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Development of a Remote Straw Mushroom Cultivation System Using IoT Technologies

Novi Azman, Muhammad Habiburrohman, Endang Retno Nugroho
Electrical Engineering Department, Engineering and Science Faculty, Universitas Nasional, Sawo Manila Street No.61, South Jakarta City, Special Capital Region of Jakarta 12510, Indonesia

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ABSTRACT

Indonesia's tropical climate offers extensive potential for straw mushroom cultivation, an important topic given frequent crop failures during the rainy season due to reduced temperatures. Addressing this issue, this paper presents an innovative Internet of Things (IoT)-based system designed to remotely control and monitor temperature and humidity in mushroom cultivation sites, a tool that can significantly minimize crop failure and optimize production. Our proposed system employs a DHT11 sensor, responsible for accurately measuring temperature and humidity levels. To ensure the mushrooms receive adequate hydration without human intervention, a DS3231 module is incorporated for automatic watering scheduling. For real-time monitoring, we use an ESP32-Cam, a specific type of camera module, to capture images of the mushroom cultivation site. The heart of this system is a NodeMCU microcontroller, which processes environmental data and adjusts the cultivation conditions automatically. The system counteracts non-optimal conditions by triggering a heater or fan for temperature control, and a humidifier or exhaust for humidity control. It syncs with the Blynk app, providing updates for prompt response. The system was tested across multiple cultivation sites, showing improved crop success and low energy use, 661.608Wh. Despite its advantages, it acknowledges potential drawbacks, such as implementation costs, compatibility issues, and connectivity. Relevant performance indicators like crop yield and profitability are also evaluated. The contributions of this research are twofold. Firstly, it provides a robust, scalable solution for optimizing straw mushroom cultivation, particularly in regions with climates like Indonesia. Secondly, it sets a new benchmark for energy-efficient, automated mushroom farming, offering substantial benefits to farmers and the overall agricultural industry while further emphasizing its potential impact.

Corresponding Author:

Novi Azman, Electrical Engineering Department, Engineering and Science Faculty, Universitas Nasional, Sawo Manila Street No.61, South Jakarta City, Special Capital Region of Jakarta 12510, Indonesia
Email: novi.azman@civitas.unas.ac.id

1. INTRODUCTION

The agricultural sector plays an important role in economic growth in a country both in terms of commodities and employment opportunities. This agricultural development follows from high market demand, in Indonesia, straw mushroom cultivation is in demand because of the market's demand for food. In the agricultural sector, precision farming-leveraging technology to monitor and optimize crop growth—has proven to be increasingly important.

Straw mushrooms are known as warm mushrooms, which means that mushrooms can live and develop at relatively high temperatures. These characteristic underscores the relevance of precision farming, as any deviations from ideal growth conditions can significantly impact the crop's health and yield. Straw mushrooms are known as warm mushrooms, which means that mushrooms can live and develop at relatively high temperatures. Required special handling in straw mushroom cultivation [1]-[3]. If the mushroom is in a place with a higher temperature than the existing standard, the performance of the enzyme will be disrupted and cause the straw mushroom to be large but light in weight [4]. The ideal temperature for mushroom growth is 30-35°C. As for the level of humidity (Relative Humidity) needed for straw mushrooms is 80-90% [5]-[7].

Applying IoT in straw mushroom cultivation translates to real-time monitoring and control of temperature and humidity within the mushroom shed. With immediate data available, adjustments can be promptly made to optimize growth conditions and enhance yields—principles at the core of precision farming. The Internet of Things (IoT) is a telecommunication concept that brings together "things" in a network so that communication between "things" occurs which can help humans in their daily activities. IoT has been used in various sectors of life, from health [8]-[10], transportation [11]-[13], energy and industry [14]-[17], also agriculture [18]-[21].

In the agricultural sector, maximizing yield and reducing crop failure are paramount. This is especially true in straw mushroom cultivation, where the mushrooms require specific temperature and humidity conditions to thrive. As we mentioned earlier the straw mushrooms can live and develop at relatively high temperatures, necessitating special handling in their cultivation. The ideal temperature for their growth is 30-35°C, and the level of humidity (Relative Humidity) needed is 80-90%. However, in Indonesia's tropical climate, the rainy season often reduces temperatures, leading to frequent crop failures.

The current methodologies for addressing this challenge primarily involve manual or semi-automated methods, which lack scalability and energy efficiency. A significant gap exists in providing a solution that is both effective and efficient. The Internet of Things (IoT) offers a promising solution to this problem. IoT, a concept that interconnects things in a network to facilitate communication and assist in daily activities, has been employed in various sectors including health, transportation, energy, and agriculture [22]-[23].

The use of the Internet of Things in various aspects of life to industry including agriculture can provide economic benefits such as increasing performance efficiency, reducing costs, and increasing productivity. Particularly in agriculture, IoT helps farmers optimize yields, reduce waste, and improve supply chains. With the use of integrated sensors and data analysis, more informed decisions can be made about when to plant, water, and harvest crops, thereby helping farmers produce better crop yields and reduce costs. IoT can also help reduce waste by monitoring and optimizing the use of resources such as water and fertilizer. The benefits of IoT also improve supply chain management by providing real-time data on crop location and condition, reducing spoilage, and increasing delivery times. Overall, the use of IoT in the agricultural industry can increase profitability and sustainability [24]-[28].

In this context, we introduce an innovative IoT-based system designed to remotely monitor and control the temperature and humidity in mushroom cultivation sites in real time via a smartphone. This system utilizes a collection of sensors that work together in a network. The results can be monitored on a smartphone or computer via the Internet, making it easier for farmers to cultivate mushrooms effectively and efficiently. By doing so, the system aims to minimize crop failure due to unsuitable environmental conditions, and optimize production significantly, filling the existing gap in the sector.

So, to get maximum yields and reduce the rate of crop failure, the use of the Internet of Things concept is needed to monitor temperature and humidity in real-time inside the mushroom shed via smartphone and have automatic control. The concept of the Internet of Things is the existence of a collection of sensors that work together and are connected in a system and the results can be monitored on a smartphone or computer via the Internet [29]-[31]. The use of the IoT concept is expected to make it easier for mushroom farmers to cultivate mushrooms effectively and efficiently.

By utilizing technology that has been previously designed and trying to redevelop it to maximize yields in mushroom cultivation. The function of this system is to monitor and control the conditions of temperature and humidity inside the mushroom house in real-time and to automate water sprinkling every morning as well as a camera inside the house to see the mushroom growth.

Several studies that have been carried out by other researchers in improving agriculture by applying the Internet of Things to carry out environmental control are as follows.

Sri Waluyo, Ribut Eko Wahyono, *et al.* designed a temperature and humidity control system inside the oyster mushroom barn using the Arduino Mega. In addition, it uses a DHT22 temperature and humidity sensor and an RTC module to access the time. This tool cannot be monitored remotely [32].

Nugraha Wicaksana, designed and built a smart greenhouse using the Arduino Uno module which is equipped with a DHT11 sensor to read temperature and humidity values as well as additional soil moisture sensors. But for the communication system between the hardware and the smartphone, it still uses Bluetooth [33].

Karsid, Rofan Aziz, *et al.* researched to design of automatic temperature and humidity control applications. Apart from that, this research uses the ATmega 8535 microcontroller and the SHT11 sensor to read the temperature and humidity values. However, this system has not been able to monitor the growth of straw mushrooms [34].

The implementation of IoT is expected to make it easier for mushroom farmers to cultivate mushrooms effectively and efficiently. It is also hoped that it can minimize crop failure due to environmental conditions that are not suitable for mushroom growth and the results of this prototype are expected to be applied to Indonesian agriculture.

The incorporation of IoT in agriculture, specifically in mushroom farming, presents a new paradigm in precision farming like other farming [35]-[38]. It enables real-time monitoring [39]-[40] and control of environmental conditions [41]-[42], crucial for the growth and development of crops such as straw mushrooms. IoT allows for the timely adjustment of conditions inside the mushroom shed, including temperature and humidity, which could potentially increase yield and mitigate risks associated with crop failure. Real-time data collected from the mushroom shed can be used to make informed decisions about cultivation practices, leading to optimized growth conditions and sustainable farming methods.

Furthermore, IoT-based systems also provide the potential for scalability [43]-[44]. As the demand for straw mushrooms continues to rise, it is crucial to develop efficient and effective farming practices that can be scaled up to meet this increasing demand. IoT enables the possibility of managing multiple mushroom sheds remotely, thus saving time and resources, reducing the need for physical monitoring, and promoting efficiency. With an IoT-based system in place, farmers can focus more on strategic planning and management, enhancing productivity, and contributing to the overall economic growth of the agriculture sector. Such innovative applications of technology in agriculture pave the way for a new era of smart farming.

This research, therefore, proposes an innovative IoT-based system designed to remotely control and monitor temperature and humidity in mushroom cultivation sites. The contributions of this research are twofold:

1. We provide a technologically advanced solution to the persistent challenges in straw mushroom farming. Our system reduces crop failure rates and enhances production, thereby addressing a notable gap in scalable and energy-efficient solutions.
2. This research is among the pioneers in applying IoT technologies to mushroom farming, setting a new benchmark in this field. The proposed system not only benefits local farmers but also holds potential implications for the broader agricultural industry.

By implementing our IoT-based system, we aim to foster effective, efficient mushroom cultivation, reducing crop failure due to unsuitable environmental conditions. The results of this prototype hold promise for broader application in Indonesian agriculture.

2. MATERIALS AND METHODS

This research was carried out in several research steps that have been carried out, briefly, the flow of research that has been carried out can be seen in Fig. 1. This research also was conducted within 6 months involving several tools and materials shown in Table 1. However, before that, we will explain some terms that we did not find in English, so we feel the need to explain them. Kumbung or mushroom house is a place to care for baglog and grow mushrooms. Baglog is a growing medium for placing mushroom seeds. The main ingredient in baglog is sawdust. The baglog is wrapped in cylindrical plastic, where one end is given a hole. Kumbung is usually a building filled with shelves for placing baglog. The building must have the ability to maintain temperature and humidity [45]-[47].

