Pertanika J. Sci. & Technol. 31 (4): 1731 - 1754 (2023)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Design of a Smart Portable Farming Kit for Indoor Cultivation Using the Raspberry Pi Platform

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ABSTRACT

The global crisis and climate change have resulted in severe food shortages worldwide. One of the solutions is self-farming by using smart farming technology. Smart and efficient agricultural production or smart farming using IoT sensors, big data, and cloud service has proven its value for a decade, but the effect depends on the agricultural environment of the country or society. Hence self-farming is likely the most feasible solution to avoid food scarcity. The smart farming system monitors and maintains essential growth parameters like light, temperature, and humidity to ensure maximum yield. In this paper, we propose a Smart Portable Farming Kit design, which is simple, lightweight, and durable to be placed indoors in an urban area. This prototype design uses the Internet of Things (IoT) based system for cultivating short-duration vegetables and mushrooms in an urban area with minimal user attention. The proposed design proved better than the traditional setup by increasing the mushroom yield. With Smart Portable Farming Kit, urban farming becomes a more viable alternative to increase food security, making oyster mushroom cultivation in the urban area easier and more profitable.

Keywords: Food security, indoor farming, internet of things (IoT), remote farming, single board computer, smart farming, urban farming

ARTICLE INFO

Article history:
Received: 22 June 2022
Accepted: 20 September 2022
Published: 24 May 2023

DOI: https://doi.org/10.47836/pjst.31.4.08

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INTRODUCTION

The global food demand has affected households worldwide, especially in food consumption and security due to climate change (Ballais et al., 2021). The demand will lead to rising food costs and affect low-

ISSN: 0128-7680
e-ISSN: 2231-8526

income families across 53 countries (Antonaci et al., 2022), especially in the urban area (Laborde et al., 2021; Rudolfsen, 2020). Based on Tan et al. (2020), the population will reach 9.8 billion by 2050, and most are expected to live in urban areas. Nowadays, smart agriculture technology is needed, especially in urban areas with limited space, to increase family food security by allowing households to grow nutritious food in their own homes. Therefore, urban smart vertical farming (USVF) (Jayasekara et al., 2021; Rajermani et al., 2020; Saad et al., 2021; Zulqarnain et al., 2020) and portable smart farming (Sutono & Selvia, 2020; Rajermani et al., 2020) are the potential solutions to help meet the demand without additional farmland. The main advantage of a portable smart farming system is that it can be relocated, installed easily in a building, and utilized by small families at home or offices.

Mushrooms are suitable for urban farming as it requires small space, do not require direct sunlight and require a shorter time for harvest. It is also sustainable and environmentally friendly and uses agricultural waste for its growing medium (Rosmiza et al., 2016). Mushroom also has commercial value as it is always in high demand (Rosmiza & Hussin, 2017). However, mushroom cultivation has specific growing conditions (e.g., humidity) to produce a high yield; therefore, an IoT system is needed to aid the cultivation process.

Indoor farming has gained much interest in urban areas because it is compact and movable to any available indoor space. However, the designs of portable smart farming kits for mushroom cultivation (Ibrahim et al., 2018; Kassim et al., 2019; Mat et al., 2019; Najmurrokhman et al., 2020; Shakir et al., 2019; Hendrawan et al., 2019) are still inadequate. Furthermore, the existing designs of indoor, portable smart farming (Ahmmad et al., 2020; Sutono & Selvia Lorena, 2020; Rankothge et al., 2022) are usually modelled specifically to the cultivated plant. Many factors should be considered when designing an indoor, portable smart farming kit, including the size, the materials used, the shape and the hardware installation. An inappropriate interior design of the portable kit could lead to the ruin of the plants and difficulty in operating and maintenance.

Therefore, this paper proposes a design of a Smart Portable Farming Kit (SPFK) for mushroom cultivation in urban areas where land is limited. The SPFK must be easy to install, lightweight, and developed on open-source platforms with cost-effective hardware components. The design automates growing vegetables in an urban indoor residential. A portable farming kit is a container designed to mimic a small agricultural land that can be moved to another location without any changes to the physical system. On the other hand, the design of the SPFK must have aesthetic values suitable for an indoor showcase.

The contribution of this paper is twofold: (1) This paper demonstrates the proposed design of a Smart Portable Farming Kit for mushroom cultivation using an IoT climate control system in an indoor environment, and (2) This paper proves that the implementation of smart farming technology in a portable farming kit provides a better environment, management and resulted in a higher yield of harvested mushroom as compared to the traditional method in an indoor environment.

RELATED WORK

Indoor cultivation refers to farming in an enclosed space environment. Since it is isolated from external environmental influences, the plant yields are unaffected by the weather or any climatic ailment. Furthermore, Sutono & Selvia Lorena (2020) mentioned that indoor plants could be grown even when the soil is barren. Our study excludes indoor aquaponics and hydroponics system because plants in these environments used different growing systems and technologies.

A design of indoor portable farming was built using steel, wood, and acrylic by Sutono & Selvia Lorena (2020) to utilize home yards in the urban area. The container did not have direct contact with the ground to avoid corrosion and had wheels to allow portability. The system was equipped with IoT technology using Arduino Mega 2560, 3 Stepper Motor and 12 Soil Moisture Sensors. Ahmmad et al. (2020) developed a portable Automatic Gardening Portable Plant with an automated watering system using a DHT22 humidity and temperature sensor and LED illumination using Light Intensity Sensor. Ample lighting was provided to the plants to undergo an appropriate photosynthesis process. The user is alerted if the water level or light intensity is low through Wi-Fi access using the Blynk app. Despite the success of testing the functionalities of their systems, no real-life implementation of plant cultivation was presented in both work.

In Rankothge et al. (2021), an indoor microgreen sprouts portable unit was developed to provide optimum growing conditions for mung-bean sprouts. Fuzzy inference engines and DHT-11 sensors were used to control the temperature and humidity, and ultrasonic sensors were utilized to monitor the plants' heights. Different temperatures, lighting durations, and watering frequencies were tested using the prototype for five days, and the optimum conditions for the sprouts were concluded. While IoT-based farming system is not new, the design of a portable IoT-based system for indoor farming is scarce. In a systematic review of IoT in smart farming (Terence & Purushothaman, 2020), the authors investigated which agriculture functions were commonly automated, whether the implementation was conducted in real-time, what IoT components were mostly used and how evaluations were done. There was no study on the design of the IoT-based system, whether for small- or large-scale cultivations.

Kassim et al. (2019), Mat et al. (2019) and Shakir et al. (2019) proposed a system using a wireless sensor network and a real-time embedded system to control the growing environment for shitake mushroom cultivation. The system provided an automated corrective action based on a pre-defined threshold of the growing variables to control the actuators. Shakir et al. (2019) also added a light intensity parameter to light up the environment. They observed increased CO_2 levels in artificial light, indicating that the mushrooms produced more CO_2 when the light was turned on. Their results showed an increase of 192.9% in mushroom yields. In another similar setting using a miniature enclosed house, Cruz-del Amen & Villaverde (2019) have used fuzzy logic to control temperature and humidity for oyster mushroom cultivations. They grew 30 blocks of oyster mushrooms in three separate houses to compare the conventional method, an IoT-based system, and an IoT-based system with thunderstorm audio sounds. While the results showed that an IoT-based system with thunderstorm audio produced more yields, no discussion was done on the significance and justifications of using the audio.

Other studies on IoT-based mushroom cultivation deployed indoor portable farming kits to encourage urban farming. Najmurrokhman et al. (2020) and Hendrawan et al. (2019) implemented IoT systems using closed plastic boxes to grow oyster mushrooms and monitored light, humidity, and temperature levels. Both papers detailed the design of their portable IoT-based farming kits. While Najmurrokhman et al. (2019) only tested the functionalities of their portable system. Hendrawan et al. (2019) proved that their fuzzy-based portable IoT system produced more mushroom yields compared to threshold-based methods. Nasution et al. (2019) did another indoor, portable mushroom cultivation where a wooden container for six mushrooms was equipped with an IoT-based system to monitor the growing environment. The design of their sensor, control and monitoring system was described, and the experiments concluded that the cultivation of oyster mushrooms with IoT is more effective by comparing the mushroom growth rate. However, all studies did not consider the aesthetic elements of the design for their indoor portable farming kits. A summary of these selected IoT-based mushroom cultivation systems is presented in Table 1.

