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Article

Smart Mushroom Cultivation House: Engineering Development and Data Analysis

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Abstract. This paper presents the engineering development of the smart mushroom cultivation house and the time-series analysis of the collected data. The cultivation house is located at the School of Agricultural Resources, Chulalongkorn University, Nan province and the experimental work has been done in June-July 2023. An automatic humidity control system, which consists of water pump, fog nozzles, water flow sensor, temperature-humidity sensor (AM2301), relay-push button board and LCD display, is developed. It is controlled by C/C++ program stored in the microcontroller board (NodeMCU ESP8266 V3). The system is specifically designed for smart mushroom cultivation. The NETPIE 2020 platform is adopted for data collection, real-time monitoring, and parameter adjustment via the web application. Temperature, humidity, pump state, and water flow volume are monitored and recorded. After this development, Japanese cone mushrooms and oyster mushrooms have successfully developed fruiting body in this cultivation house. Time-series analysis of the recorded data shows that the developed system has advantages in terms of labor, water and electrical power consumption as compared with the typical method for growing mushrooms in a cultivation house.

Keywords: Mushroom cultivation house, smart farming, Internet of Things, time-series data analysis, humidity control.

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1. Introduction

The developments of smart agricultural systems have constantly gained interest by many sectors including government and various industries [1-3]. In the past, electricity from widespread electrical distribution has been utilized to facilitate the farmers in various works. For example, a typical irrigation system usually consists of an electric water pump to either pressurize water in pipelines for irrigating or pump water to a storage tower. Recently, advanced agricultural systems contain many electric and electronic equipment. Most of them are digital electronic devices instead of predated simple analog devices. Nowadays, monitoring of plant growth has been done with various electronic sensors and devices. Automation such as the utilization of simple electronic timers is a typical farmer practice. In addition, artificial light sources have been installed in greenhouses for effective plant growth [4-6].

The Internet-of-Things (IoTs) is one of the emerging technologies that is adapted to facilitate agricultural activities [7-10]. Various 'smart' electronic devices are advertised and available in commercial markets nowadays. In agriculture, the applications of IoT devices are usually called 'smart farming'. It can be viewed as an advanced automation system because the farmers can monitor locally and remotely as well as control the system manually and automatically. This technology provides advantages to the farmers in terms of time savings, reduced labor, lower energy consumption, and increased productivity.

In Thailand, mushroom cultivation activities are still expanding [11-15]. Tropical rainy weather allows Thai farmer to cultivate various kinds of mushrooms throughout the year in all regions of the country. Nowadays, many types of mushrooms such as shiitake mushrooms, straw mushrooms, oyster mushrooms, and wood ear mushrooms are grown for domestic consumption. Mushrooms are becoming popular due to their health benefits and nutritional value. Thai farmers have adopted modern cultivation techniques and technologies such as environmental control systems and substrate preparation methods to increase efficiency and productivity [16-18]. However, a suitable modern agriculture system for mushroom cultivation is still being searched both domestically and internationally [16-20].

In this work, we describe the technical details of a smart mushroom cultivation house and the time-series analysis of the recorded operation data. The development and operation of relevant electrical/electronic devices are described in this work. The main system is the automatic humidity control with microcontroller board, temperature/humidity sensor, and water pump. Hardware integration and software development are explained. For this work, NETPIE 2020 IoT platform is applied to collect and display the data via Web App. Time-series data analysis is performed and discussed.

2. Hardware Integration

The developed mushroom cultivation house is in the School of Agricultural Resources, Nan province (latitude: 18.8183533, longitude: 100.7764229) during June-July 2023. The house has been modified for mushroom cultivation from a conventional greenhouse for general plant growth. Its size (length × width) is 4 m × 6 m. For cultivating mushrooms, the light level in the house is decreased by partially covering the house with black sunshade net. Figure 1(a) shows the photo of the mushroom cultivation house. On the ground, a water pipeline was installed for supplying water to the 200-liter water tank in the house. In addition, black plastic sheets covered the ground (flat bare soil) in this area to prevent weed growth. In this work, about four hundred packed mushroom spawns are installed.