An explanation of the flowchart of the research stages that have been carried out in Fig. 1 is as follows.

a. Field studies namely studying the process of mushroom cultivation by learning directly on mushroom cultivation. Field studies are the first step to finding out the problem and its handling.
b. Literature study by studying and collecting information on how to solve problems that occur. Materials for gathering information can be in the form of books, scientific journals, or other media. This stage is carried out to make it easier to develop innovations to overcome problems.
c. System design, namely designing how the tool system works so that it can work optimally. In the system design, there is a discussion of block diagrams, system flowcharts, and how the system works.
d. Designing hardware and software, determining the tools and materials used as well as the wiring and placement of the appropriate components to optimize results in designing hardware and software.
e. Device testing is to find out the performance and performance of the tools that have been made.
f. Data analysis, that is, after the tool is tested, an analysis is then carried out to evaluate the performance of the system on the tool that is designed.
g. The conclusion is the result of analysis of research data and then conclusions are made to find out the strengths and weaknesses.

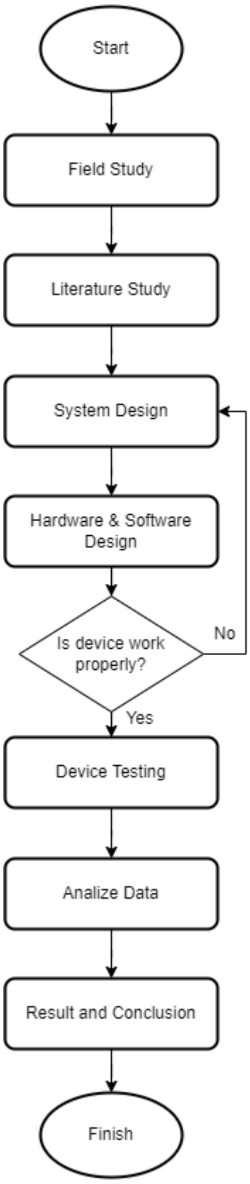


Fig. 1. Research Flowchart

Table 1. Tools and materials involved for developing prototype.

Hardware	NodeMCU ESP8266
	ESP32-Cam
	RTC Module
	DHT11 Sensor
	Relay 4 Channel
	Warmer Lamp
	Solenoid Valve
	Exhaust Fan
	Humidifier
	Polycarbonate Solid Sheet
	Breadboard
	Power supply 24V 1A, 12V 2A, 5V 1A
	Step down from DC to DC
	Digital Avometer
Software	Arduino IDE
	Blynk

In this study, researchers used NodeMCU ESP8266 due to its availability in the market so that the results of this study can be easily duplicated by other people, both researchers and non-tech people. NodeMCU ESP8266 has also been widely used in various IoT projects including agriculture [48]-[50] and even for other mushroom cultivation [51]. Besides that, the main tool is the use of a camera to record the progress of mushroom growth. One device that is compatible with the NodeMCU ESP826 uses the ESP32-Cam which is widely found in the market and is affordable in cost. In several IoT studies, ESP32-Cam has also been used as one of the devices used to record either images or videos, such as its use in agriculture, which has been carried out in several studies [52]-[54].

Another component in the form of an RTC Module is used for electronic ambits in the form of a chip that can accurately calculate time (from seconds to years) and maintain/store that time data in real-time used to decide for the actuators involved to perform actions according to the predetermined time. determined. As previously mentioned, to act as the actuator involved, a connecting switch is needed between the NodeMCU ESP8266 microcontroller using a 4-channel relay.

The actuator used will follow the objectives of mushroom cultivation in temperature and humidity conditions. The devices used are a Warmer Lamp as a heater, Solenoid Valve, Exhaust Fan, and Humidifier. Other supporting devices such as Polycarbonate Solid Sheets, Breadboard, Power Supply, step-down, and digital avometers.

All hardware used in this study is controlled by the NodeMCU ESP8266 microcontroller which is programmed using the Arduino IDE software. The Arduino IDE is the de facto software used to make it easier for users to write code and upload it to the Arduino board offline. The main Internet of Things is sending data to the Internet, therefore there needs to be a recipient of the data. Blynk was chosen by the researcher as the location for receiving data from the monitoring results that occurred. Blynk is an IoT software platform that enables users to prototype, deploy, and manage remotely connected electronic devices at any scale. Blynk offers complete solutions for building and managing connected hardware: device provisioning, sensor data visualization, remote control with mobile and web applications, firmware updates over the air, secure cloud, data analytics, user and access management, alerts, automation, and much more. Blynk has been widely used as data reception and visualization from various studies to research in the agricultural sector [55]-[59].

This initial design aims to clearly describe how the system works. In this study, the authors will create a monitoring system for remote mushroom cultivation. To facilitate understanding of the system to be created, below is a block diagram of the system concept shown in Fig. 2.

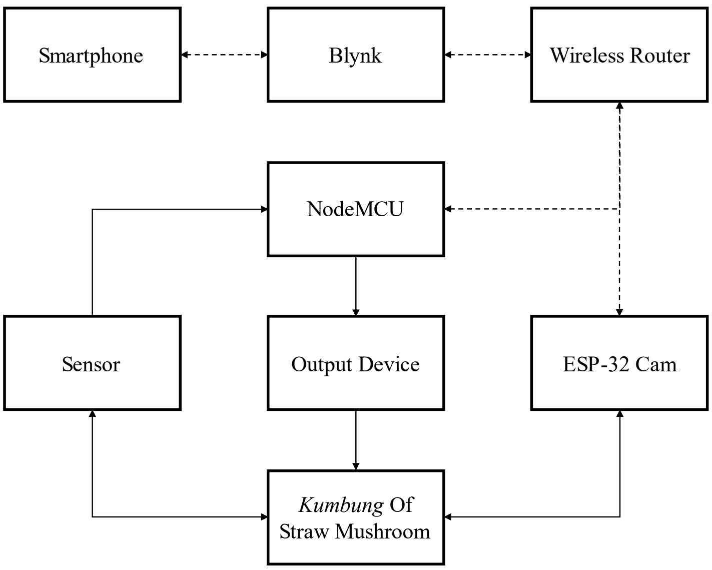


Fig. 2. Overview of System Block Diagram

The DHT11 sensor will be installed in the mushroom house, then the sensor will detect physical changes and chemical changes in the form of digital signals from inside the mushroom house. Then the signal will be sent to NodeMCU, then NodeMCU as the microcontroller will process the signal. The results of the program can be seen with a working output device. The DHT11 sensor reading results will be displayed via the blynk application on a smartphone. Likewise, the camera will be connected directly to the blynk application to take pictures of mushroom growth.

In this study, IoT devices made for mushroom cultivation are designed to perform two functions, monitoring and controlling functions. The monitoring function is used to monitor the temperature and humidity of the mushroom house, while the control function is used to maintain stable conditions inside the mushroom house. This system is also equipped with irrigation automation with an intensity of once a day at 06.00 WIB (GMT+7). To facilitate the design of the tool, a system block diagram must be made. The system block diagram can be seen in Fig. 3.

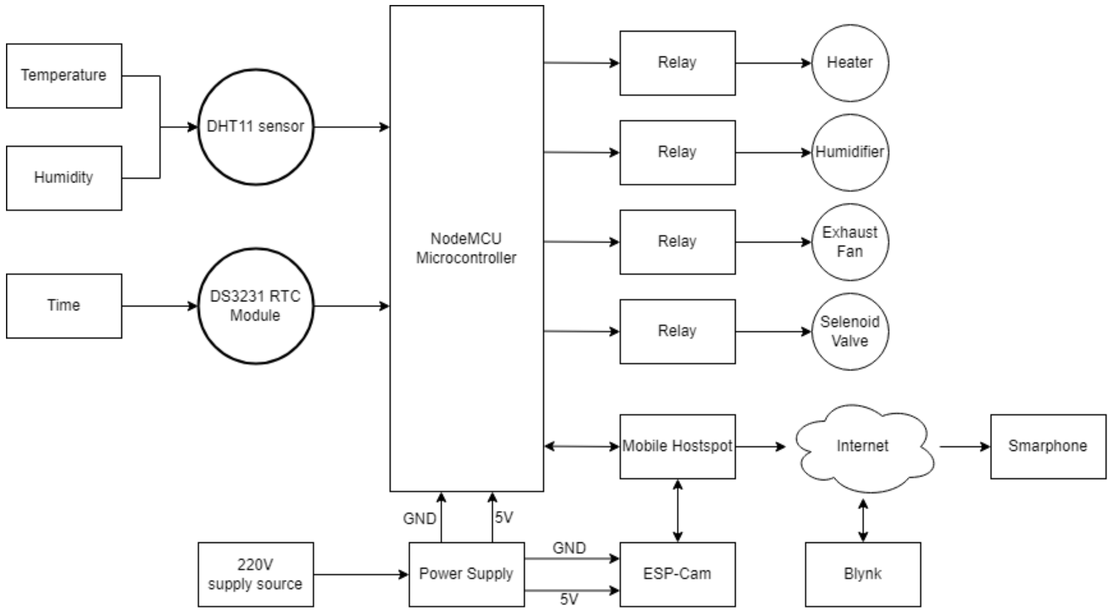


Fig. 3. Hardware Block Diagram

In the design, there are 2 inputs, namely the DHT11 sensor and the DS3231 RTC module. The DHT11 sensor is used to read the temperature and humidity values inside the mushroom house. Meanwhile, the DS3231 RTC module is used to access time data to help run the mushroom media automatic watering function with an intensity of once a day at 06.00 WIB. Data from the sensor in the form of readings from the temperature is sent to the microcontroller to make selection decisions for exhaust fan or heater actuators to optimize temperature control in the cultivation equipment room. The data from the RTC DS3231 is used to match the results of the time readings received by the microcontroller and at the appropriate time will instruct the solenoid valve to open. The NodeMCU microcontroller is used to control electronic circuits and can be called the main control of the system. The use of NodeMCU was chosen because it fits the system requirements. Some other advantages are getting integrated Wi-Fi network support and affordable prices. All control actions from the microcontroller send a signal to the relay to turn on because the relay is normally closed.

As previously mentioned, the output in the form of an actuator consists of several devices, namely a solenoid valve, humidifier, exhaust fan, heater, and camera. The relay in this study uses a 4-channel relay module. The Solenoid valve functions to drain water to automatically water the mushroom media at 06.00 WIB. Humidifiers are used to increase the humidity value when environmental conditions are less humid. Exhaust fans are used to lower the temperature and humidity in the kumbung. The heater is used to raise the temperature in the mushroom cage. There is also a camera that is used to take pictures directly so that the growth of the fungus can still be monitored. Briefly, the overall wiring of the device can be seen in Fig. 4.

The devices used in this study can be further developed, such as the use of minicomputer devices such as the Raspberry Pi which has more capabilities in terms of data processing and further control. The use of a soil moisture sensor can further see moisture from the soil. As well as the use of a higher definition camera that can be better utilized from the Raspberry Pi. The use of the MQTT protocol and machine learning can also be used to improvise devices.