Table 1 shows the two cultivation setups preferred for mushroom farming. Most medium-scale farming is done in specially built mushroom houses or rooms in a building. The other setup, which is the focus of our paper, is the indoor, portable IoT-based system designed for urban dwellers so that it can be moved around to utilize the unused space. There are two important variables which are temperature and humidity. However, the work of Mat et al. (2019) and Shakir et al. (2019) stated that CO_2 and air quality levels also play a role, especially in a growing environment where air circulation is stagnant. Cruz-del Amen & Villaverde (2019) recommended that the growing environment of oyster mushrooms must be clean from any emissions due to its sensitivity to environmental changes. To our knowledge, no portable smart farming design for mushroom cultivation has considered this factor. Thus, our proposed SPFK is equipped with a gas quality sensor to monitor the presence of harmful gases. Furthermore, our SPFK kit provides the end-user with a web dashboard and real-time camera feed so that they can monitor their plants remotely to cater for the busy lifestyle of urban dwellers.

Table 1
Summary of selected IoT-based mushroom cultivation system

Authors	Parameters			Cultivation setup	Environment	Real-time implementation
	Temperature	Humidity	CO_2			
Ibrahim et al. (2018)	✓	✓	✓	Mushroom house	Indoor	✓
Cruz-del Amen & Villaverde (2019)	✓	✓		Enclosed space	Indoor	✓
Kassim et al. (2019) Mat et al. (2019)	✓	✓	✓	Building room	Indoor	✓
Shakir et al. (2019)	✓	✓	✓	Building room	Indoor	✓
Hendrawan et al. (2019)	✓	✓		Plastic container	Indoor	✓
Nasution et al., (2019)	✓	✓		Mini wooden container	Indoor	✓
Najmurrokhman et al. (2020)	✓	✓		Plastic container	Indoor	X

We also noted that all portable smart farming listed employed Arduino-based microcontrollers. However, our SPFK is powered by the Raspberry Pi 4 computer to process the sensor data, regulate the growing condition, and display the monitoring data. Raspberry Pi is a single-board computer powered by the Linux operating system and capable of performing the general computational task and embedded low-powered processing tasks, as demonstrated by the work of Almalki et al. (2021) and Baqer et al. (2023). Almalki et al. (2021) proposed a low-cost method of monitoring farming parameters using a drone powered by a Raspberry Pi and LoRaWAN module for communication. The sensor data, such as soil moisture, were processed in the cloud. The works show a low-cost solution to help farmers monitor the farming area, but it does not discuss further how corrective action can be taken to regulate the growing environment.

METHODOLOGY

The proposed SPFK for the oyster mushroom cultivation system was designed and implemented at Universiti Teknologi MARA, Malaysia, for evaluation. During the evaluation, the oyster mushroom yield was compared to the control system and the SPFK. The primary data, such as temperature, humidity and harmful gas concentration, were captured from the sensors for analysis.

System Design

The design of the portable IoT-Based system was divided into three sections: portable and smart cultivation system using Raspberry Pi platform, control system algorithm and interface.

Portable Smart Cultivation System Using Raspberry Pi Platform

The system was designed to be portable and smart to control the growing environment effectively. The system was designed as portable to support urban farming requirements (Salim et al., 2019) to optimize the urban space. Moreover, the system must be moved around easily in urban homes. Therefore, the build material for the system housing must be lightweight, and all the electronic components must be miniaturized. The system needs to be "Smart" to control the oyster mushroom's growing condition effectively. The oyster mushroom has a specific growing condition to produce a good yield, and the temperature must be maintained within the range of 28–30°C and humidity within the range of 80%–90% (Cikarge & Arifin, 2018).

Furthermore, the quality of the oyster mushroom can also degrade if exposed to harmful aerosols found in insect repellent (Tarigan et al., 2017); therefore, the system needs to be able to detect harmful particles in the air. Manually maintaining the growing condition of the oyster mushroom is tedious and may not be possible for urban dwellers as they are not always available at home. Thus, the system was developed on the Raspberry Pi 4 platform, which allows the programmability of the system to automatically control and monitor the growing condition based on inputs of the sensors. It also allows the system to have a database to store data in a structured manner and display the data dashboard via a web server and the internet via a built-in Wi-Fi module. Figure 1 shows the overall system design diagram.

Based on Figure 1, the mushroom growing medium was placed vertically inside a custom housing built using lightweight 3mm acrylic glass. Inside the housing, an IoT system automatically monitors and regulates the growing condition. The system's brain is the Raspberry Pi 4 computer equipped with a Quad-Core 64bit 1.5Ghz ARM processor, 1GB DDR4 RAM, 256GB Flash Storage, dual-band 2.4 and 5 GHz Wi-Fi interface and 40 pin GPIO interface. The operating system was Raspbian Linux and was installed with Python3 interpreter, MySQL database and Apache2 web server software. The Raspberry Pi was powered by 5.1V 3A USB type C and was placed inside the system housing. In order to gauge the environmental condition inside the housing, the system was equipped with two sensors, a DHT22 sensor for capturing temperature and humidity values and an MQ135 for determining the presence of harmful gas in the housing. The data collected by the sensors were then sent to the Raspberry Pi via 3C 22AWG to be processed by the control system algorithm implemented in Python 3 script. The script is responsible for storing the sensor data in the MySQL database, and an alert email will be sent using SMTP if a certain exceeds the pre-determined threshold.

The system was equipped with a two-channel 5V relay which acts as an actuator to control motor or electrical devices to regulate the growing condition. In the proposed system, the relay was used to control the humidifier to increase humidity when the level was below a predetermined threshold. The humidifier can be filled with 10 litres of water to regulate the humidity level and is powered by an 18V 500mA power outlet and placed at the top level of the housing. The system was not equipped with an external fan to regulate the temperature as the setup was placed inside a building in Malaysia where the average room temperature ranges from 23°C to 30°C (Jamaludin et al., 2015); thus, it is not necessary to regulate the temperature. Nevertheless, the system can be equipped with an external fan. The system was designed to send an alert if the temperature exceeds the pre-determined threshold, and the user can move it to the area without direct sunlight. Moreover, the proposed system was also equipped with a mini 8 megapixels camera on top of the housing to allow the user to monitor the growth remotely. The camera was connected to the Raspberry Pi 4 using an FFC cable, and the user can view the video stream in real-time via a web interface served by Apache2. The IoT system was connected to the Internet via a Wi-Fi access point installed in the room using the Wi-Fi module. The end-user can access the web dashboard

