J. Electrical Systems 20-9s (2024): 1652-1661

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Cordyceps IoT-Based Smart Farm Control System

Journal of Electrical Systems

***Abstract:* -** Cordyceps, an edible and medicinal mushroom, prized for its medicinal properties, plays a significant role in regional economies. The cultivation and harvesting of Cordyceps contribute to income generation and employment opportunities for local communities. In conventional farming, the challenges associated with human intervention and the precise control of optimal cultivation conditions often impact overall crop profitability. Addressing this concern, our research introduces an innovative solution — an IoT-based Cordyceps smart farm control system. This technological advancement elevates a traditional Cordyceps farm to the realm of smart agriculture, empowering farmers with the capabilities to meticulously manage and fine-tune environmental parameters. This transformative system creates an optimal and controlled setting, fostering the flourishing cultivation of Cordyceps. In the larger context, the implementation of our smart farm system resulted in a noteworthy 20% increase in overall crop profitability, underlining the tangible economic benefits of embracing IoT technology in Cordyceps cultivation.

Keywords: Cordyceps, IoT, smart farming, smart agriculture.

I. INTRODUCTION

Cordyceps is a popular edible and medicinal mushroom. It has a notable impact on the economy, particularly in regions where it is cultivated and harvested. The demand for Cordyceps in traditional medicine, health supplements, and the food industry has led to a burgeoning market. Local economies benefit from the cultivation and sale of Cordyceps, creating opportunities for employment and income generation. The economic impact extends to sectors involved in research, cultivation technology, and the processing of Cordyceps-based products as shown in Figure 1. There have been studies on the properties of this type of mushroom, which contains important substances to protect against various diseases such as cancer, leukemic, tumor, and HIV [1], [2]. Therefore, Cordyceps cultivation has been studied in various stages. One of the most common problems with cultivating is contamination. This mushroom is susceptible to a variety of contaminants, including other fungi, bacteria, and insects. In Thailand, there are small community enterprises that have researched and cultivated the Cordyceps in the mushroom greenhouse under the control of light, humidity, and temperature by human operation. Maintaining optimal temperature, humidity, light exposure, and oxygen levels is crucial for successful Cordyceps growth. This necessitates controlled cultivation systems and careful monitoring.

The Internet of Things (IoT) represents a technological framework that links physical things/devices, appliances, and assorted objects equipped with sensors, software, and network connectivity, facilitating the collection and exchange of data with each other. The scope of IoT applications is broad and varied, with its impact already observed in sectors ranging from education and manufacturing to transportation, healthcare, and agriculture [3] [4]. As the agricultural sector continues to expand, IoT stands at the forefront of ushering in a pivotal transformation from conventional farming to smart agriculture, promising heightened productivity and increased profitability [5]. Within the domain of smart agriculture or smart farming, IoT systems and intelligent devices are utilized to monitor a diverse array of parameters, encompassing temperature, humidity, energy consumption, environmental conditions, and machine performance. The real-time analysis of this data facilitates the identification of patterns, recognition of trends, and timely alerting to anomaly events. This functionality empowers businesses to optimize their operations, ultimately leading to an enhancement in overall efficiency within the agricultural landscape.

In this research, we designed and developed an IoT-based Cordyceps smart farm control system, elevating a conventional Cordyceps farm to the realm of smart agriculture, achieved through the seamless integration of sensor-based real-time monitoring and automated controls. This transformative system allows the Cordyceps farmers to

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manage and fine-tune the environmental parameters, creating an optimal and controlled setting conducive to the thriving cultivation of Cordyceps.

Fig. 1. Cordyceps

II. Literature Review

A. Cordyceps cultivation and IoT-enabled agriculture

The growth and quality of Cordyceps are influenced by several factors, such as species, cultivation methods, environment, light, humidity, and temperature. Maintaining a sterile environment is crucial for successful cultivation. Lou, Guo, et al. illustrated the phenotypic changes after the degeneration of Cordyceps. Their study focused on the causes including environmental factors and genetic variation [6]. A recent study by Wu, Liang et al. examined the effects of different colors of LED light treatments on the production of fruiting bodies and nucleoside compounds in Cordyceps at different growth stages achieved harvest in different time frames [7].