In addition to the system block diagram as shown in Fig. 3, in designing a tool a flowchart is also needed. The flowchart is a flowchart that describes the stages of work in the system and how decisions are taken to control an event or condition. This flowchart generally describes a working system. By using a flowchart, the process of a system will be clearer and coherent and reduce the possibility of misunderstanding.

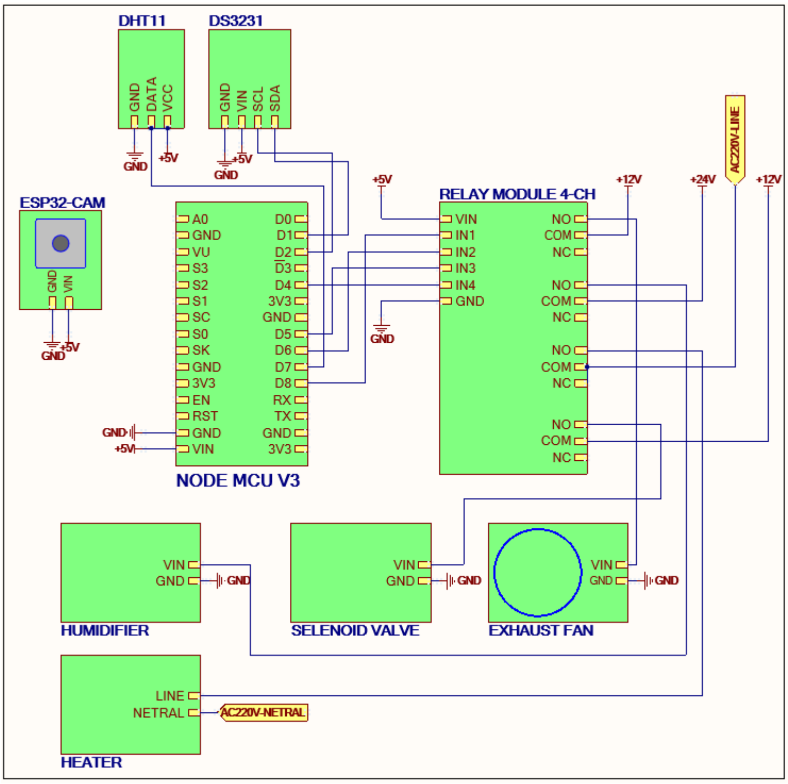


Fig. 4. Overall wiring diagram

Fig. 5 is a flowchart of the system design that will be made. The explanation of the system flowchart in Fig. 5 is as follows:

a. Initialize the serial port
b. DHT11 sensor initialization process and DS3231 module. This initialization process is to make a connection between the sensor and the microcontroller so that the program can run.
c. Furthermore, the DHT11 sensor reads the room temperature, after reading the temperature the microcontroller will process the data. If the temperature reads more than 35°C then the reading results will be sent to blynk, then relay 1 is active and the exhaust fan also works to lower the air temperature in the kumbung. If the temperature is read less than 30°C, then the results of the temperature reading will be sent to blynk, then Relay 2 is active and the heater works to raise the air temperature in the kumbung.
d. The DHT11 sensor reads the humidity in the kumbung, after the humidity is read, the microcontroller will process the data. If the humidity reading is less than 80%, the data will be sent to blynk, then relay 4 is active and the mist maker will work to increase the humidity in the kumbung. If the humidity is read more than 90%, then the reading will be sent to blynk, then relay 1 is active and the exhaust fan works.
e. The RTC module reads the time, if the time is read at 06.00 GMT+7 then the system will send a notification on the blynk application, then relay 3 is active and the solenoid valve works for 3 seconds to circulate water.

In designing the software used in this study, we will explain the algorithmic programming flow of the steps we made to be reproduced in the Arduino IDE to control temperature, humidity, and watering time in a mushroom cultivation environment using NodeMCU (ESP8266) and the Blynk platform.

Start code execution:

- Initialize pins to control devices such as heaters, humidifiers, exhaust fans, and solenoid valves.
- Initiates serial communication for debugging.
- Initializes the DHT (temperature and humidity) and RTC (Real-Time Clock) sensors.

setup():

- Sets the pin mode as OUTPUT for heaters, humidifiers, exhaust fans, and solenoid valves.
- Initiate Blynk communication using the authentication token (auth), SSID (Wi-Fi network name), and Wi-Fi password.
- Initiates serial communication at 115200 bps.
- Initializes the DHT sensor.

- Initiate I2C communication by connecting the SDA cable to pin D5 and SCL to pin D4.
- Get started with RTC.
- Delays execution for 500 milliseconds (0.5 seconds).

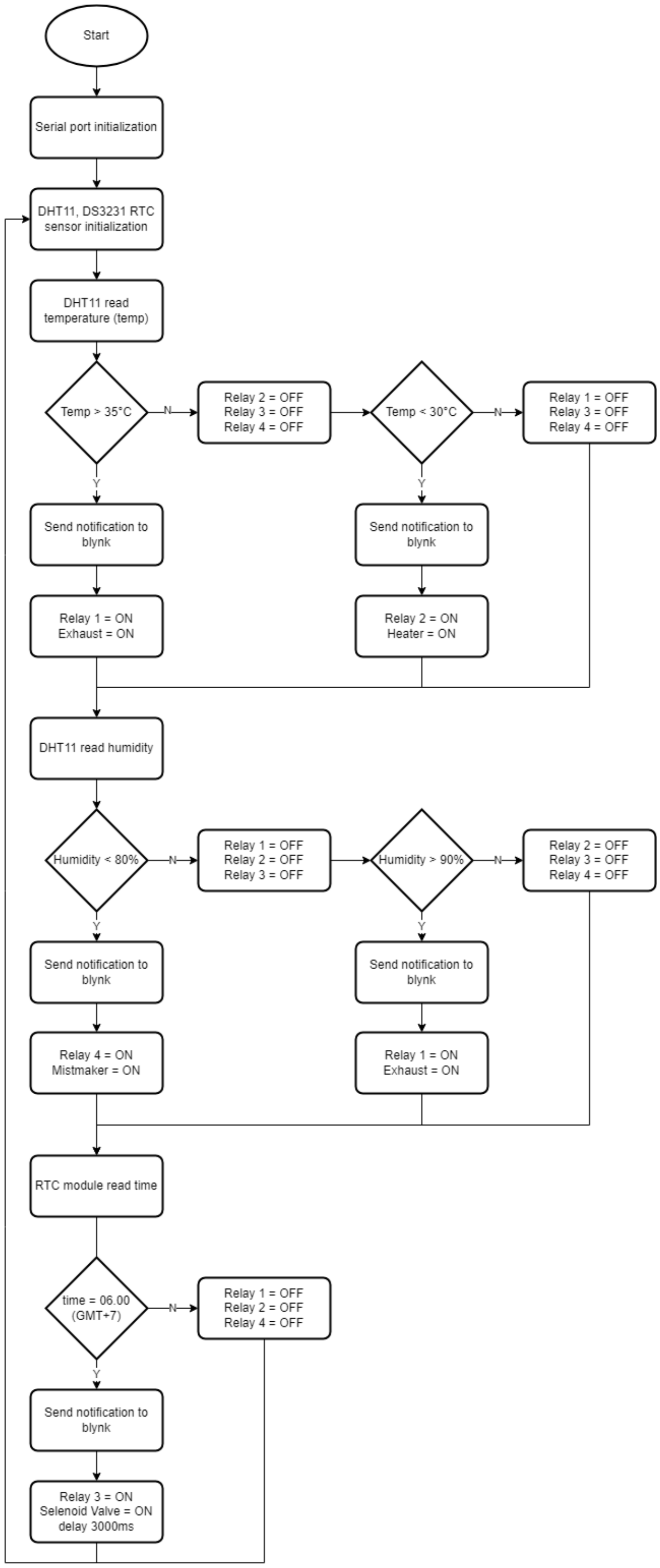


Fig. 5. System Flowchart

Loop():
- Delays execution for 500 milliseconds.
- Read the temperature (t) and humidity (h) values from the DHT sensor.
- Displays temperature and humidity values to Serial Monitor.
- Controlling the humidifier based on the humidity value:
- If the humidity is less than or equal to 80%, turn on the humidifier and send a notification to Blynk.
- Control exhaust fan based on humidity value:
- If the humidity is more than or equal to 90%, activate the exhaust fan and send a notification to Blynk.
- Control heater based on temperature value:
- If the temperature is less than or equal to 30°C, activate the heater and send a notification to Blynk.
- Control exhaust fan based on temperature value:
- If the temperature is over 35°C, activate the exhaust fan and send a notification to Blynk.
- Reads the time from the RTC and displays the date, month, year, hours, minutes, and seconds to the Serial Monitor.
- Set the watering time:
- If the hour is 10, the minutes are 00, and the seconds are less than or equal to 5, activate the solenoid valve for flushing.
- If the above conditions are not met, turn off the solenoid valve.
- Sending temperature (t) and humidity (h) data to the Virtual Pin widget in the Blynk application.

Back to Step 3 (Loop): Performs continuous iteration in a loop to control and monitor environmental conditions and interact with Blynk.

3. RESULTS AND DISCUSSION

This straw mushroom cultivation monitoring system is designed using a plastic polycarbonate solid sheet material as a shell to make it easier to test and collect data. Fig. 4 shows the results of the design of a kumbung with dimensions of 50 cm × 35 cm × 40 cm which are portable or can be moved. In short, the selection of the dimensions and volume of the chamber for mushroom development is not specific, but in a special box space for mushroom cultivation in kumbung is a technique that is commonly used, but for industrial and economical scale, the small dimensions of the kumbung will not be optimal. economically, because the kumbung requires electronic devices which will add to the cost, and if the volume is small then the production is only small, so for industrial cases, the same concept as the small kumbung can be done only by increasing the volume of the kumbung until an appropriate economic calculation is reached. This small dimension has also provided results in previous studies. The kumbung design is shown in Fig. 6.