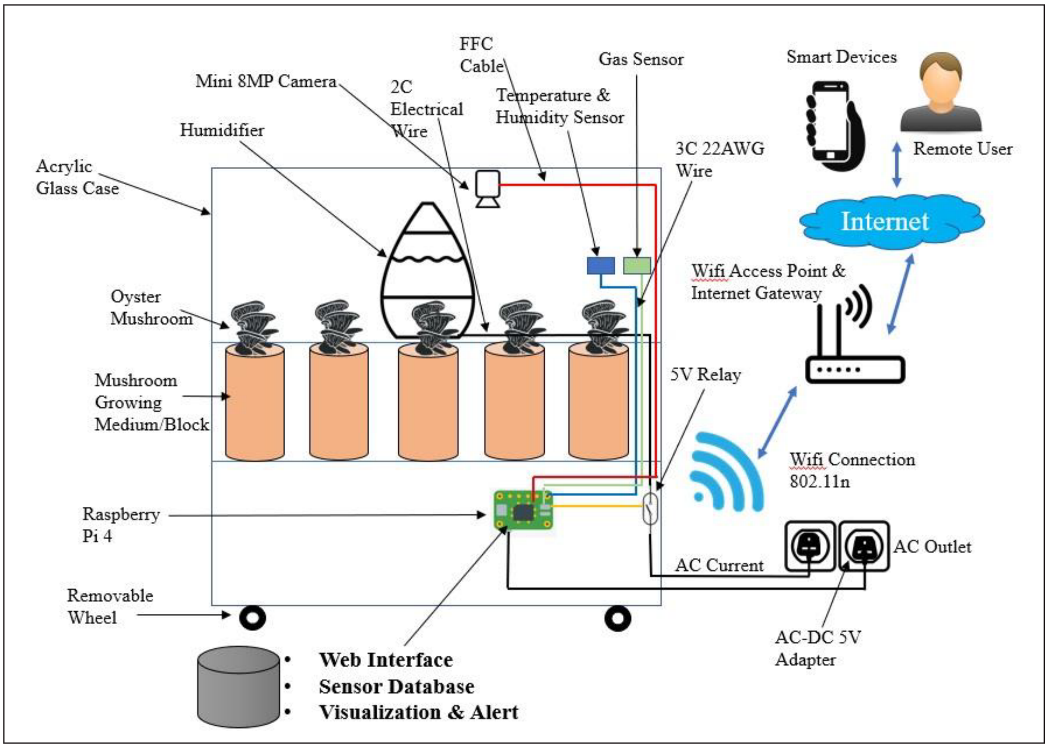

Figure 1. Overall portable smart farming system design diagram

and camera to monitor their plant remotely from anywhere. All the electronic components used in the IoT were small and could fit in the internal housing. Figure 2 shows the system's physical arrangement diagram.

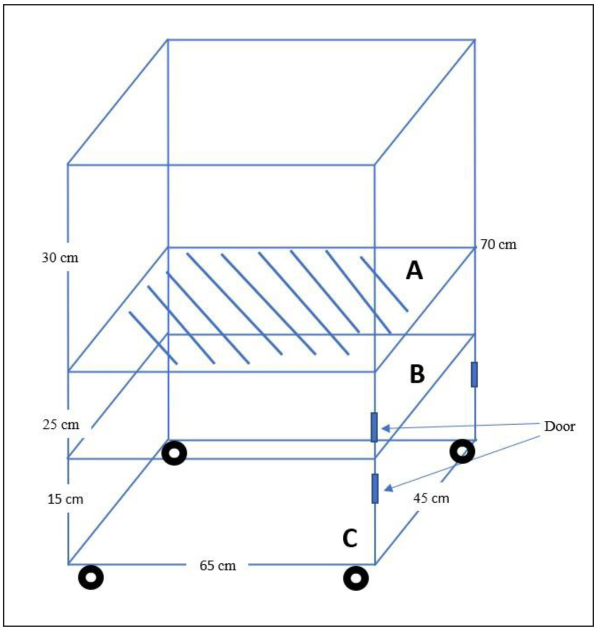

Figure 2. System physical arrangement diagram

Based on the physical arrangement shown in Figure 2, the housing size was 70cm x 65cm x 45cm, equipped with four sets of wheels for portability. The housing of the system consists of three parts. Part A provided an area for the oyster mushroom to grow; there are eight holes to place the growing medium. Part A also housed the humidifier, sensors, and camera to monitor the growing environment. The top was left open during the cultivation and can be closed with rolled blind if not used. Meanwhile, the mushroom growing medium consisting of sawdust and other agriculture by-product wrapped into a block was placed in Part B. The medium block was placed vertically in line with holes reaching Part A's area. The Raspberry Pi board is placed in Part B. The circuit diagram for the proposed IoT system is shown in Figure 3. Lastly, part C was a compartment to store miscellaneous items such as unused mushroom blocks and a cleaning cloth.

The system circuit diagram in Figure 3 shows that the Raspberry Pi 4 was the system's centre, which integrates different components. The Raspberry Pi 4 had 40 general-purpose input/output (GPIO) pins for external connection. The DHT22 sensor, which was used to capture the temperature and humidity value, has three pins: the DOUT pin was connected to GPIO 17 pin, the VCC pin was connected to GPIO 3.3v power pin and the GND pin was connected to the GPIO ground pin. The data from the DHT22 sensor was sent to the Raspberry Pi 4 in a digital signal. Meanwhile, the MQ135 sensor was used to detect the presence of harmful gas particles in the air, and it has three pins. The DOUT pin was connected to GPIO 14 pin, the VCC pin to GPIO 3.3v power pin, and the GND pin to the GPIO ground pin. The MQ135 sent a digital signal to the Raspberry Pi 4 in Boolean data form. If harmful gas was detected, it sent a True value; otherwise, a False value was sent.

For corrective action, the IoT system used a two-channel 5v relay for controlling the humidifier. The relay IN 1 pin was connected to GPIO 21 pin, VCC to GPIO 5v power

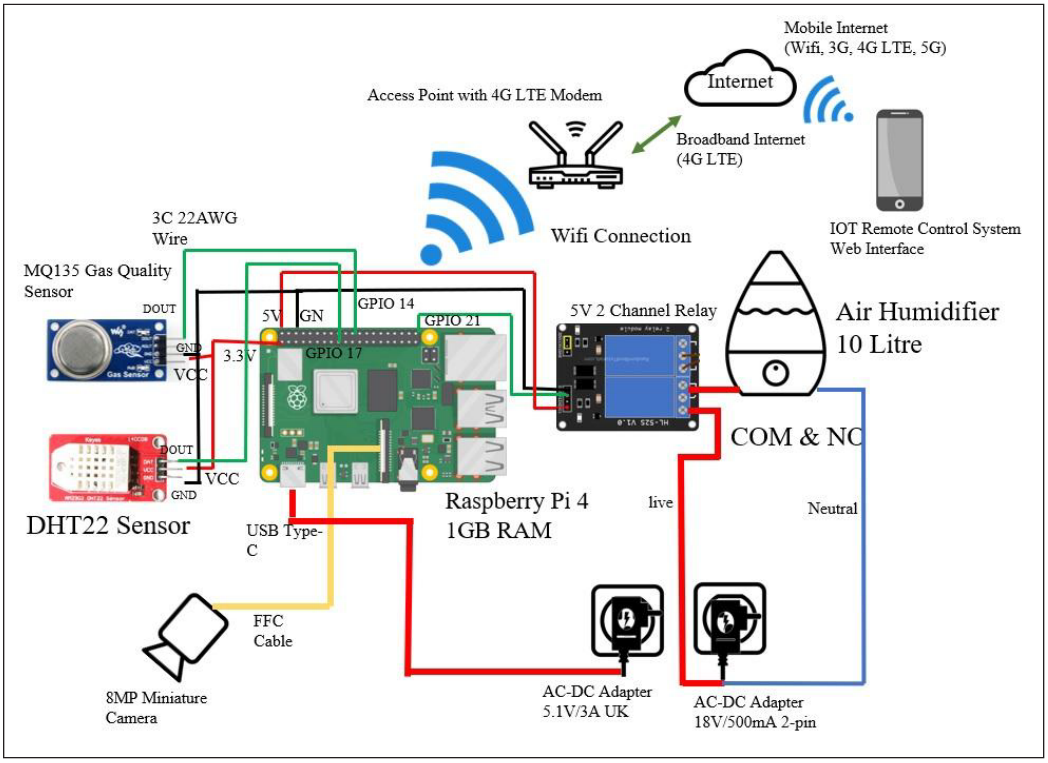

Figure 3. System circuit diagram

pin, and GND to the GPIO ground pin. The relay is a switch to turn on/off the humidifier; by default, the humidifier is always turned off. If the Raspberry Pi decided to turn on the humidifier, it sent a signal to the relay, which activated the relay. The sensors and relay were connected to the GPIO pin via a 40cm 3C 22AWG jumper wire. Meanwhile, the 8MP mini camera used to capture the growth was connected to the Raspberry Pi 4 via the FFC cable to the camera I/O port. The Raspberry pi board has an 802.11n Wi-Fi module which operates at 2.4 and 5Ghz bands. The Wi-Fi module was used to connect to the Internet, which allows it to send alert emails via SMTP protocol and allows end-users to monitor the system in real time via a web dashboard. The Raspberry Pi processes the sensor's data and takes corrective action based on the process defined in the control system algorithm.