Figure 1(b) shows the photo of the inside of the house. Water pipelines, fog nozzles and a 200-liter water tank (not shown in the figure) have been installed. Various kinds of mushrooms (e.g. yanagi matsutake mushrooms (*Agrocybe aegerita*) and oyster mushrooms (*Pleurotus ostreatus* (Fr.) Kummer)) are tested for their growth in this house. The installed water tank, water pipelines, fog nozzles and mushroom hanging rows are schematically shown in Fig. 1(c). The fog nozzles, water pipelines and mushroom hanging row are aligned evenly. Typical distance between row is ~80-100 cm. Prior to this installation, the fog nozzles were tested for the spraying area. In Fig. 1(c), the temperature/humidity sensor and the controller box are schematically shown. The details of these components are explained below.

The main installed electronic equipment is the controller box as shown in Fig. 2(a). In the figure, the components inside of the controller box are deliberately shown. They are the Modela Smart Control board [21], 12-V, 2-A power supply and the backside of the LCD display. In the Modela Smart Control board, the NodeMCU ESP8266 V3 microcontroller is installed (See Fig. 3). The software program to control the system is uploaded into this microcontroller before this hardware installation. An adapter at the power supply is used to convert the 220 V AC of the electrical distribution to DC voltage to supply the electronic equipment (via Modela board). The water pump (370 W or ½ hp.) is directly connected to the 220 V and controlled by an onboard relay in the Modela board.

Other related equipment shown in Fig. 2(a) are the water flow sensor (YF-S201) with its connector box and the water filter. The connector box changes the cable type from 3 single lines to the 3.5-mm stereo audio jack that is compatible to the female connector of the Modela board. The vertical water pipeline is connected to the submersible water pump (in 200-liter water tank, not shown) via conventional blue PVC water pipe. The water filter is an important component in this system because the irrigation water is typically not very clean. Small dust particles can quickly destroy the fog nozzles unless the water filter is installed.

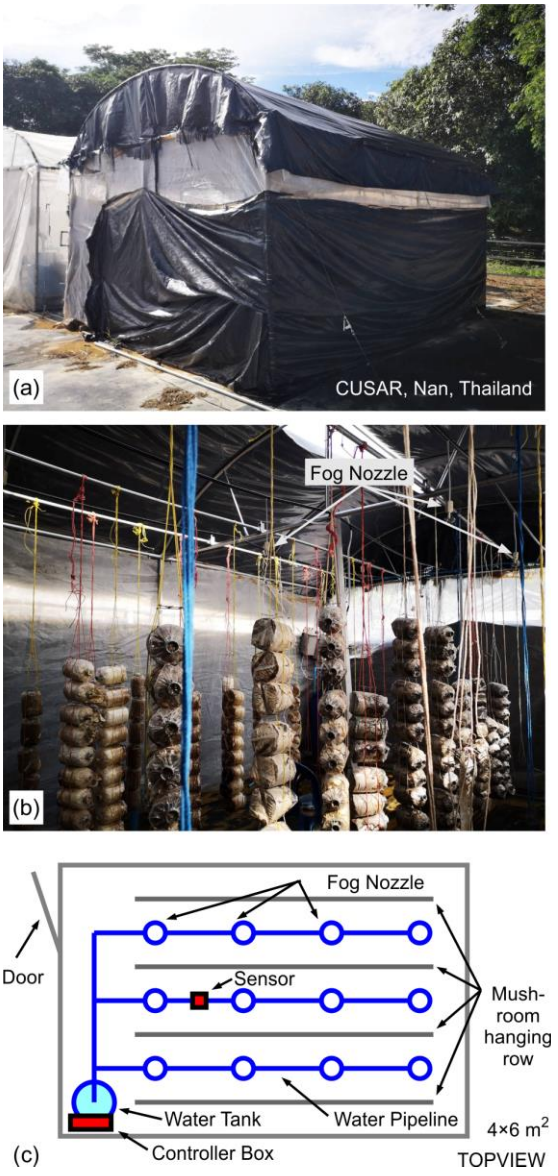

Fig. 1. Photos of the developed mushroom cultivation house (a) outside and (b) inside. In (b) three fog nozzles are pointed by arrows. (c) Top-view schematic of the installed fog nozzles, mushroom hanging row, 200-liter water tank, water pipelines, temperature/humidity sensor and controller box.