Numerous farms encounter challenges related to human intervention and monitoring. The farm requires manual control for optimal conditions, demanding increased human supervision and a greater workforce to meticulously monitor the fields, requiring considerable dedication. Unfortunately, due to time constraints and other responsibilities, farmers cannot consistently monitor their fields, impacting the overall profitability of the crops [8].

An IoT-enabled smart agriculture framework suggested by [9] outlines that the Cordyceps control system comprises five key components: a substrate module, a big data warehouse, a cloud IoT module, an IoT-enabled framework, and a mobile app. The IoT-enabled framework plays a crucial role, in overseeing the soil sampling interval for acquiring soil property data. The sensors encompass temperature, humidity, and CO_2, with water supply regulated through a solenoid valve.

The authors in [10] introduced an IoT-agro framework structured across three layers: Agriculture Perception, Edge, and Data Analytics. The Agriculture Perception Layer incorporates IoT-enabled devices that actively sense real-time variables. These devices, which encompass sensors, actuators, and weather stations, facilitate data exchange with other interconnected devices and applications. They can both collect data from other devices and locally process the data or transmit it to centralized servers or cloud-based applications.

B. Temperature and humidity sensors

Temperature and humidity are important parameters for the environment of growing Cordyceps. Selecting a precision sensor will help control a suitable environment for growing. The AM2301 as depicted in Figure 2, is a digital temperature and humidity sensor widely used for environmental monitoring applications [11]. Operating on a capacitive humidity sensing principle and incorporating a thermistor for temperature measurement, the sensor offers accurate readings within specified ranges. With a standard temperature measurement range spanning from -40°C to 80°C and a humidity measurement range covering 0% to 100% relative humidity, the AM2301 delivers extensive information about environmental conditions. It boasts a typical accuracy level of within ±0.5°C for temperature and ±3% for relative humidity.

Fig. 2. AM2301 - Temperature-humidify sensor

C. Light intensity sensor

The BH1750 as shown in Figure 3, is a digital light intensity sensor designed to measure ambient light intensity in lux [11]. Employing a photodiode and analog-to-digital converter (ADC), this sensor provides accurate readings in various lighting conditions. It features a wide dynamic range, typically spanning from 1 to 65,535 lux, allowing it to adapt to diverse environments. The BH1750 is known for its precision, and its digital output simplifies integration with microcontrollers. Its compact design and low power consumption make it suitable for applications such as automatic lighting control, display backlight control, and energy-efficient systems. The sensor's versatility, reliability, and digital interface contribute to its popularity in diverse lighting and sensing applications.

Fig. 3. BH1750 - Light intensity sensor

D. Server and Microcontroller

The Raspberry Pi 4B stands as a compact yet robust single-board computer, widely employed across various domains such as light servers and research initiatives. Featuring a 1.5GHz quad-core 64-bit ARM Cortex-A72 CPU, 2GB or 4GB of RAM, Bluetooth, Wi-Fi capabilities, and the ability to support dual 4K displays, the Raspberry Pi 4B excels in tasks ranging from database management and data logging to acting as a web server and functioning as an MQTT broker. On the other hand, the NodeMCU ESP8266 emerges as a versatile and potent microcontroller (MCU) with broad applicability in IoT devices, sensors, actuators, robotics, and beyond. With its integrated Wi-Fi, low power consumption, an extensive array of I/O peripherals, high compatibility, and robust security features, the NodeMCU ESP8266 has become a favored choice for diverse IoT applications.