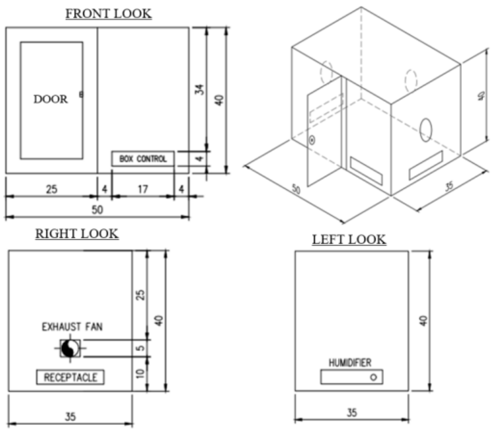


Fig. 6. Kumbung straw mushroom design

As for the design of the placement of electronic components, it can be seen in Fig. 7. The finished results of this research product can be seen in Fig. 8 for the front view and 9 for the side view. The software designed in this study is an application program that can connect between the running hardware and its users via a smartphone. The programming application used on NodeMCU and ESP32-Cam is the Arduino IDE. While the user interface that is applied is using blynk. The use of blynk in this study was chosen because it is compatible with the Arduino IDE, besides that the blynk application can be downloaded for free and is also easy to operate. Result Product shown in Fig. 9.

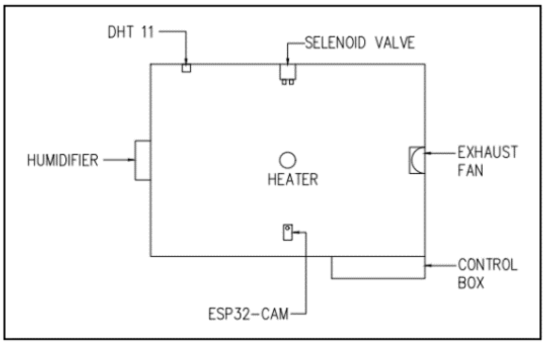


Fig. 7. Electronic Part Placement on Kumbung

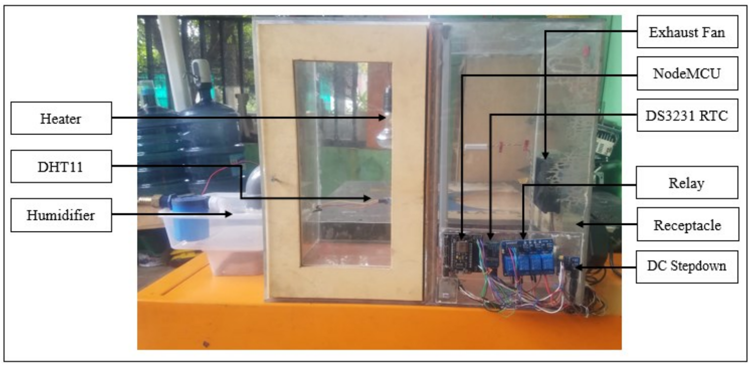


Fig. 8. Result Product (Front View)

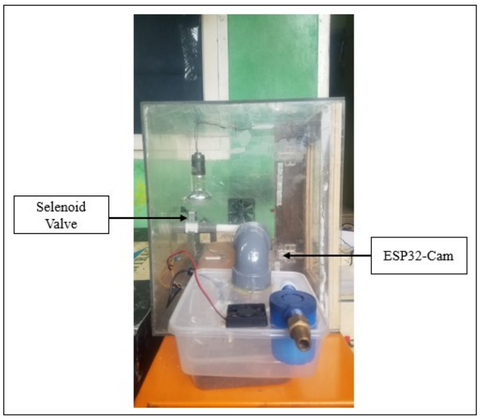


Fig. 9. Result Product (Side View)

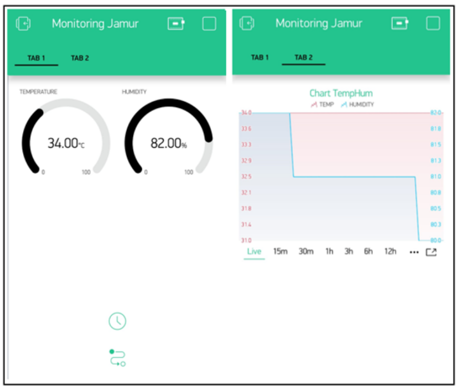
Fig. 10 shows the display of mushroom monitoring in the blynk application. Fig. 10 (i) shows the monitoring display for temperature and humidity parameters. As for it, there are notification and eventor widgets. The notification widget is used to notify a condition in the system that is currently running, while the eventor widget is used to notify a condition in the system that is currently active and can provide a solution to that condition. Meanwhile, Fig. 10 (ii) shows the super chart widget. The widget is to display graphs for temperature and humidity values, the temperature and humidity graphs can be viewed in real-time as well as the previous 12 hours of history.

In testing this system will explain testing monitoring and testing automation. The monitoring test will discuss system trials for the Blynk application and compatibility with the sensors used. Automation testing will explain experiments on the system to make conditions ideal when conditions are not ideal.

Monitoring testing is carried out to monitor and determine the performance of the system made for the applications used. Monitoring testing is very important because it displays the core parameters, namely temperature and humidity. These parameters are the focus of this research.

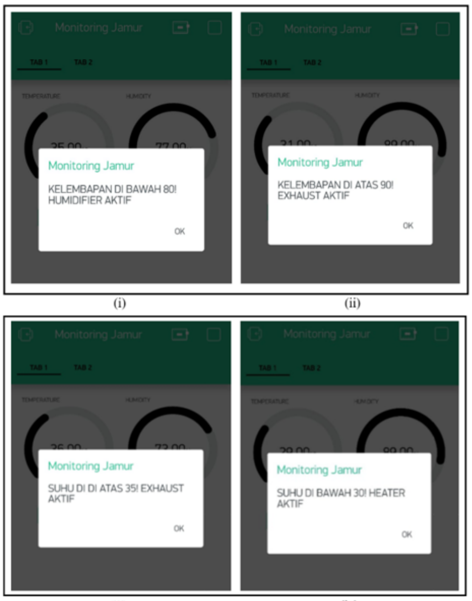
Fig. 11 displays several notifications when conditions match the settings on the eventor widget. Letter (i) displays a notification that the humidity level is below 80% and the humidifier will work. Letter (ii) displays a notification that the humidity level is above 90% and the exhaust fan will work. Letter (iii) indicates if the temperature is above 35°C and the exhaust fan is working. Letter (iv) indicates if the temperature is below 30°C and the heater is working.

Blynk is a platform that allows users to create graphical interfaces for their Internet of Things (IoT) projects via mobile or web applications. In this case, Tab 2 of the Blynk view displays the super chart widget, which displays a graph of temperature and humidity against time. Fig. 12 shows the Blynk view for Tab 2, where you can see graphs of temperature and humidity plotted against time. This allows users to monitor environmental conditions in real-time and make informed decisions to maintain optimal growing conditions.



(i) (ii)

Fig. 10. Application of Monitoring System, monitoring jamur (mushroom monitoring)



(i) (ii) (iii) (iv)

Fig. 11. Notification Eventor, monitoring jamur (mushroom monitoring), Kelembapan di bawah 80 humidifier aktif (Humidity below 80 humidifier active), Kelembapan di atas 90 exhaust aktif (Humidity above 90 exhaust is active), suhu di atas 35 exhaust aktif (temperatures above 35 exhaust active), suhu di bawah 35 heater aktif (temperature below 35 heater active)

This automation test aims to determine the reliability of the system in regulating temperature and humidity. This automation test is carried out by creating conditions outside the normal limits so that the system will automatically return to normal conditions. The statistical calculation we use to measure the average deviation can be seen in Equation 1. This equation allows us to measure how well the system can regulate temperature and humidity by calculating the average deviation from normal conditions. By performing this automation test, we can evaluate the reliability of the system in maintaining optimal growth conditions.

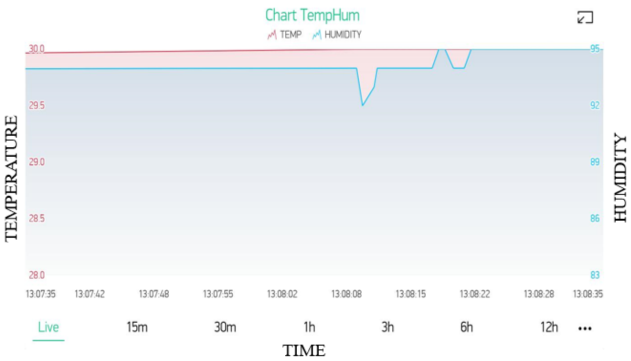


Fig. 12. Blynk Display: Tab 2

$$mean\ deviation = \frac{1}{n}\sum|x_i - \bar{x}| \quad (1)$$

3.1. Temperature automation test less than 30°C (Night)

Automation testing at temperatures below 30°C is carried out to check the reliability of the system in controlling the temperature. In mushroom cultivation, the ideal temperature needed for mushroom growth is 30-35°C. If the temperature is below 30°C it will inhibit the mycelium from growing. The test was carried out 5 times by making the temperature of the kumbung less than 30°C. When the temperature is less than 30°C, the system will automatically make the heater work to raise the temperature to 30°C. Table 2 is data on the results of automation testing at temperatures of less than 30°C at night.

Table 2 shows data on the results of temperature automation tests of less than 30°C at night. In each test, data collection was carried out 5 times to increase the temperature. Obtained an average deviation of 0.00024. This shows that the tested system can reliably control the temperature and keep it within the ideal range for mold growth, which is between 30-35°C. When the temperature drops below 30°C, the system will automatically activate the heater to raise the temperature back to the ideal range. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 2. Temperature Automation Test Data < 30°C (Night)

No	Experiment	Date	Start Temp (°C)	Final Temp (°C)	Temp difference (°C)	Increase time (s)	Temperature Rising Speed
1	I	22-01-2023	27.5	30	2.5	90	0.028
2	II	22-01-2023	26.8	30	3.2	115	0.029
3	III	22-01-2023	25.6	30	4.4	154	0.028
4	IV	22-01-2023	28.3	30	1.7	66	0.025
5	V	22-01-2023	25	30	5	169	0.030
			Average				0.028

3.2. Temperature automation test less than 30°C (Daylight)

In the automation test, the temperature is less than 30°C is carried out 5 times during the day. The test was carried out during the day to see the difference in speed with the automation test which was carried out at night. Data on the results of temperature automation tests during the day shown in Table 3.