In Fig. 2(a), the LCD display can be connected to the Modela board with 4 lines (via I2C bus interface) since a small PCF8574 I2C bus interface board is integrated to this LCD display. This display provides the important information during the hardware/software debug period, and it is used for local monitoring of the system. The display information is the ambient temperature in the house, the relative humidity, the calculated consumed water, the pump 'on' status. Figures 2(b) and 2(c) show the photos of the display when the information is shown. All of them are sent to record in cloud server (with NETPIE 2020 [22]). Moreover, the pump status (on/off) is also included in the sent data.

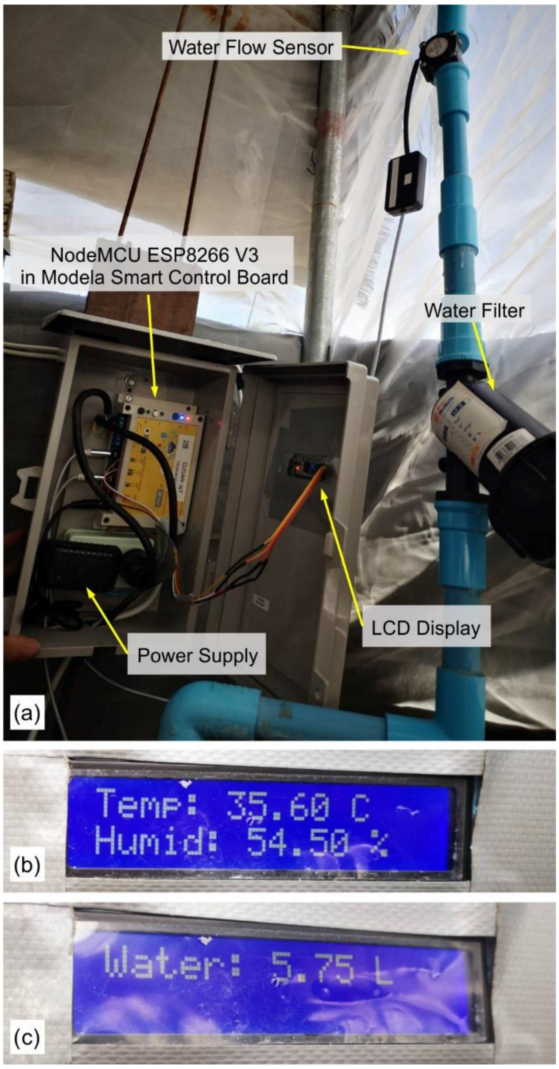

Fig. 2. (a) Photo of the controller box installed in the mushroom cultivation house. Other related components (water flow sensor and water filter) are also shown. (b) and (c) show the LCD display with the display information ('Temp' for the temperature, 'Humid' for the relative humidity, and 'Water' for the recorded consumed water.

Table 1 summarizes the electrical and electronic components used in the development of smart mushroom cultivation house. In addition to above mentioned components, an AM2301 (or DHT11) temperature/humidity sensor is also installed. Its location is schematically shown in Fig. 1(c). A similar connector box to the water flow sensor is used to change its connector type from 3 single lines to the 3.5-mm stereo audio jack that compatible to the Modela board.

The connections of electronic components (temperature/humidity sensor, water flow sensor, LCD display, relay, and power supply) and water pipeline are schematically shown in Fig. 3. In the figure, the opened Modela board is shown. The NodeMCU ESP8266 V3 microcontroller, which is installed on the Modela board, can be seen. This microcontroller, which has Wi-Fi

Table 1. List of electrical and electronic components used in the development of smart mushroom cultivation house.