E. Humidifier

A humidifier operates as a mist-producing device utilized to augment or manage room humidity by diffusing mist into the air. Utilizing a high-frequency ultrasonic head, the process generates exceedingly fine water droplets with a mere 1-micron diameter, dispersing them into the air to form a delicate mist [12]. The 10-head mist maker as depicted in Figure 4, is equipped with 10 spray units, generating a rapid and substantial mist output to enchantingly transform the atmosphere [11]. Operating on ultrasonic frequencies, this humidifier employs electrical oscillation to produce mist and water spray, concurrently releasing negative ions for air freshness. Its IP67 waterproof design, coupled with over-current/heating protection and a sufficiently long power adapter cable, ensures security during use, complemented by automatic water induction off protection. Operating this mist maker is effortlessly simple: just place it in water, plug it in, and the mist materializes. With features like a copper cavity for improved heat dissipation and a replaceable atomizing sheet, maintenance is easy. The versatility of this 10-head ultrasonic mist maker extends to various horticultural applications, including propagation, foliar feeding, and greenhouse humidity generation, while its adaptability allows placement in ponds, rockeries, fish tanks, vases, and more.

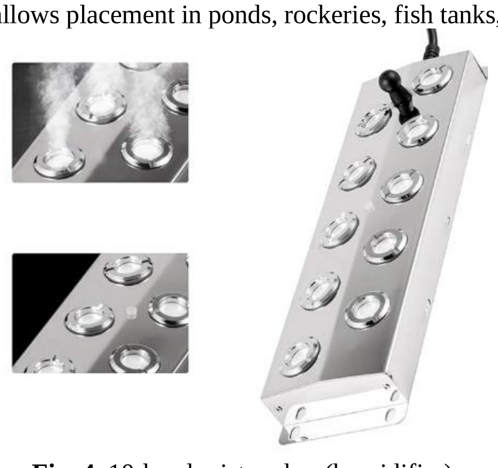

Fig. 4. 10-head mist maker (humidifier)

III. Requirement Gathering and Analysis

Various farms adhere to distinct criteria for cultivating Cordyceps. A local cooperative specializing in Cordyceps cultivation, with a successful operational history spanning over six years, discloses the optimal parameters for fostering Cordyceps growth as follows:

Temperature plays a crucial role in the cultivation of golden Cordyceps mushrooms. Maintaining a temperature range of 17.5 to 22.5 degrees Celsius fosters optimal growth for these mushrooms, particularly resulting in robust golden Cordyceps mushrooms. Notably, a temperature of 22 degrees Celsius yields the highest concentration of cordycepin. Deviating from this temperature range—whether higher or lower—significantly diminishes the cordycepin content. Beyond 30 degrees Celsius, mushroom growth is impeded, attributed to the inhibitory effects of elevated temperatures on both mushroom growth and cordycepin production. This phenomenon may be attributed to the golden Cordyceps mushroom's natural origins in the colder regions of China, rendering it less tolerant to warmer climates.

Humidity is a critical factor in the cultivation of Cordyceps, demanding a delicate balance in ambient moisture—neither excessively high nor too low—for optimal conditions. The Cordyceps thrive best within a relative humidity range of 60% to 70%. It's imperative to acknowledge the symbiotic relationship between humidity and temperature; any fluctuations beyond the recommended range can significantly impact the overall growth dynamics of these Cordyceps.

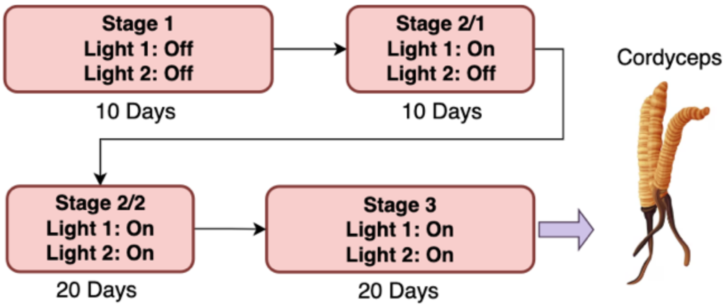

Fig. 5. Cordyceps cultivation

Lighting for golden Cordyceps is segmented into three distinct stages, as shown in Figure 5:

1. In the initial period (stage 1: days 0-10), the Cordyceps in the culture jars necessitate complete darkness to stimulate their early growth.
2. Transitioning to the second phase (stage 2: days 11-40), an orange light is introduced. This phase is further divided into two segments: firstly, providing light level 1 for ten days, followed by light level 2 for another twenty days.
3. Moving into the third phase (stage 3: days 41-60), this marks the pre-harvest period for the Cordyceps.