Control System Algorithm

The control system algorithm defined the processing of data and actions taken by the Raspberry Pi 4 platform. The growing environment of the oyster mushroom was monitored and regulated based on pre-determined thresholds. The algorithm was implemented in Python 3, and several modules were used to access the MySQL database (pymysql), GPIO port (RPi.GPIO), DHT22 sensors (Adafruit_DHT), Raspberry Pi Camera (picamera) and

SMTP protocol (smtplib). Figure 4 shows the flowchart of the algorithm. To support the operation of the control script, all necessary software, as listed in Table 2, was installed on the Raspberry Pi 4.

Based on Figure 4 starts by initializing the database connection, web service, SMTP connection and GPIO port. This step was important to ensure all the essential dependencies were ready. If one of the components failed to initiate, the script exited the process and logged the error. Next, the script entered an infinite loop; if there was no interruption, the script continued to repeat the step in a loop. At the start of the loop, the script obtained the current time using the time library and read the current temperature, humidity, and gas

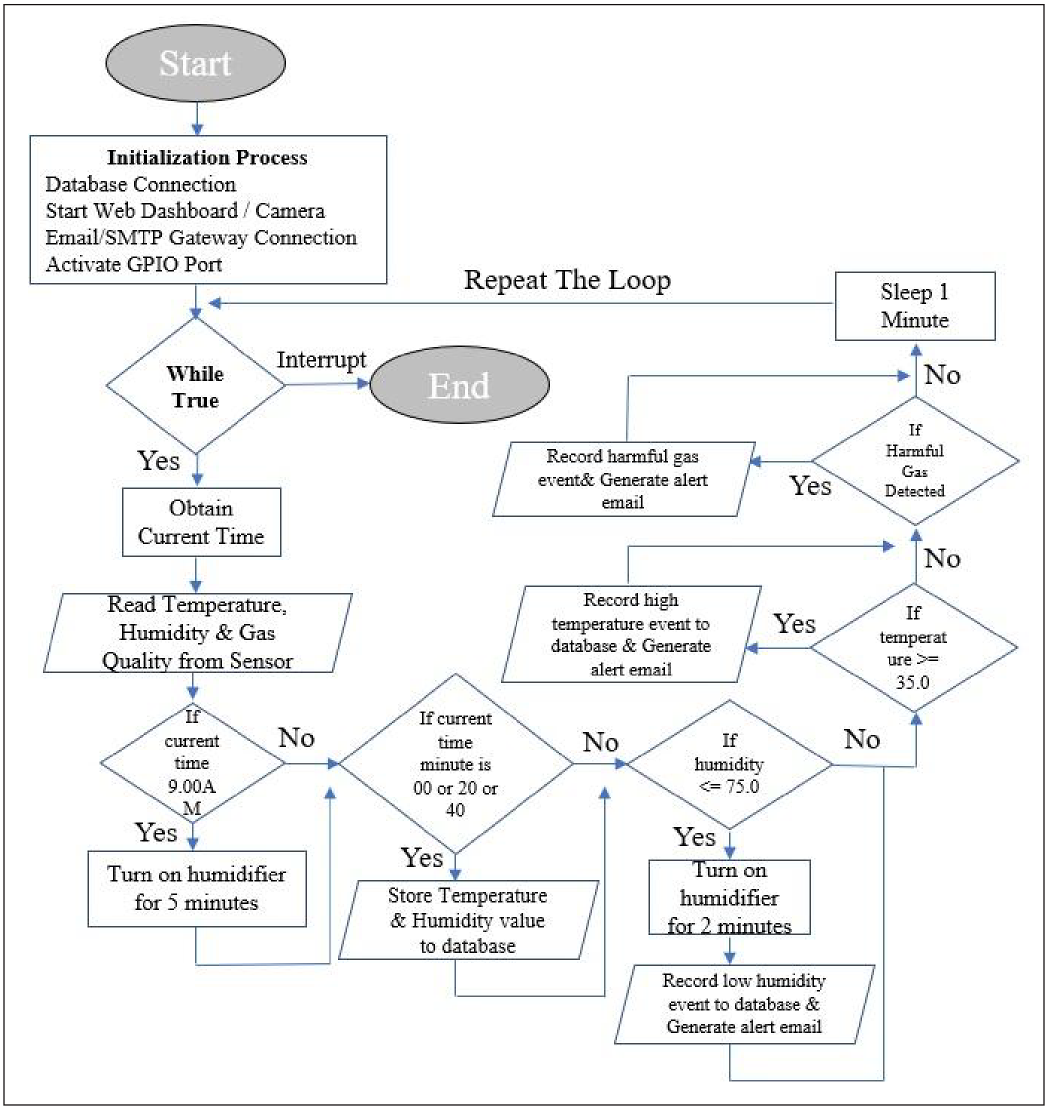

Figure 4. Control system process flowchart

Table 2
List of installed software

No	Software	Version	Description
1.	Raspberry Pi OS (Raspbian) 64bit	10 Buster	A Debian-based GNU/Linux operating system for the Raspberry Pi 4. Manage hardware and resources of the platform. Pre-Installed with all essential UNIX libraries.
2.	Python 3	3.7.3	Python 3 interpreter for running Python script.
3.	Pip Tools	18.1	Tool for installing and managing Python packages or modules.
4.	Adafruit DHT sensor library	-	A library for DHT22 sensors.
5.	Apache2	2.4.38	Server for serving Web service used for the dashboard and viewing camera stream.
6.	PHP7	7.3.31-1	Use alongside Apache2 web server for serving dynamic web content.
7.	MySQL	10.3.31	Open-Source relational database. The sensor's data and events were stored structurally in this database.

quality level from the sensors. If the current time was 9.00 am, the script sent a signal to the relay to turn on the humidifier for 5 minutes. It is to ensure that the growing environment is humid every morning. After that, the script checks the minute for every hour. If the minute is 00, 20 or 40, the script stores the temperature and humidity in the database.

The data from the database was displayed on the dashboard and stored. After that, the script checked the current reading of humidity. If it is less than 75.0%, the script instructs the humidifier to be turned on, alerts the user, and stores the record of the events in the database. The 75% threshold is chosen based on the optimal range identified in the work of Cikarge & Arifin (2018). The user can later use the record to identify the frequency of low-humidity events. Then the script checked the current temperature value. If the value was more than 35°C, the script sent an email alert to the user, and the high-temperature event was recorded in the database. After that, the script checked for the presence of harmful gases. If the gas sensor detects harmful gases, it sends an alert to the user and records the event in the database. Then the script remained idle for one minute before repeating the loop. The algorithm was implemented as a Python 3 script and continuously ran on the Raspberry Pi. The pseudocode of the algorithm is elaborated in Algorithm 1.

Algorithm 1: Control System Algorithm Implementation

Input: *temperature*, *humidity, currentTime, gasQuality,* temperature (float), humidity (float), Current Time (datetime) and Gas Quality (Boolean) reading from two sensors.

```
DatabaseObject = StartDatabaseConnection()
StartWebDashboard()
StartWebCamera()
EmailObject = StartSMTPConnection()
```

```
GPIOObject = initializeGPIO()
while True:
    currentTime = getCurrentTime()
    temperature = GPIOObject.getTemperature()
    humidity = GPIOObject.getHumidity()
    gasQuality= GPIOObject.getGasQuality()
    if currentTime == 0900:
            GPIOObject.startHumidifier()
            Sleep(300)
            GPIOObject.stopHumidifier()
     minute = getMinute(currentTime);
     if minute == 00 or minute == 20 or minute == 40:
             DatabaseObject.storeValue(currentTime, temperature, humidity)
     if humidity <= 75.0:
             GPIOObject.startHumidifier()
             Sleep(120)
             GPIOObject.stopHumidifier()
             DatabaseObject.storeValue(currentTime, humidity, "Low Humidity")
             EmailObject.sendEmail("Low Humidity, Check your plant")
     if temperature >= 35.0:
             DatabaseObject.storeValue(currentTime, temperature, "High Temperature")
             EmailObject.sendEmail("High Temperature, Check your plant")
     if gasQuality == True:
             DatabaseObject.storeValue(currentTime, gasQuality, "Harmful gas detected")
             EmailObject.sendEmail("Harmful gas detected, Check your plant")
```

IoT System Interface

The proposed system has several interfaces, such as a web dashboard, web camera, and database, which the end user can access. The end-user can access the web dashboard remotely via a web browser anywhere. Figure 5 shows the screenshot of the web dashboard interface. The dashboard displayed real-time information to end-users, such as an ongoing alert event, a total alert for harmful gas detection, and low-humidity and high-temperature events. Moreover, the dashboard also displayed a time-series graph for daily humidity and temperature value. The graph provides useful insights regarding humidity and temperature pattern. Besides, the proposed system can display a live feed from the camera, which can be used to monitor the condition remotely. Figure 6 shows the web camera interface. The live camera feed can also be used to verify the email alert sent by the system. For example, after receiving an alert regarding harmful gas detection, use the live feed to verify whether there is smoke or any harmful gases near the cultivation area.