Item	Function
Microcontroller Board: Node MCU ESP8266 V3	Control the system via program & communicate with NETPIE 2020
Modela Smart Control board	Receive data from the temperature/humidity sensor & control water pump via the onboard relay
AM2301 Sensor (or DHT11)	Measure temperature/humidity in the mushroom cultivation house
LCD Display (with PCF8574 I2C bus interface)	Display the read values & show the system status
Water Pump 220 V, 370 W	Submersible pump for pumping water to the fog nozzles
YF-S201 Water Flow Sensor	Detect and measure the flow for calculating the water volume
12-V, 2-A Power Supply	Provide power to the Modela board

capability, is online connected to NETPIE 2020 cloud server. The transmitted signals are electrically buffered by the circuit in the Modela board because the standard volage level of the ESP8266 is 3.3 V while 5 V is still a typical voltage level for supplying sensors. On the Modela board, one of the onboard relays is connected to the 220-V line to control the water pump via a push-button (in manual mode) or software program (in automatic mode). The Modela board, which is developed and distributed by a commercial company named Modela Store [21] comes with its own software package. However, we have developed our software program to fully control and customize the system for this smart mushroom cultivation house. Details of the software are provided in the next section.

Concerning the cost of main components for the system, they can be divided into 3 parts. One is the cultivation house, which costs 13,300 Baht. The previously mentioned electrical and electronic components cost 4,200 Baht. And the preparation of mushroom spawn costs 4,800 Baht. Since both cultivation house and electrical and electronic components can be re-used, the farmer must invest only in the first time for this smart mushroom cultivation house.

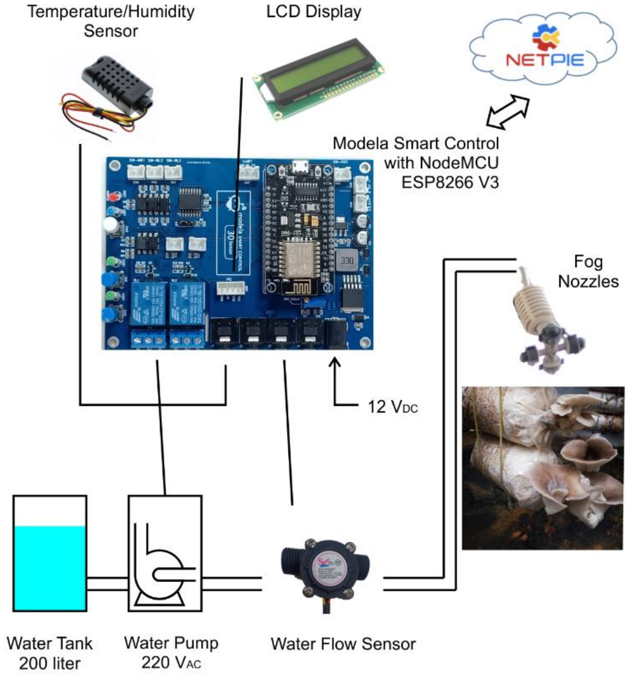

Fig. 3. The schematic diagram of the electronic and water connections. In the center, the same Modela board (without box cover) is shown.

3. Software Development

The software for automatic humidity control in the mushroom cultivation is developed in Arduino IDE 1.8.19 in C/C++ programming language [23]. For this work, all sensors (temperature/humidity sensor and water flow sensor) were tested separately before the installation to the mushroom cultivation house. Long-term reliable values were received. The control of the relay on the Modela board via onboard push-button was also checked. Registration to be a free user of the NETPIE 2020 IoT platform was also done. Codes to monitor/control all connected components were then combined. In Fig. 4, the flowchart of the main part of the developed software is shown. It starts with the initialization of all connections (the sensors, the relay, the LCD display, and the Wi-Fi internet connection). Many supported libraries are used but the details are not shown here as they can easily be found in Arduino IDE (via the library manager) and open resources in GitHub [24]. After the initialization, the program will allow the user to select manual or automatic ('AUTO') mode for controlling the water pump. In the AUTO mode, the state of water pump (on/off) is controlled by the read relative humidity value. The dashed box in Fig. 4 emphasizes the autonomous control loop where the setpoints of the minimum/maximum humidities ($H_{\min}/H_{\max}$) for switching the pump state (from off to on / from on to off) can be set in the web application of the NETPIE (See Fig. 5).