Table 3 shows data on the results of temperature automation tests of less than 30°C during the day. In each test, data collection was carried out 5 times to measure changes in temperature increase. From the test results, the average speed of increasing temperature is 0.043 and the average deviation is 0.000944. This demonstrates that the system under test can reliably control temperature and increase the temperature at a consistent rate when the temperature drops below 30°C. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 3. Temperature Automation Test Data < 30°C (Daytime)

No	Experiment	Date	Start Temp (°C)	Final Temp (°C)	Temp difference (°C)	Increase time (s)	Temperature Rising Speed
1	VI	23-01-2023	26	30	4	80	0.050
2	VII	23-01-2023	27	30	3	62	0.048
3	VIII	23-01-2023	28	30	2	45	0.044
4	IX	23-01-2023	27.4	30	2.6	69	0.038
5	X	23-01-2023	28.5	30	1.5	41	0.037
			Average				0.043

3.3. Temperature Automation Test over 35°C (Night)

This test is carried out to ensure that the system works when the temperature is more than 35°C. If the temperature is too hot, it will be difficult for the mushroom to grow. For this reason, automatic testing of temperatures over 35°C is required to control the temperature so that it does not exceed 35°C. Table 4 shows the data on the results of temperature automation tests of more than 35°C at night. In each test, the temperature drop data was collected 5 times. From the test results, the average temperature management is 0.076 and the average deviation is 0.00064. This demonstrates that the system under test can reliably control temperature and degrade at a consistent rate when the temperature rises above 35°C. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 4. Temperature Automation Test Data > 35°C (Night)

No	Experiment	Date	Start Temp (°C)	Final Temp (°C)	Temp difference (°C)	Increase time (s)	Temperature Rising Speed
1	I	22-01-2023	38	35	3	42	0.071
2	II	22-01-2023	38.6	35	3.6	48	0.075
3	III	22-01-2023	39	35	4	54	0.074
4	IV	22-01-2023	39.7	35	4.7	59	0.080
5	V	22-01-2023	40	35	5	62	0.080
			Average				0.076

3.4. Temperature automation test over 35°C (Daylight)

The temperature automation test > 35°C was carried out 5 times during the day. Tests were carried out to prove the difference in the speed of temperature reduction with tests carried out at night. The test results data can be seen in Table 5. Table 5 shows the data on the results of temperature automation tests of more than 35°C during the day. In each test, the temperature drop data was collected 5 times. The average speed of temperature reduction is 0.063 with an average deviation of 0.000352. The average temperature increase speed is almost the same in each test. This demonstrates that the system under test can reliably control temperature and degrade at a consistent rate when temperatures rise above 35°C during the day. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 5. Automation Test Data for Temperature > 35°C (Daylight)

No	Experiment	Date	Start Temp (°C)	Final Temp (°C)	Temp difference (°C)	Increase time (s)	Temperature Rising Speed
1	VI	23-01-2023	40.6	35	5.6	91	0.061
2	VII	23-01-2023	41	35	6	89	0.067
3	VIII	23-01-2023	41.5	35	6.5	103	0.063
4	IX	23-01-2023	42	35	7	114	0.061
5	X	23-01-2023	42.8	35	7.8	126	0.062
			Average				0.063

3.5. Humidity Testing Automation Less Than 80% (Night)

Humidity automation testing is carried out to test system performance, especially humidifiers which play a role in increasing humidity. The minimum humidity so that the mushroom can continue to grow optimally is 80%. The test was carried out 5 times by lowering the humidity value to less than 80%. When the humidity is less than 80%, the humidifier will work to increase the humidity. Table 6 shows data on the results of humidity automation tests of less than 80% at night. In each test, data collection on the increase in humidity was carried out 5 times. The average value of the speed of increase in humidity is 0.084 with an average deviation of 0.00104, which means the speed of increase in average temperature is almost the same. This shows that the system under test can reliably control humidity and increase humidity at a consistent rate when humidity drops below 80%. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 6. Data for Testing Humidity < 80% (Night)

No	Experiment	Date	Start Humidity (%)	Final Humidity (%)	Humidity difference (%)	Increase time (s)	Humidity Rising Speed
1	I	22-01-2023	76	80	4	46	0.087
2	II	22-01-2023	75	80	5	59	0.085
3	III	22-01-2023	74	80	6	69	0.087
4	IV	22-01-2023	73	80	7	84	0.083
5	V	22-01-2023	72	80	8	102	0.079
			Average				0.084

3.6. Automation test humidity less than 80% (Day)

This humidity automation test was carried out during the day with experiments at a humidity of less than 80%. The test was carried out 5 times under different humidity conditions. The following is humidity testing data of less than 80% during the day.

Table 7 shows data on the results of humidity automation tests of less than 80% during the day. In each test, data collection on the increase in humidity was carried out 5 times. The average value of the speed of increase in humidity is 0.052 with an average deviation of 0.00024, which means that the speed of increase in average humidity is almost the same. This shows that the system under test can reliably control humidity and increase humidity at a consistent rate when humidity drops below 80% during the day. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 7. Data for Testing Humidity < 80% (Day)

No	Experiment	Date	Start Humidity (%)	Final Humidity (%)	Humidity difference (%)	Increase time (s)	Humidity Rising Speed
1	VI	23-01-2023	71	80	9	177	0.050
2	VII	23-01-2023	70	80	10	194	0.051
3	VIII	23-01-2023	69	80	11	211	0.052
4	IX	23-01-2023	68	80	12	226	0.053
5	X	23-01-2023	67	80	13	245	0.053
			Average				0.052

3.7. Humidity Test Automation more than 90% (Night)

This test serves to ensure the system works normally and the exhaust fan can work to reduce humidity. The test was carried out 4 times by increasing the humidity value. When the humidity value is more than 90%, the exhaust fan automatically works to lower the humidity level in the kumbung. The following is data for testing automation of humidity temperatures of more than 90%.

Table 8 shows data on the results of humidity automation tests of more than 90% at night. Humidity data collection for each test was carried out at different humidity. The average speed of moisture reduction is 0.112 and the average deviation value is 0.008175. This means that the average humidity reduction speed is almost the same. This shows that the system under test can reliably control humidity and decrease humidity at a consistent rate when humidity rises above 90%. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 8. Automated Test Data Humidity > 90% (Night)

No	Experiment	Date	Start Humidity (%)	Final Humidity (%)	Humidity difference (%)	Increase time (s)	Humidity Rising Speed
1	I	22-01-2023	91	90	1	8	0.125
2	II	22-01-2023	92	90	2	14	0.142
3	III	22-01-2023	93	90	3	20	0.150
4	IV	22-01-2023	94	90	4	133	0.030
			Average				0.112

3.8. Humidity Test Automation Over 90% (Daylight)

This humidity automation test was carried out during the day with experiments at a humidity of more than 90%. The test was carried out 4 times under different humidity conditions. The following is humidity testing data of more than 90% at night.

Table 9 shows data on the results of humidity automation tests of more than 90% during the day. In each test, different moisture reduction data were collected. The average speed of moisture reduction is 0.076 and the average deviation is 0.00025. This demonstrates that the system under test can reliably control humidity and decrease humidity at a consistent rate when humidity rises above 90% during the day. These results indicate that the system can work well in maintaining optimal growth conditions for mushroom cultivation.

Table 9. Automated Test Data Humidity > 90% (Night)

No	Experiment	Date	Start Humidity (%)	Final Humidity (%)	Humidity difference (%)	Increase time (s)	Humidity Rising Speed
1	V	23-01-2023	91	90	1	13	0.076
2	VI	23-01-2023	92	90	2	27	0.074
3	VII	23-01-2023	93	90	3	39	0.077
4	VIII	23-01-2023	94	90	4	51	0.078
			Average				0.076

3.9. System Testing with Mushroom Growth Experiments

The straw mushroom growth experiment aims to see the development of the straw mushroom in the system that has been designed. Several aspects need to be considered so that the straw mushroom can grow, namely the quality of the planting medium, the thickness of the planting media, the method of spreading the mushroom seeds, and environmental factors.

The influencing environmental factor is that the mushroom house must be free from pests, another big environmental factor is keeping the temperature and humidity inside the mushroom house stable. The optimal temperature required for the growth of mushrooms is known to range from 30-35°C with a humidity level of 80-90%. Growing straw mushrooms can identify if the tool has worked properly. It is known that on the 8th to 12th day after stocking the seeds, the fruiting bodies of the mushroom have reached the button stage (bud) and are ready to be harvested. The following are the results of the straw mushroom growth experiment shown in Table 10.

Table 10. Straw Mushroom Growth Experiment

Date	Time	Temp (°C)	Humidity (%)	Photo of straw mushroom grow
9-11-2022	10:15 13:22 18:36	32.6 34.2 32.2	85 81 87	
10-11-2022	07:15 11:42 19:43	33.2 35.1 31.3	83 81 87	

Date	Time	Temp (°C)	Humidity (%)	Photo of straw mushroom grow
11-11-2022	06:55 13:12 18:14	31.5 34.7 32.3	84 82 86	
12-11-2022	07:05 11:14 17:36	30.6 34.1 32.8	85 82 84	
13-11-2022	07:19 11:48 18:52	31.7 34.2 31.2	84 80 85	
14-11-2022	07:14 12:14 19:48	31.5 34.4 30.6	85 81 87	
15-11-2022	10:04 13:32 18:52	32.1 34.3 32.1	84 82 87	

Date	Time	Temp (°C)	Humidity (%)	Photo of straw mushroom grow
16-11-2022	08:05 13:18 19:23	32.2 31.2 31.7	82 80 88	
17-11-2022	07:02 12:53 21:57	31.3 34.5 30.2	83 80 88	

The average temperature and humidity measurements on the system test results for 9 days are shown in Table 11. From Table 11, the average value and average deviation value for measuring temperature and humidity in testing the system with the straw mushroom growth experiment are obtained. In testing the system, the average value is divided into 3 times, namely morning, afternoon, and evening. In testing the system, the average values of temperature and humidity for 9 days are still following the standard habitat for mushroom growth, which is at a temperature of 30°C - 35°C and humidity of 80% - 90%.