Figure 5. System web dashboard interface

Figure 6. System web camera interface

To access the sensors and event data stored in the database, the user can access the MySQL database via SQL software. Figure 7 shows the database data interface via Heidi SQL software. To connect to the MySQL interface, the SQL client needs to connect to TCP port 3306 with TLS enabled to ensure data security while in transit. Users will be prompted to provide valid database credentials for authentication and authorization purposes.

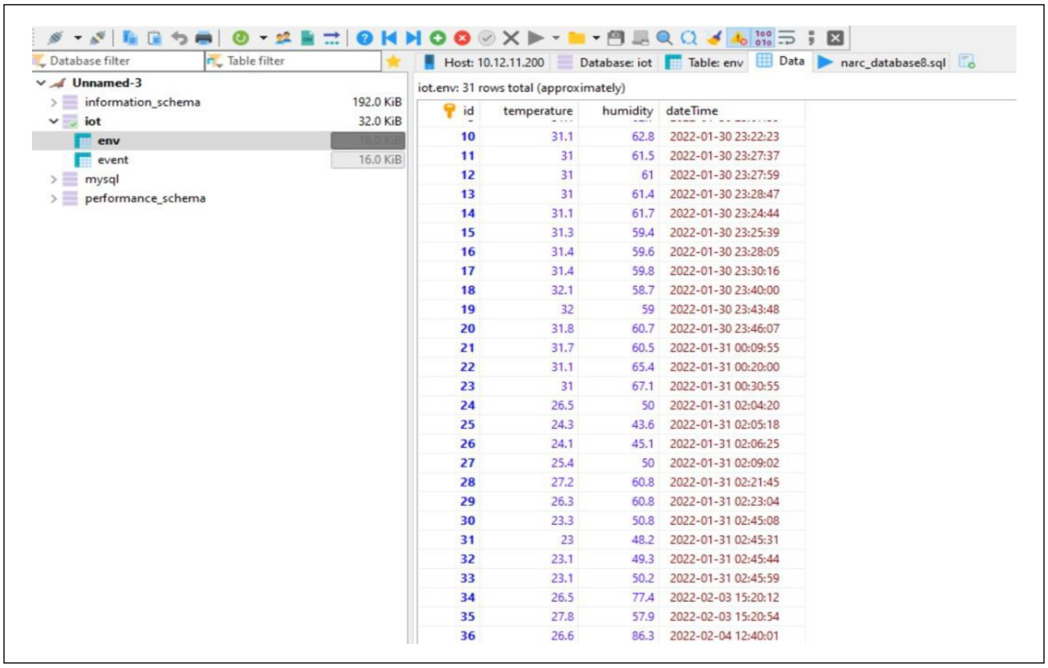

Figure 7. Database data interface

The proposed system will send an alert if low humidity, high temperature and harmful gas are detected in the growing environment. The alert was sent via email using SMTP protocol. Figure 8 shows an example of the system's alert notification to the end user.

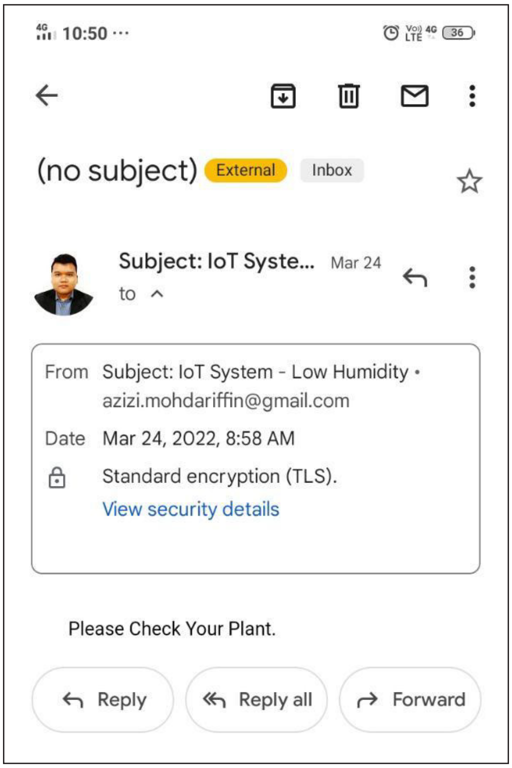

Figure 8. Alert notification from IoT system

Summary of System Design

As this paper is improving the previous IoT-based system for mushroom cultivation proposed by Ariffin et al. (2020) and Ariffin et al. (2021), comparisons of features and specifications are presented in Table 3.

The first two designs in 2020 and 2021 were for a mushroom house, and the oyster mushroom cultivations were for small, home business purposes. The design for the proposed Smart Portable Farming system was scaled down and revamped to cater for

Table 3
Summary of improved features and specifications compared to Ariffin et al., 2020 and Ariffin et al., 2021

No	Features / Specification	(Ariffin et al., 2020)	(Ariffin et al., 2021)	Portable IoT-Based Smart System
1.	Platform	Arduino NodeMCU	Arduino NodeMCU	Raspberry Pi 4
2.	Microcontroller Logic	Threshold-based Logic	Fuzzy Logic	Threshold-based Logic
3.	Power & Connection	Two 5V External power sources and connection were via Breadboard	Single External power source powering the NodeMCU Baseboard with 5V voltage regulator	Single External power source
4.	Rack Arrangement	Vertical arrangement	Horizontal arrangement to allow optimal airflow and to avoid wetting the mushroom block during rainfall	Do not use a rack
5.	Water Nozzle Placement	The nozzle was not installed to spray the roof	Installed nozzle to spray water on the roof	Using Humidifier
6.	Portability	No	No	Yes
7.	Operating Size	Large, Fixed Mushroom House	Large, Fixed Mushroom House	Small and Lightweight
8	Harmful Gas Detection	No	No	Able to Detect

portability. Another feature is harmful gas detection was also added to the system to optimize plant yield further. Figure 9 shows that the IoT system sends an alert when harmful gas is detected.

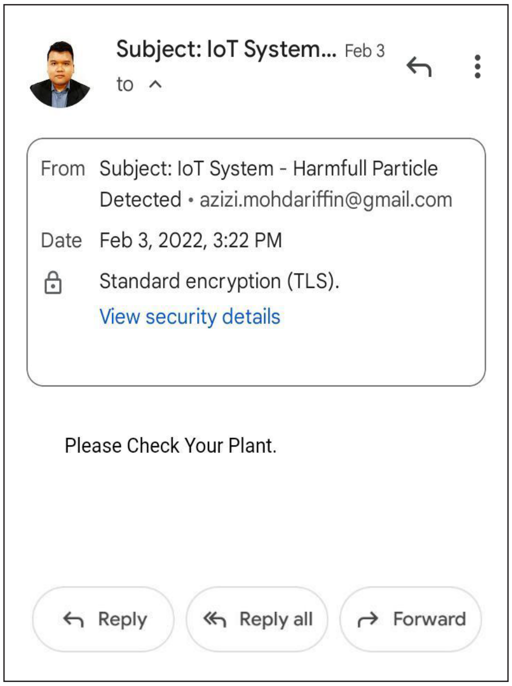

Figure 9. Harmful gas detection alert

System Implementation

It discusses how the Smart Portable Farming Kit for oyster mushroom cultivation system was implemented in Universiti Teknologi MARA as a proof of concept and to validate its functionality via experiments.