The system requirements were analyzed and concluded from insights obtained through in-depth interviews with a small community enterprise Cordyceps farm that has successfully operated for over six years, utilizing the requirements engineering framework [13]. The ensuing are the determined functional requirements delineated in terms of actions and functionalities:

1) Functionality: Staff members possess the capability to control or preset parameters, including temperature, humidity, growth stages, and duration, utilizing either a mobile device or a PC.
2) User-Friendly Interface: Tailored for local staff, the interface offers support for the Thai language. It is designed to feature a straightforward and intuitive user interface, ensuring ease of use for all workers, irrespective of their IT proficiency.
3) Seamless Integration: The system seamlessly collaborates with the existing infrastructure, requiring minimal or no modifications, thereby ensuring minimal downtime during the integration process.
4) Offline Capabilities: The system boasts the ability to operate even in the absence of an internet connection, guaranteeing reliable performance in areas with poor connectivity.
5) Maintenance Ease: Engineered for simplicity in maintenance, the system facilitates the effortless location and replacement of components such as the main server, sensors, and actuators.
6) Decouple or Independence: Acknowledging the need for flexibility, certain components of the system are designed to function manually. This flexibility allows the system to operate in either auto-mode or manual mode, catering to diverse operational requirements.

These conclusions not only highlight the system's functionality but also underscore its adaptability to the specific operational dynamics and preferences of the local Cordyceps farm. This meticulous consideration ensures the smooth integration of technological advancements while preserving a harmonious coexistence with existing practices.

IV. System Architecture

This section describes the system architecture. There are three major components, a server, an IoT sensor module, and an IoT actuator module as shown in Figure 6.

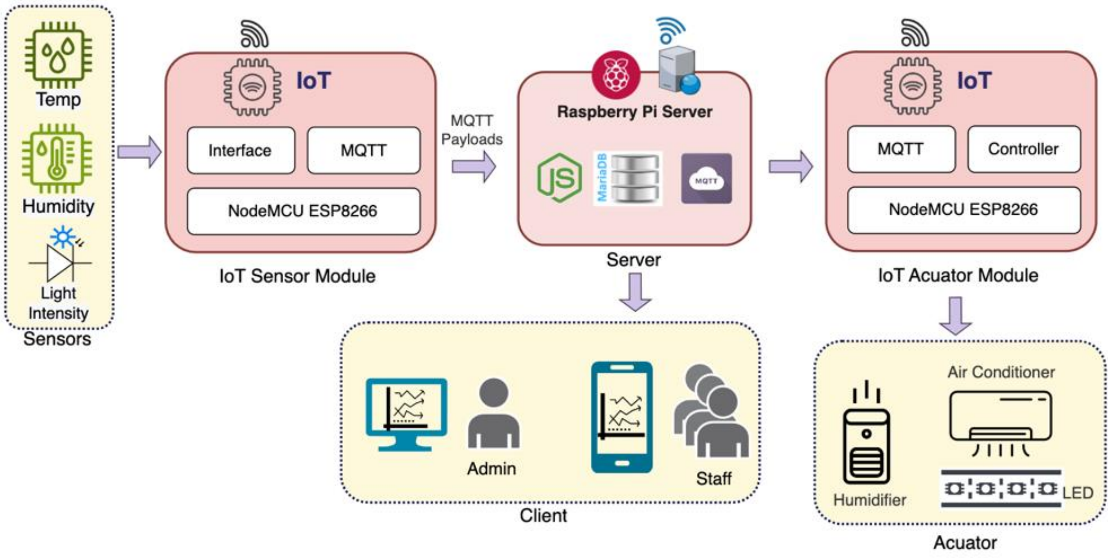

Fig. 6. System architecture

A. IoT sensor module

The IoT sensor module plays a crucial role in gathering vital environmental data that directly influences the optimal growth conditions for Cordyceps. The collected data, encompassing temperature, humidity, and light intensity, are seamlessly integrated into a unified payload and securely transmitted to the server via the MQTT protocol, employing a robust TLS connection.