Table 11. System Testing Result

No	Time	Average		Mean deviation	
		Temp (°C)	Humidity (%)	Temp (°C)	Humidity (%)
1	Morning	31.90	83.75	0.63	0.81
2	Afternoon	34.08	81.00	0.64	0.67
3	Night	31.60	86.56	0.69	1.04

3.10. Power Consumption

The use of the tool in this study required electric power to turn on all the components, so in this case, the power usage measurement was carried out on this tool. Table 12 shows the power usage of several components. For power usage, it is divided into 2, namely during the day and at night. The power usage can be calculated as follows.

a) Total power calculation for 1 hour during the day
Total = (0.07613 + 0.8032 + 0.0033 + 0.00066 + 0.08016 + 0.15 + 0.78 + 2) Wh
Total = 3.893 Wh
b) Total power calculation for 1 hour at night
Total = (0.07613 + 0.8032 +0.0033 + 0.00066 + 0.08016 + 0.13 + 1.14) Wh
Total = 2.233 Wh
c) The total power usage in 1 day is as follows:
Total = (Day Power Calculation × 12) + (Night Power Calculation × 12)
Total = (3.893 Wh × 12) + (2.233 Wh × 12)
Total = (46.716 + 26.796) Wh
Total = 73.512 Wh
d) Total Power usage in 9 days
Total = Power usage in 1 day × 9
Total = 73.512 Wh × 9

Total = 661.608 Wh
The estimated power consumption required for the system to work for 9 days is 661,608 Wh.

Table 12. Power Consumption Under Working Conditions

No	Alat	Voltage (Volt)	Current (Ampere)	Power (Watt)
1	NodeMCU ESP8266	3.31	0.023	0.07613
2	Relay	5.02	0.16	0.8032
3	DHT11	3.3	0.001	0.0033
4	DS3231	3.3	0.0002	0.00066
5	ESP32-Cam	5.01	0.016	0.08016
6	Exhaust Fan	12.1	0.02	0.242
7	Humidifier	23.95	0.20	4.79
8	Heater	220	0.1	22
9	Solenoid Valve	11.96	0.16	2

3.11. System Testing and Trends Analysis

The data that has been tested is then analyzed to obtain conclusions in assessing system performance. Analyzing a system's performance, both in terms of monitoring and controlling.

DHT11 readings taken during the day have a greater value than those taken at night. This happens because during the day the temperature tends to be hot and at night the temperature is cooler. Likewise, for the humidity in the mushroom house, the time of day and night is also different. Humidity at night has a greater value than during the day, this can be caused because at night it tends to be cool and there is more water vapor in the air than during the day [60].

From the results of automation tests carried out during the day and at night, there is a difference in the speed of decreasing temperature and humidity which proves that the tool has worked well in controlling temperature and humidity.

From the results of automation tests carried out during the day and at night, there are differences in the speed of decreasing temperature and humidity which proves that the tool has worked well in controlling temperature and humidity. From the experimental data for 9 days, the tool works well, it can be seen from the results of measuring temperature and humidity which are still included in the category of straw mushroom growth habitat, namely the results of controlled temperatures between 30.2°C to 35.1°C while in controlled humidity is 80% to 88%. For the results of the average deviation of temperature and humidity in the morning of 0.63 and 0.81. Then the average deviation during the day for temperature and humidity values is 0.64 and 0.67. While the average deviation of temperature and humidity at night is 0.69 and 1.04. In system testing, the DHT11 sensor is the most important because the DHT11 sensor reading will determine the output. In this case, the results of temperature and humidity readings are very good, this is evidenced by the temperature and humidity readings still within the tolerance of the DHT11 sensor.

Based on the data obtained in this study, we can see that from several temperature and humidity tests carried out either during the day or night, adjustments are needed to obtain the optimum temperature. The system briefly performs environmental conditioning by increasing or decreasing temperature or humidity. Based on these data we can see that the system will work longer when increasing the temperature with a temperature change speed of around 0.028-0.043 in Table 2 and Table 3 compared to decreasing temperature which has a temperature change speed starting from 0.063-0.076 which can be seen in Table 4 and Table 5.

Furthermore, for changes in humidity, we can see that the trend is the same as for temperature changes. The increase in humidity will be slower than the decrease in humidity. The speed of increase in humidity ranges from 0.052-0.084 which can be seen in Table 6 and Table 7. These results are slower than the decrease in humidity whose speed of change ranges from 0.076-0.112 which can be seen in Table 8 and Table 9.

So, we can see that in adjusting both temperature and humidity, the time taken to adjust to the target required is slower in the process of increasing temperature and humidity.

In system testing, the DHT11 sensor is the most important because the DHT11 sensor reading will determine the output. In this case, the results of temperature and humidity readings are very good, this is evidenced by the temperature and humidity readings still within the tolerance of the DHT11 sensor.

3.12. Monitoring Test Analysis

The data in the monitoring test is also on the server so that the data can be accessed. The camera to monitor the growth of the mushroom should be placed behind the door of the kumbung so that the capture of the mushroom can be optimal. Components that are placed in a shed, require intensive care because the effect of humidity inside the shed will cause a short circuit to occur in the components, but using a box or sealant on the components can be the best solution in this study.

3.13. Comparative Analysis

The mushroom cultivation monitoring system that we created in this study has several advantages and unique features compared to other existing methods or systems. First, there is a system of using sensors based on the Internet of Things that focus on measuring environmental parameters such as temperature, and humidity, and taking pictures in real time and accurately. The use of DHT11 as a temperature sensor is a unique approach to maintaining the quality of the temperature of the kumbung that is made. Automating watering with the RTC module is also a unique approach rather than using a soil moisture sensor, so that the supply of nutrients to the mushroom plants is regular, not due to dry conditions, then The ESP32-CAM camera, as previously mentioned, is used to obtain real-time mushroom growth processes. Another uniqueness is combining various actuators to maintain optimum environmental conditions in the kumbung with a heater, humidifier, exhaust fan, and solenoid valve.

This remote control and monitoring system for mushrooms also allows the user to remotely monitor and control mushroom growth conditions such as temperature, humidity, light intensity, and progress of mushroom growth. Users can also visualize mushroom growth from images obtained via the internet. It can reduce labor costs through automation and increase yields by providing optimal conditions for growth. As well as this system can optimize the use of resources such as water and other plant nutrients which in turn maximizes the quality and productivity of mushroom growth [61]-[64].

Overall, the Internet of Things-based kumbung environmental monitoring and control system for mushroom cultivation that has been implemented offers a unique, innovative, and efficient solution to increase productivity, quality, and efficiency of mushroom cultivation as well as reduce costs and risks [65]-[66].

The implementation of technology as a novelty from a traditional approach cannot be separated from questions about the economic effects or benefits. The implementation of an Internet of Things-based monitoring and control system for mushroom cultivation has significant economic significance. Automation and environmental control can reduce labor costs because the system created provides optimal conditions for mushroom growth. In addition, the system created can optimize the use of water and nutrient resources as previously mentioned where this step is in line with maximizing the quality and productivity of mushroom growth.

But of course, in carrying out the transformation from traditional cultivation to technologically advanced cultivation, farmers or users need investment costs for the technology used. As in this study, researchers need funds to provide related technology ranging from microcontrollers, power supplies, and sensors, to actuators. The cost of maintaining this technology will be cheaper compared to a more efficient workforce. Economic calculations were not involved in this research but briefly, it can be said that the use of this technology accelerates the growth of mushrooms which can be harvested in just 9 days, where in general the total growth cycle takes 4-5 weeks and for optimum conditions it can take 2 weeks [67]. With a short time of course it will be cheaper in terms of economics in the long run once the investment in the technology has been implemented.

One of the limitations of this process is the impossibility of implementing artificial intelligence or machine learning because the microcontroller used is not qualified for the process. The use of mini-PCs such as the Raspberry Pi helps in artificial intelligence and machine learning processes. In terms of scalability for upscaling, it will be more capable if you use a mini-PC than the microcontroller that we use. However, the use of the same components for larger kumbung can be made possible by adding more actuators such as solenoid valves, heaters, exhaust fans, and humidifiers. In its use for other types of mushrooms, it is possible because in general, in developing kumbung or places for mushroom cultivation what needs to be considered is how to optimize the environment by maintaining temperature and humidity [68]-[71].

4. CONCLUSION

Based on the results of the study, it was found that controlling the environment at optimal temperature and humidity at temperatures of 30°C – 35°C and humidity of the straw mushroom habitat, which is around 80% -90% is carried out automatically, increases the efficiency of operational costs and manual work. It also increases yields due to shorter growth times by controlling the kumbung environment. This automation also controls the supply of air which can save the resources used. The devices used in this study are widely found in the market so that readers can easily replicate the research conducted. Furthermore, with the device made in this study, it is also possible to combine the growth of straw mushrooms through cellphones on the blynk application in real-time using photos.

As mentioned in the previous section, the limitations of the devices made are the inability to implement artificial intelligence or machine learning due to the poor utilization of microcontrollers. Therefore, researchers suggest conducting further research by utilizing mini-PC devices as a substitute for microcontrollers to be able to carry out better and more precise control by utilizing artificial intelligence and machine learning. Soil moisture sensors may also be able to increase the effectiveness of using air and nutrients needed for further optimization of fungal growth. Larger kumbung sizes can also be tested further. In this study with a research scale, it is very uneconomical because the amount of investment is not proportional to the results obtained. Therefore, further improvement needed to gain economic advantage can be researched.

This research has proven that using an environmentally controlled kumbung to achieve an environment with optimal temperature and humidity can shorten the mushroom growth time which is generally 2 to 5 weeks to 9 days which can reduce operational costs because the automation system that is carried out can also reduce manual work reduces labor costs. Its growth can protect other devices such as the user's cell phone in real-time.

REFERENCES

[1] J. E. Bermuli, W. Irawati, and R. M. Tammu, "The Effect of Pasteurization Stage on the Production of Straw Mushroom (Volvariella Volvacea, Bull. EX. FR./SING.)," *BIOLINK (Jurnal Biologi Lingkungan Industri Kesehatan)*, vol. 8, no. 2, pp. 242–256, 2022, https://doi.org/10.31289/biolink.v8i2.6167.

[2] X. Wang *et al.*, "Low temperature (15 C) reduces bacterial diversity and prolongs the preservation time of Volvariella volvacea," *Microorganisms*, vol. 7, no. 10, p. 475, 2019, https://doi.org/10.3390/microorganisms7100475.

[3] L. V. Thuc *et al.*, "Rice-straw mushroom production," *Sustainable rice straw management*, pp. 93–109, 2020, https://doi.org/10.1007/978-3-030-32373-8_6.

[4] N. P. Minh and L. P. Hang, "Several Factors Affecting to Shelf-Life o Paddy Straw Mushroom (Volvariella SPP.) in Preservation," *Plant Archives*, vol. 19, no. 2, pp. 444–448, 2019, http://plantarchives.org/SPL%20ISSUE%20SUPP%202,2019/79%20(444-448).pdf.

[5] A. M. Aloria, M. B. Z. Aclan, C. D. Agito, and C. N. D. Almares, "Design and development of a rice straw-based mushroom growing substrate pasteurizing and cooling system," *Int Adv J Eng Res*, vol. 2, pp. 6-18, 2019, https://www.iajer.com/wp-content/uploads/2019/06/B260618.pdf.