Deployment of Portable IoT-Based Smart Mushroom Cultivation System

The proposed portable IoT-based smart mushroom cultivation system was implemented at the National Autism

Resource Centre (NARC), Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM), Malaysia. The system was placed in an unused space inside the room equipped with a central air conditioner (only turned on in the daytime), and the windows are tinted and installed with sunlight shade. Thus, the room did not receive direct sunlight, and the temperature varied between 23°C and 30°C. Figure 10 shows the IoT-based portable system deployment in UiTM.

Figure 10 shows that the oyster mushroom growing block or medium was placed in Part B (middle) of the housing, with the exposed part of the block placed at the corresponding hole, which went into Part A (top). The oyster mushroom grew in Part A, where the system automatically monitored and regulated the environment . The humidifier used to regulate the humidity was placed inside Part A with DHT22 and MQ135 sensors. Figure 11 shows that the humidifier is turned on. The 8MP mini camera was placed at the top overlooking Part A to ensure a clear view of the growth of the oyster mushroom.

Figure 10. Portable system deployment in Universiti Teknologi MARA

Figure 11. Humidifier operation

Meanwhile, Figure 12 shows the side of the housing with an open cover. The Raspberry Pi 4 with relay and other electronic components were inside part B. The mushroom block was placed vertically inside Part B. Figure 12 also shows that Part C can store other miscellaneous items, such as power extension.

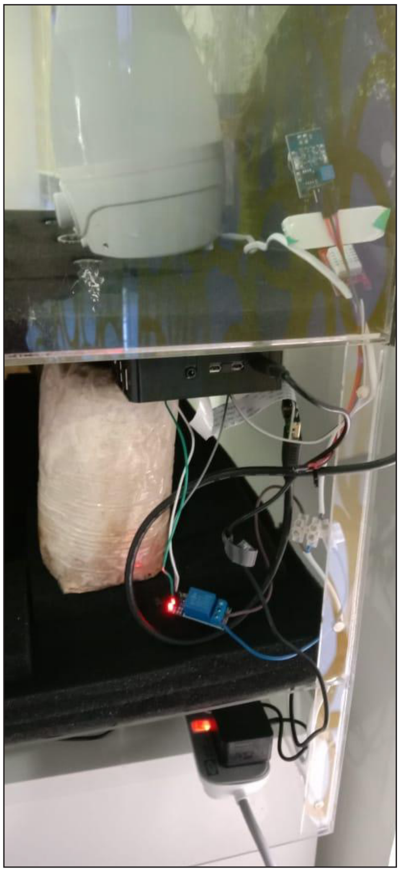

Figure 12. Raspberry Pi 4 platform and sensors for the portable system

System Testing and Evaluation

Two oyster mushroom cultivation experiments were set up simultaneously inside a room in the National Autism Resource Centre (NARC), Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA (UiTM), Malaysia, to test and evaluate the effectiveness of the proposed system. Both cultivation setups used eight mushroom medium blocks, and the duration of the experiments was one week. The first experiment was the controlled experiment where the oyster mushroom was cultivated without the IoT-based system. Figure 13 shows the setup for the controlled experiment. Based on Figure 13, a wet towel was used to keep the controlled environment humid. The towel was changed and soaked with water every two days. An electronic thermometer was used to record the temperature and humidity of the control experiment, and the value was recorded daily throughout the one week of experimenting.

Meanwhile, the second experiment used the proposed Smart Portable Farming Kit. The first and second experiments were placed in the same room, as seen in Figure 14. At the end of a week, the oyster mushroom yield weight was measured quantitatively using a digital weighing device, and the quality of the oyster mushroom produced was verified qualitatively using visual inspection. Besides that, the pattern of the temperature and humidity recorded for one week will be compared between the two experiments.

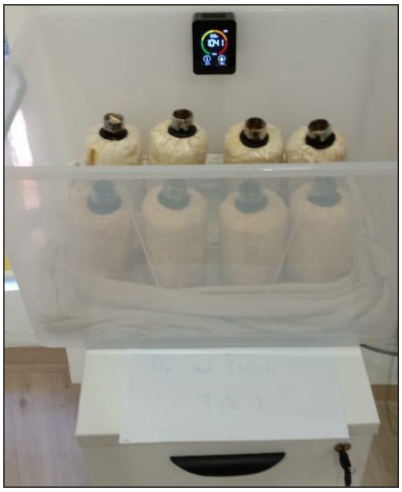

Figure 13. Control experiment setup

Figure 14. Control and IoT-based experiments in the same room

RESULTS AND DISCUSSION

Comparisons of the control experiment and SPFK were made based on four parameters:

(i) Temperature
(ii) Humidity
(iii) Weight of mushroom yield
(iv) Quality of mushroom yield

Temperature and Humidity Control

Figures 15 and 16 show the average temperature and humidity monitored for seven days. The temperature and humidity readings were taken three times a day, specifically at 10.00 am, 3.00 pm, and 8.00 pm from 17 to 23 March 2022 and were then averaged.

The line graph in Figure 15 shows that the average temperature is lowermost days in the SPFK as the temperature was kept at the preferred value for cultivation between 28°–30°C.

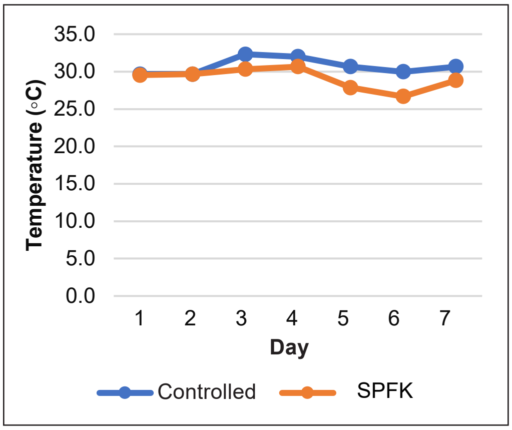

Figure 15. Comparisons of average temperature of controlled and Smart Portable Farming (SPFK)

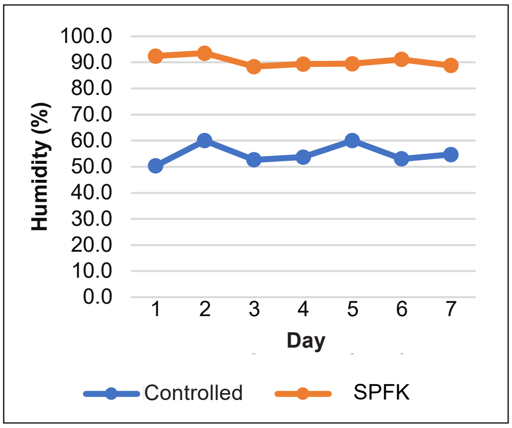

Figure 16. Comparisons of average humidity of controlled and Smart Portable Farming (SPFK)

The temperature of the controlled experiment averages slightly above 30°C depending on the weather. A check at AccuWeather (2022) recorded the lowest temperature of 24°C and the highest temperature of 35°C during the stated week. The temperature of the control setup was higher because it was placed in a closed room, and the central air conditioner was turned on for an average of only four hours during the daytime.

The average humidity in March 2022, as reported in Weather (2022), was 77%. The humidity readings for the stated week in March for the SPFK, as shown in Figure 16, range from a minimum of 78.5% to a maximum of 97.7%. The humidity was kept within the optimum range of cultivation (Cikarge & Arifin, 2018) between 80% to 90%. However, the humidity recorded by the controlled experiment was as low as 47% and highest at 71%. The air conditioning caused the low humidity readings, which are known to reduce humidity levels.

Weight of Mushroom Yield

Three mushroom yield cycles were recorded from the SPFK and the control setup. One cycle took seven days, beginning with taking off the medium block cover and harvesting the mushroom. Table 4 shows the weight of the oyster mushroom's yield.