B. Server

The server comprises three key components: an MQTT broker, a web server, and a database server. The MQTT broker handles the reception and processing of sensing data from the IoT sensor module (including temperature, humidity, and light). It also sends commands to manage the IoT actuator module, which includes devices such as the air conditioner, humidifier, and LED light panels.

The web server facilitates user access to control various parameters, providing an interface for clients such as PCs and mobile devices. The farm workers can control settings and also visually monitor the current sensor data and access historical records. Additionally, the web server functions as a central processor and data logger, efficiently managing and recording information. It plays a crucial role in sending essential notifications to the farm workers (users) ensuring timely updates on the system's status and any significant events.

C. IoT actuator module

The IoT actuator module securely receives a payload from the server via the MQTT protocol on a protected channel. As data arrives in the form of a payload, the module adeptly extracts signals tailored for each actuator (air conditioner, humidifier, and LED light panel), which are then dispatched to control the respective actuators in the farm. To establish this seamless communication between the server and IoT actuator module, it is imperative for the IoT devices to subscribe to specific topics on each communication channel. This ensures that relevant and targeted data is transmitted, enabling precise control over the individual components.

D. Client

The system utilizes a client/server model, accommodating clients ranging from computers to mobile devices. This functionality enables users and administrators to conveniently preset and monitor essential parameters, including stage durations, temperature, and humidity, using their computers or mobile devices. Furthermore, users have the capability to check real-time status updates, such as current temperature, humidity levels, and lighting status, and perform remote control over the actuators. This inclusive design ensures that users can effectively manage and monitor the cultivation environment with ease and flexibility across multiple platforms.

V. Implementation

This section describes the implementation of hardware and software.

A. IoT sensor module

There are two distinct sensor modules in use: one for temperature-humidity and another for light intensity. Each IoT sensor module utilizes an MCU (NodeMCU ESP8266) as its primary processor. The temperature and humidity sensors are integrated into a single package (AM2301) and are connected to the MCU through digital pins (D0). Within the room, a central temperature and humidity sensor (TH) is positioned in the middle, as illustrated in Figure 7.

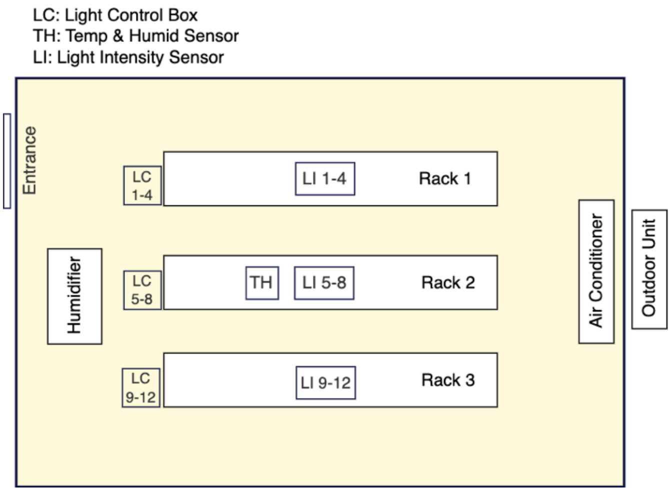

Fig. 7. Cultivation room layout

The cultivation room comprises three racks, each housing four shelves, as depicted in Figure 8. To ensure adequate light exposure for the Cordyceps on every shelf, light intensity sensors (BH1750), shown in Figure 9, are placed on top of the Cordyceps cultivation jars on each shelf, resulting in a total of twelve light sensors (3 racks x 4 shelves), as indicated in Figure 10. Each light intensity sensor connects to the MCU through the IIC interface, specifically via SCL-D1 and SDA-D2.