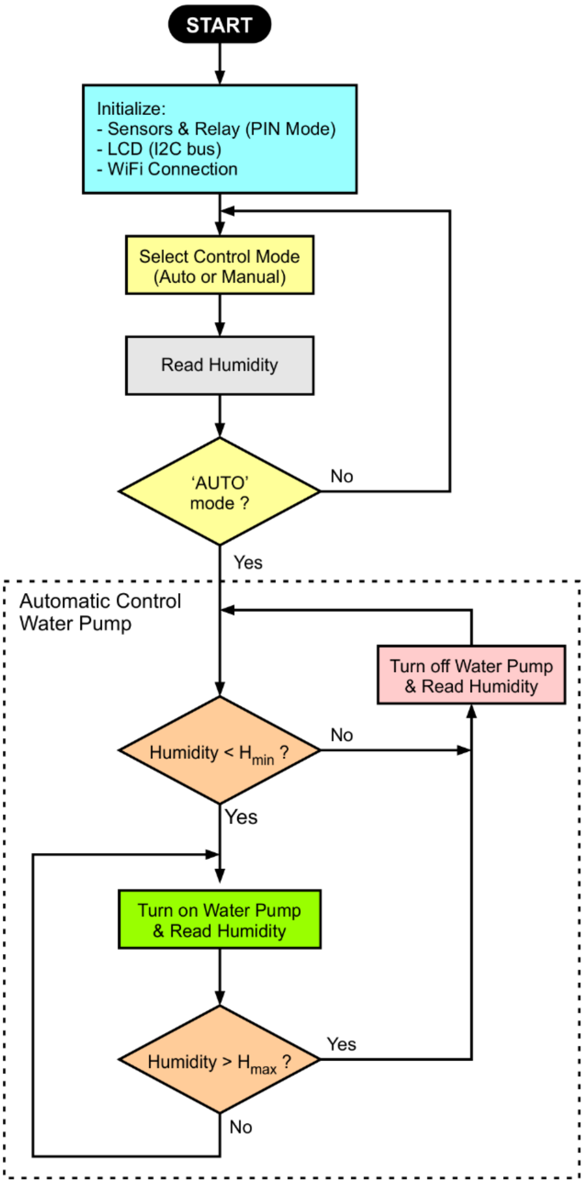

Fig. 4. The flowchart of the main software program for automatic control of the humidity in the mushroom cultivation house. The dashed box emphasizes the autonomous control loop.

Apart from the main software code for the humidity control, other codes are the communication with NETPIE 2020, control of the LCD display, the check of push-button state (for switching manual/auto mode), the reading of the water flow sensor. They are also integrated into the complete software program. However, we do not present all of them here because it is well-documented by the relevant hardware developers. The readers who are interested in these other codes, can find the detail elsewhere [23, 24].

For the calculation of the water flow volume, we perform a numerical integration of the flow rate over the time by summing the average flow rate values (sampling six times per one minute) [25]. This method might not be accurate since the flow can rapidly change at the beginning/ending of the water pump operation, which are independently controlled by the humidity value (See Fig. 4). Since the change is faster (a few seconds) than the data recording rate (one minute). However, we found that quite reasonable values for the rough estimation of the water consumption is obtained. This data will support the farmer's decision on the manual filling of 200-liter water tank inside the mushroom cultivation house since the user can access this value online.