Table 4
Percentage of mushroom yield difference

Date	Weight (gm)		Difference (gm)	Difference (%)
	Smart Portable Farming Kit	Controlled Setup		
24 March	584	428	156	26.7
4 April	200	0	200	100.0
27 April	167	152	15	8.98

In the first cycle, 584gm of oyster mushroom was harvested compared to 428gm for the controlled setup. The SPFK produced 26.7% more yield, equivalent to 156gm. For the second cycle, 200 grams were collected from SPFK, while the controlled setup failed to produce any yield. The third cycle harvested from the same eight mushroom blocks only produced 167gm for the SPFK and 152gm for the controlled setup. The proposed SPFK still produced higher mushroom yields of 8.98% (15gm) compared to the controlled setup. These results demonstrate that SPFK facilitates maintaining and controlling the environmental requirement for better mushroom cultivation.

Quality of Mushroom Yield

In the Malaysian Standard of mushroom quality (MS 2515: 2012) by FAMA (2012), the grade specification for oyster mushrooms is divided into premium grades, Grades 1 and 2, as detailed in Table 5. For premium grade, if the percentage of freshness, size uniformity, matureness and defect of the mushroom is above 95%, the mushroom's grade is considered premium. Furthermore, if the damage is less than 3%, the pile of mushrooms is categorized as a premium class. A pile of mushrooms is classified as Grade 1 when the freshness, matureness and non-damages are above 95%. While the size uniformity must be at least 90%, and the defect percentage must be less than 10%. The third class of Grade 2 is required to attain freshness, uniformity of matureness and non-defect of above 90%. Meanwhile, the mushroom must have more than 80% of size uniformity, and less than 5% of the mushrooms be damaged.

Table 5
Oyster mushroom grade specification by FAMA, Malaysia

Grade	Specification	Criteria	Tolerance (%)
Premium	Oyster mushrooms in this class must have a uniformity of size and maturity, fresh and clean, and free of defects and damage	Fresh	≤5
		Size uniformity	≤5
		Uniformity of matureness	≤5
		Defect	≤5
		Damage	≤3
1	Oyster mushrooms in this class must have a uniformity of size and maturity, fresh and clean, and free of defects and damage	Fresh	≤5
		Size uniformity	≤10
		Uniformity of matureness	≤5
		Defect	≤10
		Damage	≤5
2	Oyster mushrooms in this class must have a uniformity of size and maturity, fresh and clean, and be unobvious of defects and damage	Fresh	≤10
		Size uniformity	≤20
		Uniformity of matureness	≤10
		Defect	≤10
		Damage	≤5

Based on Figure 17, the mushroom produced from SPFK displays all characteristics of Premium grade. The freshness, size uniformity and matureness uniformity are above

Figure 17. Mushroom yields by SPFK (left) and controlled setup (right)

95%. Only 5% of mushroom defects and less than 3% damage are observed in one pile of mushrooms.

Furthermore, research done by Khan et al. (2016) highlighted that the quality of mushrooms could be measured based on physic-chemical analysis (moisture, protein, and sensory evaluation). Therefore, we focus on the sensory evaluation based on texture and manual observation. The texture of the mushroom from the SPFK was better, and the size was larger than the control system. It can be concluded that the SPFK produces higher quality mushrooms compared to the controlled system.

CONCLUSION

This paper proposed a design of a Smart Portable Farming Kit to ease oyster mushroom cultivation in the urban area. Up to the writing, the most portable smart farming system used Arduino-based IoT setups and did not consider harmful gases in the air, such as CO_2. In our SPFK, we used the Raspberry Pi 4 platform to process the sensor data such as temperature, humidity and air quality value stored in the MYSQL database. Our design also incorporates aesthetic elements because the portable system will be used indoors. Unlike the common usage of sprinkler that requires water pumps to regulate the humidity, our SPFK utilized a humidifier that simplifies maintenance and provides a much more pleasant visual misty effect. Moreover, SPFK was also installed with a webcam and dashboard for a better UI/UX experience for the users. The dashboard can display the sensor data and real-time camera feed to enable the user to monitor their plant remotely. The design of a portable smart farming system for indoor use needs to be compact, pleasant-looking, and lightweight. We have detailed the designs by presenting the overall system architecture, physical arrangement, system circuit, control system flowchart, fuzzy algorithm pseudocode, and the user interfaces to be used as guidelines.

To demonstrate SFK effectiveness, the mushroom yields of SFK and the conventional method setup were presented, and a cumulative of 951gm and 580gm of oyster mushroom was collected over three cycles, respectively. Overall, SFK has been shown to produce more than 39% oyster mushrooms compared to the conventional method. However, SFK has more room for improvement and can be refined with more features. Since the deployment system was conducted in Malaysia, the system has only been tested in a tropical climate with constant indoor temperatures. Our next step is to investigate the performance of SFK in different climates and explore other technologies to add more features, such as image recognition or using artificial intelligence techniques to automatically track the mushroom's growth phase based on the live camera feed. There are also some limitations to the evaluations of SFK's performance. Due to time allocation, and financial resources, only sixteen mushroom blocks are used in this study, and the results of mushroom yield are based on three times of cultivation. More cycles should be done over a longer period to test the robustness of SFK.

ACKNOWLEDGEMENT

The authors thank Universiti Teknologi MARA, Malaysia, for providing a research grant (100-TNCPI/INT 16/6/2 (039/2021)) to complete this project.

REFERENCES

AccuWeather. (2022, June 6). AccuWeather, Shah Alam, Selangor. https://www.accuweather.com/en/my/shah-alam/230464/june-weather/230464

Ahmmad, S. N. Z., Jaafar, M. M., Muchtar, F., & Yusof, M. A. (2020). Automated gardening portable plant using IoT. *International Journal of Advanced Trends in Computer Science and Engineering*, *9*(1.1), 205-211. https://doi.org/10.30534/ijatcse/2020/3691.12020

Almalki, F. A., Soufiene, B. O., Alsamhi, S. H., & Sakli, H. (2021). A low-cost platform for environmental smart farming monitoring system based on IoT and UAVs. *Sustainability, 13*(11), Article 5908. https://doi.org/10.3390/SU13115908

Antonaci, L., Atieno, I., Baoua, I., Chotard, S., Difrancesco, P., Gayford, M., Goetschal, N., Hamadoun, M., Herwanger, N., Hoffine, T., Hohfeld, L., Hoover, S., Husain, A., Hussein, P., Jama, A., Jayasekaran, D., Joud, D., Kabuyaya, J., Khosravi, A., … & Verstraeten, R. (2022). *Global Report on Food Crises*. Food Security Information Network.

Ariffin, M. A. M., Ramli, M. I., Amin, M. N. M., Ismail, M., Zainol, Z., Ahmad, N. D., & Jamil, N. (2020). Automatic climate control for mushroom cultivation using IoT approach. In *2020 IEEE 10th International Conference on System Engineering and Technology (ICSET)* (pp. 123-128). IEEE Publishing. https://doi.org/10.1109/ICSET51301.2020.9265383

Ariffin, M. A. M., Ramli, M. I., Zainol, Z., Amin, M. N. M., Ismail, M., Adnan, R., Ahmad, N. D., Husain, N., & Jamil, N. (2021). Enhanced IoT-based climate control for oyster mushroom cultivation using fuzzy logic approach and NodeMCU microcontroller. *Pertanika Journal of Science and Technology*, *29*(4), 2863-2885. https://doi.org/10.47836/PJST.29.4.34

Ballais, L. J., Sharma, T. N., Thu, H. W., Sanadeera, S. D. A. P., Taparugssanagorn, A., & Dailey, M. N. (2021). IoT-Based terrace farming system for cities. In *25th International Computer Science and Engineering Conference (ICSEC)* (pp. 11-16). IEEE Publishing. https://doi.org/10.1109/ICSEC53205.2021.9684609

Baqer, N. S., Mohammed, H. A., & Albahri, A. S. (2023). Development of a real-time monitoring and detection indoor air quality system for intensive care unit and emergency department. *Signa Vitae*, *19*(1), 77-92. https://doi.org/10.22514/sv.2022.013

Cikarge, G. P., & Arifin, F. (2018). Oyster mushrooms humidity control based on fuzzy logic by using Arduino ATMega238 microcontroller. *Journal of Physics: Conference Series, 1140*, Article 012002. https://doi.org/10.1088/1742-6596/1140/1/012002