[6] V. K. Yella, A. Chadrapati, A. Kuri, I. Miglani, A. A. Andrews, and S. Singh, "Cultivation technology and spawn production of Volvariella volvacea: Paddy straw mushroom," *Pharm. Innov. J*, vol. 10, no. 5, pp. 1184–1190, 2021, https://www.thepharmajournal.com/archives/2021/vol10issue5/PartO/10-4-241-719.pdf.

[7] W. A. W. Mahari *et al.*, "A review on valorization of oyster mushroom and waste generated in the mushroom cultivation industry," *J Hazard Mater*, vol. 400, p. 123156, 2020, https://doi.org/10.1016/j.jhazmat.2020.123156.

[8] F. M. Musyoka, M. M. Thiga, and G. M. Muketha, "A 24-hour ambulatory blood pressure monitoring system for preeclampsia management in antenatal care," *Inform Med Unlocked*, vol. 16, p. 100199, 2019, https://doi.org/10.1016/j.imu.2019.100199.

[9] N. Azman, M. K. Bin Abd Ghani, S. R. Wicaksono, B. Kurniawan, and V. V. R. Repi, "Insomnia analysis based on internet of things using electrocardiography and electromyography.," *Telkomnika*, vol. 18, no. 3, 2020, http://doi.org/10.12928/telkomnika.v18i3.14897.

[10] N. Azman, M. K. A. Ghani, S. R. Wicaksono, and L. Salahuddin, "The Development of IoT Tele-Insomnia Framework to Monitor Sleep Disorder," *Internasional Journal of Advanced Trends in Computer Science and Engineering*, vol. 8, no. 6, pp. 2831–2839, 2019, https://doi.org/10.30534/ijatcse/2019/25862019.

[11] S. Muthuramalingam, A. Bharathi, S. Rakesh Kumar, N. Gayathri, R. Sathiyaraj, and B. Balamurugan, "IoT based intelligent transportation system (IoT-ITS) for global perspective: A case study," *Internet of Things and Big Data Analytics for Smart Generation*, pp. 279–300, 2019, https://doi.org/10.1007/978-3-030-04203-5_13.

[12] A. H. Sodhro *et al.*, "Quality of Service Optimization in an IoT-Driven Intelligent Transportation System," *IEEE Wireless Communications*, vol. 26, no. 6, pp. 10-17, 2019, https://doi.org/1.1109/MWC.001.1900085.

[13] S. Chavhan, D. Gupta, B. N. Chandana, A. Khanna and J. J. P. C. Rodrigues, "IoT-Based Context-Aware Intelligent Public Transport System in a Metropolitan Area," *IEEE Internet of Things Journal*, vol. 7, no. 7, pp. 6023-6034, 2020, https://doi.org/10.1109/JIOT.2019.2955102.

[14] N. Hossein Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of Things (IoT) and the energy sector," *Energies (Basel)*, vol. 13, no. 2, p. 494, 2020, https://doi.org/10.3390/en13020494.

[15] N. Azman, F. Soleman, and I. Kusuma, "Optimization 5 × 195 kw chiller compressor motor with ETAP," *International Journal of Advanced Trends in Computer Science and Engineering*, vol. 9, no. 5, pp. 7696–7703, 2020, https://doi.org/10.30534/ijatcse/2020/112952020.

[16] T. Ahmad and D. Zhang, "Using the internet of things in smart energy systems and networks," *Sustainable Cities and Society*, vol. 68, p. 102783, 2021, https://doi.org/10.1016/j.scs.2021.102783.

[17] A. R. Diana, E. R. Nugroho, S. R. Wicaksono, and N. Azman, "Industrial internet of things solution for monitoring ammonia and carbon monoxide in industrial staging areas," *AIP Conference Proceedings*, vol. 2664, no. 1, p. 30005, 2022, https://doi.org/10.1063/5.0108056.

[18] V. K. Quy *et al.*, "IoT-enabled smart agriculture: architecture, applications, and challenges," *Applied Sciences*, vol. 12, no. 7, p. 3396, 2022, https://doi.org/10.3390/app12073396.

[19] P. K. Kashyap, S. Kumar, A. Jaiswal, M. Prasad and A. H. Gandomi, "Towards Precision Agriculture: IoT-Enabled Intelligent Irrigation Systems Using Deep Learning Neural Network," *IEEE Sensors Journal*, vol. 21, no. 16, pp. 17479-17491, 2021, https://doi.org/10.1109/JSEN.2021.3069266.

[20] M. S. Farooq, S. Riaz, A. Abid, K. Abid and M. A. Naeem, "A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming," *IEEE Access*, vol. 7, pp. 156237-156271, 2019, https://doi.org/10.1109/ACCESS.2019.2949703.
[21] V. Suma, "Internet-of-Things (IoT) based smart agriculture in India-an overview," *Journal of ISMAC*, vol. 3, no. 1, pp. 1-15, 2021, https://doi.org/10.36548/jismac.2021.1.001.
[22] W. F. Pereira, L. da Silva Fonseca, F. F. Putti, B. C. Góes, and L. de Paula Naves, "Environmental monitoring in a poultry farm using an instrument developed with the internet of things concept," *Computers and Electronics in Agriculture*, vol. 170, p. 105257, 2020, https://doi.org/10.1016/j.compag.2020.105257.
[23] M. Humayun, N. Z. Jhanjhi, A. Alsayat, and V. Ponnusamy, "Internet of things and ransomware: Evolution, mitigation and prevention," *Egyptian Informatics Journal*, vol. 22, no. 1, pp. 105–117, 2021, https://doi.org/10.1016/j.eij.2020.05.003.
[24] Y. Mitake, Y. Tsutsui, S. Alfarihi, M. Sholihah, and Y. Shimomura, "A life cycle cost analysis method accelerating IoT implementation in SMEs," *Procedia CIRP*, vol. 104, pp. 1424–1429, 2021, https://doi.org/10.1016/j.procir.2021.11.240.
[25] M. Dayoub, A. Nakiyemba, and J. Plosila, "Applications of Internet of Things (IoT) in Agriculture-The Potential and Challenges in Smart Farm in Uganda," *The International Conference on Artificial Intelligence and Computer Vision*, pp. 135–144, 2021, https://doi.org/10.1007/978-3-030-76346-6_13.
[26] M. E. Pérez-Pons, M. Plaza-Hernández, R. S. Alonso, J. Parra-Domínguez, and J. Prieto, "Increasing profitability and monitoring environmental performance: A case study in the agri-food industry through an edge-IoT platform," *Sustainability*, vol. 13, no. 1, p. 283, 2020, https://doi.org/10.3390/su13010283.
[27] Y. Mitake, Y. Tsutsui, S. Alfarihi, M. Sholihah, and Y. Shimomura, "A life cycle cost analysis method accelerating IoT implementation in SMEs," *Procedia CIRP*, vol. 104, pp. 1424–1429, 2021, https://doi.org/10.1016/j.procir.2021.11.240.
[28] P. N. Andono, F. Ocky Saputra, G. F. Shidik and Z. Arifin Hasibuan, "End-to-End Circular Economy in Onion Farming with the Application of Artificial Intelligence and Internet of Things," *2022 International Seminar on Application for Technology of Information and Communication (iSemantic)*, pp. 459-462, 2022, https://doi.org/10.1109/iSemantic55962.2022.9920447.
[29] J. H. Nord, A. Koohang, and J. Paliszkiewicz, "The Internet of Things: Review and theoretical framework," *Expert Syst Appl*, vol. 133, pp. 97–108, 2019, https://doi.org/10.1016/j.eswa.2019.05.014.
[30] M. Lombardi, F. Pascale, and D. Santaniello, "Internet of things: A general overview between architectures, protocols and applications," *Information*, vol. 12, no. 2, p. 87, 2021, https://doi.org/10.3390/info12020087.
[31] A. M. Rahmani, S. Bayramov, and B. Kiani Kalejahi, "Internet of things applications: opportunities and threats," *Wireless Personal Communications*, vol. 122, no. 1, pp. 451–476, 2022, https://doi.org/10.1007/s11277-021-08907-0.
[32] H. A. Kusuma, R. Anjasmara, T. Suhendra, H. Yunianto, and S. Nugraha, "An IoT based coastal weather and air quality monitoring using GSM technology," in *Journal of Physics: Conference Series*, vol. 1501, vo. 1, p. 012004, 2020, https://doi.org/10.1088/1742-6596/1501/1/012004.
[33] J. Classen and M. Hollick, "Inside job: diagnosing bluetooth lower layers using off-the-shelf devices," *Proceedings of the 12th Conference on Security and Privacy in Wireless and Mobile Networks*, pp. 186-191, 2019, https://doi.org/10.1145/3317549.3319727.
[34] S. Triyono *et al.,* "Cultivation of straw mushroom (Volvariella volvacea) on oil palm empty fruit bunch growth medium," International Journal of Recycling of organic waste in *Agriculture*, vol. 8, pp. 381-392, 2019, https://doi.org/10.1007/s40093-019-0259-5.
[35] L. Lambrinos, "Internet of Things in Agriculture: A Decision Support System for Precision Farming," *2019 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Intl Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress (DASC/PiCom/CBDCom/CyberSciTech)*, pp. 889-892, 2019, https://doi.org/10.1109/DASC/PiCom/CBDCom/CyberSciTech.2019.00163.
[36] I. Ardiansah, N. Bafdal, E. Suryadi, and A. Bono, "Greenhouse monitoring and automation using Arduino: a review on precision farming and internet of things (IoT)," *Int J Adv Sci Eng Inf Technol*, vol. 10, no. 2, pp. 703–709, 2020, https://doi.org/10.18517/ijaseit.10.2.10249.
[37] V. P. Kour and S. Arora, "Recent Developments of the Internet of Things in Agriculture: A Survey," *IEEE Access*, vol. 8, pp. 129924-129957, 2020, https://doi.org/10.1109/ACCESS.2020.3009298.
[38] G. Gagliardi *et al.*, "An internet of things solution for smart agriculture," *Agronomy*, vol. 11, no. 11, p. 2140, 2021, https://doi.org/10.3390/agronomy11112140.
[39] P. Sanjeevi, S. Prasanna, B. Siva Kumar, G. Gunasekaran, I. Alagiri, and R. Vijay Anand, "Precision agriculture and farming using Internet of Things based on wireless sensor network," *Transactions on Emerging Telecommunications Technologies*, vol. 31, no. 12, p. e3978, 2020, https://doi.org/10.1002/ett.3978.
[40] H. B. Mahajan, A. Badarla, and A. A. Junnarkar, "CL-IoT: cross-layer Internet of Things protocol for intelligent manufacturing of smart farming," *J Ambient Intell Humaniz Comput*, vol. 12, no. 7, pp. 7777–7791, 2021, https://doi.org/10.1007/s12652-020-02502-0.