For the connection with NETPIE 2020, a standard MQTT protocol (with the recommended code from the NETPIE developer) is used [22]. Typical free quota of the data storage and dashboard component in this IoT platform are sufficient for this mushroom cultivation house. For this work, we have decided to record the time-series data with one-minute resolution. This is considered as high resolution for agricultural activities while it is too low for capturing many abrupt activities that might happen in the system such as the change of the water flow rate.

Figure 5 shows a screenshot of the dashboard of our smart mushroom cultivation house. It can be accessed via web application with any browser. The main part is the automatic humidity control system. Several widgets (gauge, textbox, button, slide bars, and graph) are shown in this

Fig. 5. The captured dashboard screen that shows the real-time data for temperature (upper left), humidity (upper center), water pump control (upper right), setpoints for the minimum/maximum humidity values (center slide bars) and time-series data of the humidity that is recorded for the last 24 hours (lower part).

figure. They represent real-time data for temperature, humidity, water pump control, setpoints for the minimum/maximum relative humidity values and time-series data of the relative humidity that is recorded for 24 hours. Note that all the data can be retrieved and exported for the detail analysis as shown in more detail in the Section 4.

Data displayed in Fig. 5 show that during the night (18:00 p.m. - ~8:00 a.m.) the humidity control (the water pump) does not need to be operated. During the day (8:00 a.m. – 18:00 p.m.) the humidity can be well controlled in the pre-defined range ($H_{\min}$ = 60% and $H_{\max}$ = 80% in this work) when humidity inside the cultivation house drops due to the lower external relative humidity of the air outside the cultivation house. This graph confirms the successful initial operation of the developed IoT system in the mushroom cultivation house. The cultivation house is under the automatic operation with this IoT system for ~3 months.

4. Time-Series Data Analysis

After the successful installation of the automatic humidity control system, an additional commercial IP camera was installed to regularly monitor the mushroom growth remotely. An example of the monitored scene is shown in Fig. 6(a). With this tool, one does not need to open the door that leads to humidity leakage. After 4 weeks of cultivation, several mushrooms developed fruiting body. As examples, Figs. 6(b) and (c) show the photos of two cultivated mushrooms. They are yanagi matsutake mushrooms (*Agrocybe aegerita*) (Fig. 6(b)) and oyster mushrooms (*Pleurotus ostreatus* (Fr.) Kummer) (Fig. 6(c)). Since the suitable conditions for growing different kinds of mushrooms are different [12, 17], we cannot further evaluate our system based on this initial test production. Anyway, we are confident that the developed mushroom cultivation house can be applied to advance mushroom growth technologies. However, further research needs to be done in this direction.

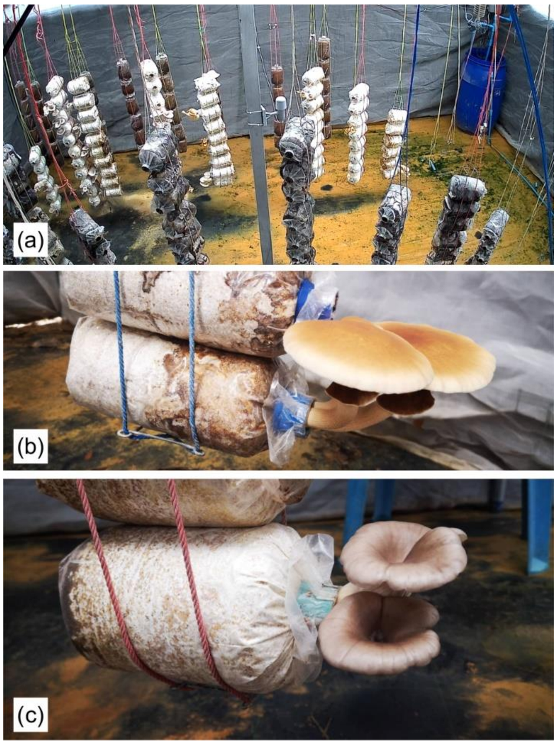

Fig. 6. Photos of some mushrooms that develop fruiting body after 4 weeks for the cultivation. They are (a) yanagi matsutake mushrooms (*Agrocybe aegerita*) and (b) oyster mushrooms (*Pleurotus ostreatus* (Fr.) Kummer).