Cruz-del Amen, J. d., & Villaverde, J. F. (2019). Fuzzy logic-based controlled environment for the production of oyster mushroom. In *2019 IEEE 11th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment, and Management, HNICEM 2019* (pp. 1-5). IEEE Publishing. https://doi.org/10.1109/HNICEM48295.2019.9072902

FAMA. (2012). *Kualiti Cendawan Tiram Kelabu MS2515:2012* [Oyster Mushroom Quality Malaysia Standard MS2515:2012]. Federal Agricultural Marketing Authority. https://www.fama.gov.my/documents/20143/0/cendawan+red.pdf/63676187-392a-48ce-4405-6d4090cb5568?fbclid=IwAR2YUzIitHgpd6zhCs0BaoFaIttLRhkXOKySrrym6j9o6DpH1-G7my7p3eo

Hendrawan, Y., Anta, D. K., Ahmad, A. M., & Sutan, S. M. (2019). Development of fuzzy control systems in portable cultivation chambers to improve the quality of oyster mushrooms. *IOP Conference Series: Materials Science and Engineering*, *546*(3), Article 032013. https://doi.org/10.1088/1757-899X/546/3/032013

Ibrahim, N. H. N., Brahim, A. R., Mat, I., Harun, A. N., & Witjaksono, G. (2018). IR 4.0 using IoT and LORAWAN to accelerate lentinula edodes growth. In *2018 2nd International Conference on Smart Sensors and Application, ICSSA 2018* (pp. 28-32). IEEE Publishing. https://doi.org/10.1109/ICSSA.2018.8535954

Jamaludin, N., Mohammed, N. I, Khamidi, M. F., & Wahab, S. N. A. (2015). Thermal comfort of residential building in Malaysia at different micro-climates. *Procedia-Social and Behavioral Sciences*, *170*, 613-623. https://doi.org/10.1016/j.sbspro.2015.01.063

Jayasekara, C., Banneka, S., Pasindu, G., Udawaththa, Y., Wellalage, S., & Abeygunawardhane, P. K. W. (2021). Automated crop harvesting, growth monitoring and disease detection system for vertical farming greenhouse. In *ICAC 2021 - 3rd International Conference on Advancements in Computing, Proceedings* (pp. 228-233). IEEE Publishing. https://doi.org/10.1109/ICAC54203.2021.9671074

Kassim, M. R. M., Mat, I., & Yusoff, I. M. (2019). Applications of internet of things in mushroom farm management. In *2019 13th International Conference on Sensing Technology (ICST)* (pp. 1-6). IEEE Publishing. https://doi.org/10.1109/ICST46873.2019.9047702

Khan, S. H., Rani, S., Shah, A. S., Javeria, S., Hasham, M., & Amin, S. (2016). Quality evaluation of oven dried and fresh oyster mushroom store at room temperature. *The Open Agriculture Journal*, *1*(1), 18-22.

Laborde, D., Martin, W., & Vos, R. (2021). Impacts of COVID-19 on global poverty, food security, and diets: Insights from global model scenario analysis. *Agricultural Economics*, *52*(3), 375-390. https://doi.org/10.1111/AGEC.12624

Mat, I., Kassim, M. R. M., Harun, A. N., & Yusoff, I. M. (2019). Smart agriculture using internet of things. In *2018 IEEE Conference on Open Systems (ICOS)* (pp. 54-59). IEEE Publishing. https://doi.org/10.1109/ICOS.2018.8632817

Najmurrokhman, A., Kusnandar, Daelami, A., Nurlina, E., Komarudin, U., & Ridhatama, H. (2020). Development of Temperature and humidity control system in internet-of-things based oyster mushroom cultivation. In *2020 3rd International Seminar on Research of Information Technology and Intelligent Systems (ISRITI)* (pp. 551-555). IEEE Publishing. https://doi.org/10.1109/ISRITI51436.2020.9315426

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

Rajermani, T., Sarasvathi, N., & Eng, J. H. (2020). Smart vertical farming using IoT. *Inti Journal*, *2020*(49), 1-6.

Rankothge, W., Kehelella, P., Perera, D., Kanchana, B., Madushan, K., & Peiris, R. (2022). IOT based smart microgreen sprouter. In K. Arai (Ed.), Proceedings of the Future Technologies Conference (FTC) 2021). Lecture Notes in Networks and Systems, (Vol 358, pp. 321-329). Springer. https://doi.org/10.1007/978-3-030-89906-6_22

Rosmiza, M. Z., & Hussin, J. M. (2017). Kecenderungan penglibatan agropreneur dalam industri tanaman cendawan di Johor [Agropreneurs' inclination to participate in the Johor mushroom industry]. *Malaysian Journal of Society and Space*, *13*(4), 37-46. https://doi.org/10.17576/GEO-2017-1304-04

Rosmiza, M., Davies, W., Aznie, R. C., Jabil, M., & Mazdi, M. (2016). Prospects for increasing commercial mushroom production in Malaysia: Challenges and opportunities. *Mediterranean Journal of Social Sciences*, *7*(1 S1), 406-415. https://doi.org/10.5901/MJSS.2016.V7N1S1P406

Rudolfsen, I. (2020). Food price increase and urban unrest: The role of societal organizations. *Journal of Peace Research, 58*(2), 215-230. https://doi.org/10.1177/0022343319899705

Saad, M. H. M., Hamdan, N. M., & Sarker, M. R. (2021). State of the art of urban smart vertical farming automation system: Advanced topologies, issues and recommendations. *Electronics, 10*(12), Article 1422. https://doi.org/10.3390/electronics10121422

Salim, S. A., Alaa, M., Yusof, Z. M., Ibharim, L. F. M., Salim, S. H., & Hashim, F. (2019). Urban farming activities in Southeast Asia: A Review and future research direction. *MATEC Web of Conferences*, *266*, Article 02010. https://doi.org/10.1051/MATECCONF/201926602010

Shakir, A. A., Hakim, F., Rasheduzzaman, M., Chakraborty, S., Ahmed, T. U., & Hossain, S. (2019). Design and implementation of SENSEP ACK: An IoT based mushroom cultivation monitoring system. In *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 1-6). IEEE Publishing. https://doi.org/10.1109/ECACE.2019.8679183

Sutono, & Lorena, B. R. G. S. (2020). Portable farming. *IOP Conference Series: Materials Science and Engineering*, *879*, Article 879. https://doi.org/10.1088/1757-899X/879/1/012099

Tan, E. K., Chong, Y. W., Niswar, M., Ooi, B. Y., & Basuki, A. (2020). An IoT platform for urban farming. In *Proceedings. 2020 International Seminar on Intelligent Technology and Its Application: Humanification of Reliable Intelligent Systems (ISITIA)* (pp. 51-55). IEEE Publishing. https://doi.org/10.1109/ISITIA49792.2020.9163781

Tarigan, Y. G., Chen, R. Y., Lin, H. C., Jung, C. Y., Kallawicha, K., Chang, T. P., Hung, P. C., Chen, C. Y., & Chao, H. J. (2017). Fungal bioaerosol exposure and its effects on the health of mushroom and vegetable farm workers in Taiwan. *Aerosol and Air Quality Research*, *17*(8), 2064-2075. https://doi.org/10.4209/AAQR.2016.09.0401

Terence, S., & Purushothaman, G. (2020). Systematic review of internet of things in smart farming. *Transactions on Emerging Telecommunications Technologies*, *31*(6), Article e3958. https://doi.org/10.1002/ETT.3958

Weather, A. (2022). *Shah Alam, Malaysia - Climate & Monthly weather forecast*. Weather Atlas. https://www.weather-atlas.com/en/malaysia/shah-alam-climate#humidity_relative

Zulqarnain, Man, N., Sharifuddin, J., Roslan, M., & Hassan, S. (2020). Factors influencing attitude towards technology adoption among permanent food production park (PFPP) program participants in West Malaysia. *Journal of Agricultural Science and Technology B*, *10*(2), 89-97. https://doi.org/10.17265/2161-6264/2020.02.004