Fig. 8. Cultivation room

Fig. 9. Light intensity sensor

Fig. 10. Light control box

B. IoT actuator module

1. Cooling system

The farm's current cooling system relies on a traditional split-type air conditioner, where temperature is monitored by a thermistor attached to the indoor unit. However, due to the low precision of this sensor, the temperature within the cultivation room experiences fluctuations, leading to inaccuracies that are unsuitable for the Cordyceps cultivation environment. Due to budget constraints, the decision has been made to continue using the existing air conditioner. To address this issue, we developed an IoT actuator unit specifically designed to directly manage the outdoor unit, as illustrated in Figure 11. This IoT actuator unit utilizes a high-precision sensor (IoT sensor module) to sense the temperature, comparing it with preset range values within the system. When the temperature surpasses a predetermined threshold, the IoT actuator triggers the outdoor unit. Conversely, if the temperature falls below the established threshold, the IoT actuator halts the outdoor unit. To comply with safety standards, a 2-minute delay is implemented before re-initiating the compressor.

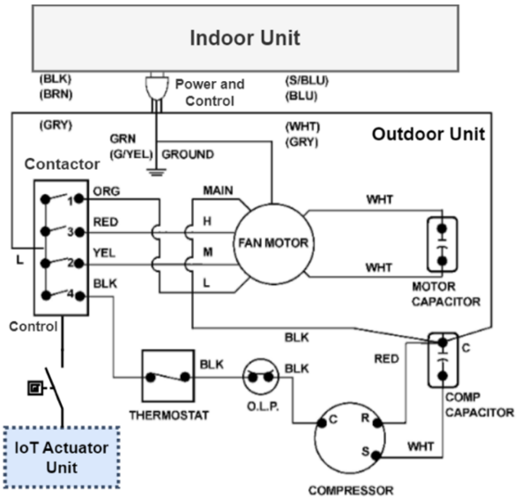

Fig. 11. Outdoor unit control diagram

2. Humidifier

We built a humidifier, depicted in Figure 12, autonomously delivers and maintains the optimal humidity conditions for Cordyceps cultivation in the room. Constructed with a plastic container, ultrasonic humidifier, blower, and controller, this humidification system ensures precise control over humidity levels. The ultrasonic humidifier was strategically positioned at the container's base, submerged in water, and was regulated by the IoT actuator module. This configuration transforms water into a fine mist, subsequently released into the air to elevate the humidity levels in the room. Users have the flexibility to preset the desired humidity level through the control panel, facilitating customized environmental adjustments for Cordyceps cultivation.

Fig. 12. Humidifier

3. Light panel

As mentioned earlier, the cultivation room comprises three racks, each hosting four shelves. Within this setup, every shelf is equipped with two LED light panels, denoted as Light 1 and Light 2, strategically positioned at the ceiling to establish two distinct levels of light intensity. This configuration is intended to optimize the growth acceleration of Cordyceps. As depicted in Figure 10, these light panels can be independently controlled, both manually and automatically, through a dedicated controller located on each shelf. The IoT actuator module responsible for light panel control consists of an MCU and a relay, receiving commands from the main processor. The activation and deactivation of the light panels are synchronized with the cultivation stage and its preset duration within the system, as depicted in Figure 15(c). This ensures a dynamic and tailored lighting environment conducive to the specific growth stages of Cordyceps. This orchestrated approach ensures a dynamic and customizable lighting environment, tailored to the specific growth stages of Cordyceps.

C. Server

In this project, we employed a Raspberry Pi 4 Model B as a single-board server, operating on the Raspberry Pi OS. This server serves as the hub for receiving sensing data from the IoT sensor module (temperature/humidity/light) and processes it. Subsequently, it sends commands to control the IoT actuator module, which includes the air conditioner, humidifier, and LED light panels. Connected to the main router, the server facilitates access for IoT modules and clients (PC and mobile devices). It operates as a data logger and dispatches crucial notifications to users.

To address the project's requirements, we installed Node.js, MQTT broker, and a database server on the system. The developed software modules cover diverse needs, incorporating features such as authentication and access control for security, MQTT for communication, data logging for storing time-series data from sensors, a control panel, a dashboard, and visualization to present the system's status and display time-series charts. The control panel and dashboard are depicted in Figure 15(a) and (b).