Apart from the obtained mushroom product, the developed software also provides the recorded time-series data as shown as an example in Fig. 7. The data is analyzed by self-developed code in Spyder IDE of free Anaconda software package [26]. The data for four consecutive days are analyzed and shown for relative humidity of the air (Fig. 7(a)), air temperature (Fig. 7(b)), the pump state (Fig. 7(c)) and the accumulated water volume (Fig. 7(d)). The latest data (the water volume) is calculated from the integration of the flow rate as mentioned in the previous section. Shade areas in Fig. 7 are marked for the time between 18:00 p.m. and 6:00 a.m. of the next day. They are approximated as nighttime. It is obvious from the graphs

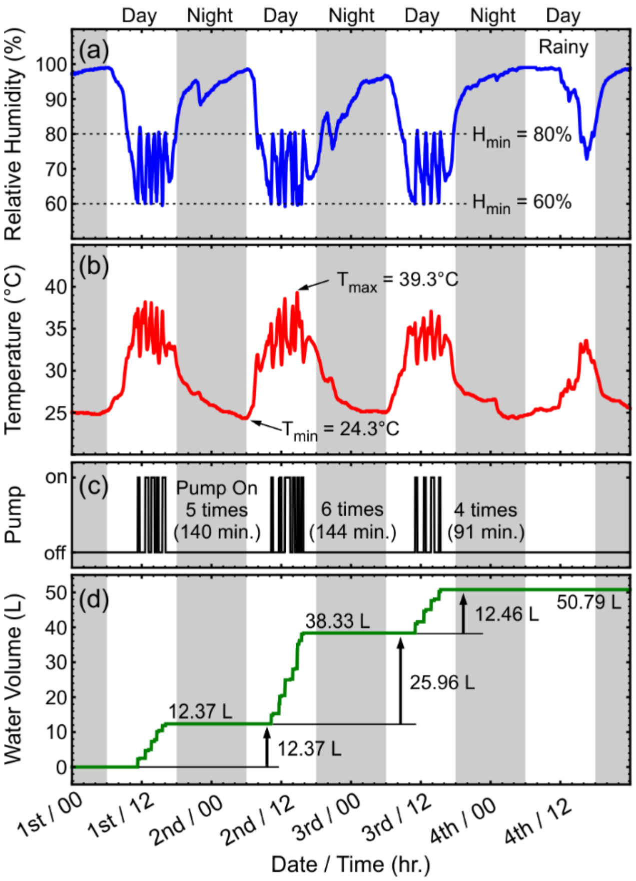

Fig. 7. Time-series data for four consecutive days (13th – 16th July 2023) of (a) the relative humidity, (b) temperature, (c) pump state, and (d) accumulated water volume. Shade areas are between 18:00 p.m. and 6:00 a.m. of the next day.

that humidity control is *not* necessary during night because of the high external humidity and low external temperature. Relative humidity of more than 80% and temperature of less than 30°C are usually obtained without any control during the test period (July 2023). During the daytime (6:00 a.m. – 18:00 p.m.), the situation is largely changed due to the sunlight. The humidity in the cultivation house monotonically drops in the morning time while the temperature increases because of the heat from the sun. When the relative humidity drops below 60%, the water pump is switched on, and the installed fog nozzles operate. The sprayed water increases the relative humidity in the house and reduces the temperature. The zigzag patterns in the humidity and temperature graphs are observed during the first 3 days. Since the setpoints of the minimum humidity ($H_{\min}$) and maximum humidity ($H_{\max}$) are 60% and 80%, we can claim that the automatic humidity control system is successfully developed and stably run.

Since the system is controlled by the humidity value, the duration and frequency of the water pump operation might be different from one to the other day. In Fig. 7(c), pump is on for 5, 6, and 4 times for the first 3 days. The 'on' durations are 140, 144, and 91 min., respectively. On the last day (the 4th day), the pump was not on because it was a rainy day on that day. The humidity was higher than 60% for the whole day. This implies that the water supply and electricity were not consumed on that day.

