uses fuzzy logic. Web servers required for the IoT application were developed individually for their application (Ariffin *et al*., 2021; Ariffin *et al*., 2020). At the same time, many researchers used the IoT platform, such as Blynk, Cayenne, ThingSpeak, and Ubidots, to develop web and mobile applications (Hakim *et al*., 2022; Mohammed *et al*., 2018; Najmurrokhman *et al*., 2020; Nasution *et al*., 2019). In the present study, Arduino cloud was used to develop web and mobile applications. The data obtained from the DHT22 sensor and other attributes were recorded simultaneously in the Google sheet for future reference.

The developed system effectively maintains the desired temperature and humidity levels throughout the oyster mushroom cultivation. Integration of IoT-based technology, streamlines data acquisition, providing real-time data and reducing the need for extensive manual labour in mushroom cultivation. Moreover, future enhancements may involve the integration of light and CO_2 sensors alongside the DHT22 sensor for comprehensive monitoring and analysis of system performance.

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