[41] J. Astill, R. A. Dara, E. D. G. Fraser, B. Roberts, and S. Sharif, “Smart poultry management: Smart sensors, big data, and the internet of things,” *Comput Electron Agric*, vol. 170, p. 105291, 2020, https://doi.org/10.1016/j.compag.2020.105291.

[42] A. Castañeda-Miranda and V. M. Castaño-Meneses, “Internet of things for smart farming and frost intelligent control in greenhouses,” *Comput Electron Agric*, vol. 176, p. 105614, 2020, https://doi.org/10.1016/j.compag.2020.105614.

[43] M. Dhanaraju, P. Chenniappan, K. Ramalingam, S. Pazhanivelan, and R. Kaliaperumal, “Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture,” *Agriculture*, vol. 12, no. 10, p. 1745, 2022, https://doi.org/10.3390/agriculture12101745.

[44] S. Vadlamudi, “Internet of Things (IoT) in Agriculture: The idea of making the fields Talk,” *Engineering International*, vol. 8, no. 2, pp. 87–100, 2020, https://doi.org/10.18034/ei.v8i2.522.

[45] K. Agustianto, R. Wardana, P. Destarianto, E. Mulyadi, and I. G. Wiryawan, “Development of automatic temperature and humidity control system in kumbung (oyster mushroom) using fuzzy logic controller,” *IOP Conference Series: Earth and Environmental Science*, p. 12090, 2021, https://doi.org/10.1088/1755-1315/672/1/012090.

[46] I. Taskirawati, W. Sari, G. K. Lebang, M. Nurharis and E. I. Abadi, “The Composition of Coconut Fibers And Tofu Pulp As A Growing Media Of Oyster Mushrooms (Pleurotus ostreatus),” *IOP Conference Series: Earth and Environmental Science*, vol. 830, no. 1, p. 012060, 2021, https://doi.org/ 10.1088/1755-1315/830/1/01206.

[47] R. A. Saputra, M. I. Nugraha, and A. Wahyudianur, “Essential Dynamics of Rice Cultivated Under Intensification on Acid Sulfate Soils Ameliorated with Composted Oyster Mushroom Baglog Waste.,” *Pertanika J Trop Agric Sci*, vol. 45, no. 3, 2022, https://doi.org/10.47836/pjtas.45.3.02.

[48] A. H. Adam, R. Tamilkodi and K. V. Madhavi, "Low-Cost Green Power Predictive Farming Using IOT and Cloud Computing," *2019 International Conference on Vision Towards Emerging Trends in Communication and Networking (ViTECoN)*, pp. 1-5, 2019, https://doi.org/10.1109/ViTECoN.2019.8899500.

[49] S. N. M. Al-Faydi and H. N. Y. Al-Talb, "IoT and Artificial Neural Network-Based Water Control for Farming Irrigation System," *2022 2nd International Conference on Computing and Machine Intelligence (ICMI)*, pp. 1-5, 2022, https://doi.org/10.1109/ICMI55296.2022.9873650.

[50] V. Kanhekar, T. Deshbhratar, Y. Matey, K. Kalbande and A. Deshmukh, "Hydroponic Farming using IoT," *2022 International Conference on Edge Computing and Applications (ICECAA)*, pp. 583-586, 2022, https://doi.org/10.1109/ICECAA55415.2022.9936366.

[51] A. Wahid, D. Syahbani, and F. Adiba, “Implementation of Smart Farming for Oyster Mushroom Cultivation Based on Wireless Sensor Network Using ESP8266,” *Internet of Things and Artificial Intelligence Journal*, vol. 3, no. 2, pp. 148–160, 2023, http://www.pubs.ascee.org/index.php/iota/article/view/610.

[52] M. V Subramanyam, S. S. Thasleem, Y. Sravani, K. Poojitha, N. Swetha, and K. L. Chaitanya, “IoT Based Farm Protection from Animals and Human Theft using Esp32 with Camera Module,” *International Research Journal of Modernization in Engineering Technology and Science*, vol. 5, no. 4, 2023, https://www.irjmets.com/uploadedfiles/paper/issue_4_april_2023/36852/final/fin_irjmets1682404708.pdf.

[53] P. Manikandan, G. Ramesh, P. Lokesh, P. N. Raju, M. D. Prasad and P. Madhu, "IOT Based Farm Protection System from Animals and Humans Theft using ESP32 with Camera Module," *2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE)*, pp. 1861-1864, 2022, https://doi.org/10.1109/ICACITE53722.2022.9823912.

[54] P. W. Rusimamto, L. A. Endryansyah, R. Harimurti, and Y. Anistyasari, “Implementation of arduino pro mini and ESP32 cam for temperature monitoring on automatic thermogun IoT-based,” *Indones. J. Electr. Eng. Comput. Sci*, vol. 23, no. 3, pp. 1366–1375, 2021, http://doi.org/10.11591/ijeecs.v23.i3.pp1366-1375.

[55] S. Pawar, S. Tembe, R. Acharekar, S. Khan and S. Yadav, "Design of an IoT enabled Automated Hydroponics system using NodeMCU and Blynk," *2019 IEEE 5th International Conference for Convergence in Technology (I2CT)*, pp. 1-6, 2019, https://doi.org/10.1109/I2CT45611.2019.9033544.

[56] V. Kanhekar, T. Deshbhratar, Y. Matey, K. Kalbande and A. Deshmukh, "Hydroponic Farming using IoT," *2022 International Conference on Edge Computing and Applications (ICECAA)*, pp. 583-586, 2022, https://doi.org/10.1109/ICECAA55415.2022.9936366.

[57] A. Rajput, S. Chaudhary, L. Varshney and D. Singh, "IOT based Smart Agriculture Monitoring Using Node MCU AND BLYNK App," *2022 International Conference on Machine Learning, Big Data, Cloud and Parallel Computing (COM-IT-CON)*, pp. 448-451, 2022, https://doi.org/10.1109/COM-IT-CON54601.2022.9850847.

[58] M. S. D. Abhiram, J. Kuppili and N. A. Manga, "Smart Farming System using IoT for Efficient Crop Growth," *2020 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, pp. 1-4, 2020, https://doi.org/10.1109/SCEECS48394.2020.147.

[59] J. Doshi, T. Patel, and S. kumar Bharti, “Smart Farming using IoT, a solution for optimally monitoring farming conditions,” *Procedia Comput Sci*, vol. 160, pp. 746–751, 2019, https://doi.org/10.1016/j.procs.2019.11.016.

[60] I. Saraswati, A. R. Putra, Masjudin and Alimuddin, "Monitoring System Temperature and Humidity of Oyster Mushroom House Based on the Internet of Things," *2022 International Conference on Informatics Electrical and Electronics (ICIEE)*, pp. 1-7, 2022, https://doi.org/10.1109/ICIEE55596.2022.10010066.

[61] P. Chwietczuk, M. Siarnowski, and S. Lipiński, “Optimizing mushroom cultivation process-concepts for control and monitoring system,” *Agricultural Engineering*, vol. 24, no. 4, 2020, https://doi.org/10.1515/agriceng-2020-0032.

[62] W. K. Mok, Y. X. Tan, and W. N. Chen, “Technology innovations for food security in Singapore: A case study of future food systems for an increasingly natural resource-scarce world,” *Trends in food science & technology*, vol. 102, pp. 155-168, 2020, https://doi.org/10.1016/j.tifs.2020.06.013.

[63] J. L. Chong, K. W. Chew, A. P. Peter, H. Y. Ting, and P. L. Show, "Internet of things (IoT)-based environmental monitoring and control system for home-based mushroom cultivation," *Biosensors (Basel)*, vol. 13, no. 1, p. 98, 2023, https://doi.org/10.3390/bios13010098.
[64] A. Subedi, A. Luitel, M. Baskota, and T. D. Acharya, "IoT Based Monitoring System for White Button Mushroom Farming," *The 6th International Electronic Conference on Sensors and Applications*, 2019, http://dx.doi.org/10.3390/ecsa-6-06545.
[65] M. R. M. Kassim, I. Mat and I. M. Yusoff, "Applications of Internet of Things in Mushroom Farm Management," *2019 13th International Conference on Sensing Technology (ICST)*, pp. 1-6, 2019, https://doi.org/10.1109/ICST46873.2019.9047702.
[66] A. Subedi, A. Luitel, M. Baskota, and T. D. Acharya, "IoT Based Monitoring System for White Button Mushroom Farming," *The 6th International Electronic Conference on Sensors and Applications*, 2019, http://dx.doi.org/10.3390/ecsa-6-06545.
[67] O. P. Ahlawat and R. P. Tewari, "Cultivation technology of paddy straw mushroom (Volvariella volvacea)," *National Research Centre for Mushroom India*, vol. 36, 2007, http://agridaksh.iasri.res.in/temp/Paddy%20Straw%20mushroom.pdf.
[68] M. Konain, R. Janapati, S. M. Ahmed and M. M. Ahmed, "IoT based Solar-Powered Mushroom Farming for Sustainable Agriculture," *2023 International Conference on Sustainable Computing and Smart Systems (ICSCSS)*, pp. 944-948, 2023, https://doi.org/10.1109/ICSCSS57650.2023.10169539.
[69] D. A. Setiawati, S. G. Utomo, and G. M. D. Putra, "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*, p. 012002, 2021, https://doi.org/10.1088/1755-1315/712/1/012002.
[70] M. Awtoniuk, M. Daniun, D. Komarchuk, and S. Syrotyuk, "Predictive modelling for air temperature and humidity in a mushroom production process," *IOP Conference Series: Materials Science and Engineering*, p. 012011, 2019, https://doi.org/10.1088/1757-899X/710/1/012011.
[71] A. Najmurrokhman, Kusnandar, A. Daelami, E. Nurlina, U. Komarudin and H. Ridhatama, "Development of Temperature and Humidity Control System in Internet-of-Things based Oyster Mushroom Cultivation," *2020 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)*, pp. 551-555, 2020, https://doi.org/10.1109/ISRITI51436.2020.9315426.