The accumulated water volume is shown in Fig. 7(d). The initial value is set to zero. For each day, the consumed water volume varies. We found that on the second day the consumed water (25.96 liters) is high. This can be related to the high temperature for a long period (~10 hours) during the day. Maximum temperature $T_{\max}$ of 39.3°C was observed on this day (See Fig. 7(b) and Fig. 8).

Compared with conventional farmer practice for operating a mushroom cultivation house, our developed mushroom cultivation house has advantages in terms of labor, water, and electrical power consumption. Since the system needs no operator for doing this humidity control, the labor work is much less. One needs to only monitor the water consumption (via Web App interface) to be sure that there is no lack of the supply water. The required water volume depends on the required controlled humidity. Only the necessary water is supplied in the automatic humidity control system. No additional water is needed. This is unlike the case of human operations, where excessive water is usually supplied in order to be sure that the humidity is always sufficient. Part of the supply water infiltrates to the beneath ground. This is considered as the loss of the water resource. With respect to electricity consumption, one must use an electric water pump for the fog nozzles. Since the supply water is usually less in this automatic humidity control, the electrical power consumption must be less as well. A rough estimation of the consumed electricity is ~8 Baht/day or ~240 Baht/month. Assumed that 1 unit of electricity (or 1 kWh) costs 7 Baht.

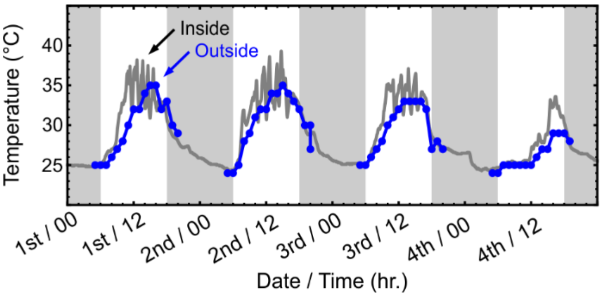

Fig. 8. Time-series data for the four consecutive days of the inside and outside temperature.

To get deeper insight into the temperature variation in the cultivation house, the recorded temperature of Nan province is retrieved [27] and plotted along with the temperature in the cultivation house in Fig. 8. During the day, it is obvious that the inside temperature of the mushroom cultivation house is higher than the outside temperature. This is due to the high absorption of sunlight on the black sunshade net, and it becomes heat. Since the mushroom cultivation house is typically closed to avoid humidity leakage, the temperature goes higher under the sunlight during the daytime. Only the water from the fog nozzle can reduce the temperature because of the heat transfer from air to the cold water to equilibrate the temperature. This results in the transformation of the cold water to vapor. However, once the water supply is stopped, the inside temperature rapidly increases. From this investigation, we suggest that a simple temperature reduction technique is requested for the cultivation of mushrooms at reasonable temperature range. Evaporative cooler might provide this feature [16].

5. Conclusion

We present the details of our engineering development of the smart mushroom cultivation house. The integrated electrical and electronic components are an electric water pump, fog nozzles, a water flow sensor (YF-S201), a temperature-humidity sensor (AM2301), a Modela relay-push button board and an LCD display. The software program is developed in Arduino IDE and installed in the NodeMCU ESP8266 V3 microcontroller, which is installed on the Modela board. Data obtained from this system is monitored and recorded via NETPIE 2020 IoT platform. Controlled parameters can also be controlled via the Web App. With the successful automatic control of relative humidity, some mushrooms developed fruiting body during the test period. Time-series analysis of the recorded humidity, temperature, pump state and water volume show some reasonable features that can be well explained qualitatively. The developed system is assumed to have advantages in terms of labor, water and power consumption as compared with typical farmer practice for growing mushrooms in a cultivation house. This work paves the way for realizing the practical, smart, and sustainable mushroom cultivation house.

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