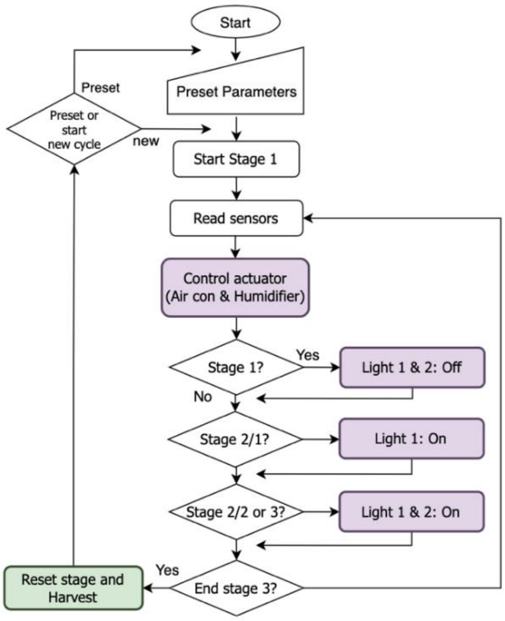

Fig. 13. System flow

The system's workflow, outlined in Figure 13, commences with the user setting preferred parameters, including the number and duration of stages, temperature, and humidity. Following parameter input, the system initializes the first stage, retrieves sensor data, processes it on the server, and issues commands to control the air conditioner, humidifier, and LED light panels. Upon completing stage 3, the Cordyceps are ready for harvest, and the system can either initiate a new cycle or allow users to preset parameters for a new cycle.

VI. Results

The hardware investment totaled approximately 820 USD, with all components easily procurable from local suppliers. The IoT system was deployed on a small community Cordyceps farm and evaluated by the farm staff. The temperature and humidity levels within the cultivation room remained stable, aligning with the requirements for Cordyceps growth stages. Notably, temperature and humidity errors or offsets were found to be less than 1% when compared with high-precision measurement instruments, a level deemed acceptable. The system effectively prompted staff to adhere to necessary care steps, ensuring timely harvesting, and issuing notifications for significant events. Operating autonomously 24 hours a day, the system mitigated maintenance errors and allowed for remote environmental monitoring, ensuring comprehensive control. Consequently, the implementation resulted in increased productivity compared to previous practices. Usability evaluations yielded highly favorable results, while assessments of the system's accuracy and precision were also rated at a very high level. The implementation of our smart farm system resulted in a noteworthy 20% increase in overall crop profitability.

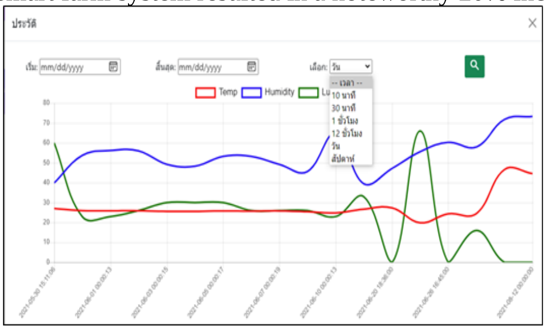

Fig. 15 (a). Dashboard: parameters monitoring

Fig. 15 (b). Dashboard: temperature and humidity control

Fig. 15 (c). Dashboard: light control

VII. Conclusion

In this study, we developed an IoT-based system to transform a traditional farm into a smart farm. The existing manual management of various processes in the farm, including manually controlling the humidifier, using an infrared control for the air conditioner, and manually toggling the lighting, led to inappropriate environmental conditions for Cordyceps cultivation. To transform, the IoT system was designed, featuring the Raspberry Pi 4 B as the central server and utilizing the NodeMCU ESP8266 as the microcontroller attached to sensors. The total expense for implementing this IoT system was approximately 820 USD, and all necessary components were conveniently procured from local suppliers. Subsequent to the system's integration, the cultivation room demonstrated consistent stability in temperature and humidity levels, precisely meeting the specified requirements for various Cordyceps growth stages. This transformation to a smart farming solution yielded a substantial enhancement in productivity by 20% compared to the previous manual practices.

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