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Development and Validation of a Low-Cost IOT-Based Prototype for Smart Mushroom Cultivation System

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Abstract - Mushroom cultivation requires precise control over environmental variables like Temperature, Relative Humidity (RH), and CO2 levels. Traditional methods are labor-intensive, prone to error, and often result in inconsistent yields. This paper presents a novel approach to automated mushroom farming using a framework that integrates the Internet of Things (IoT) and Artificial Intelligence (AI). Our proposed system utilizes a network of IoT sensors to continuously monitor critical environmental data within a cultivation chamber. An AI-powered control algorithm then analyses this data to make intelligent, autonomous decisions, such as activating humidifiers, ventilation fans, or cooling systems, to maintain optimal conditions for mushroom growth.

The system incorporates machine learning models to predict ideal harvest times and detect diseases early, addressing key challenges in mushroom cultivation. A Convolutional Neural Network (CNN) analyses images captured by an integrated camera system to monitor mushroom growth stages and identify signs of common diseases. This predictive and diagnostic capability allows for proactive intervention, minimizing crop loss and maximizing yield. The results validate the effectiveness of our integrated IoT-AI framework in creating a self-regulating, high-efficiency mushroom farming environment, paving the way for more sustainable and productive agricultural practices.

Key Words: Artificial Intelligence; Convolutional Neural Network (CNN); Internet of Things (IoT); Mushroom Cultivation; Precision Agriculture

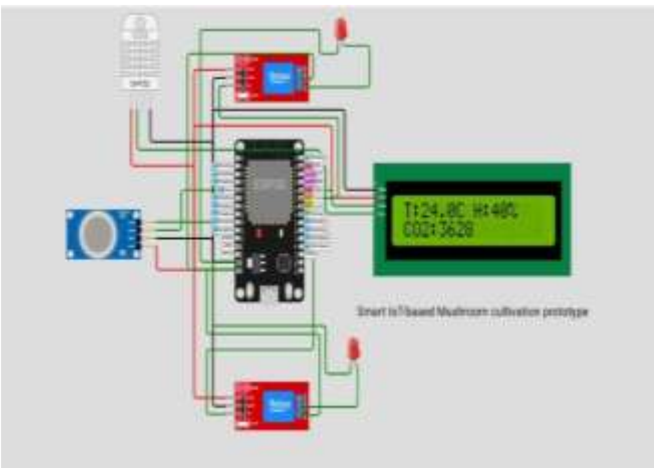
1. INTRODUCTION

The implementation of Internet of Things (IoT) technologies in agriculture have led to the creation of smart systems that boost productivity, resource efficiency, and crop quality. In controlled environment agriculture, environmental factors including temperature, relative humidity and CO_2 concentration levels must be carefully regulated, much like in mushroom cultivation. Even minor variations in these parameters can have a major impact on mushroom growth, production and quality. In particular, small farmers seeking cost-effective alternatives find that traditional monitoring methods are labor-intensive, prone to mistakes, and unsuitable for consistent inspection.

Recent studies have applied to the Internet of Things (IoT) and designed many intelligent systems for mushroom cultivation to provide higher precision monitoring and automation. Some of these solutions are expensive, energy-intensive, and complex for small and medium-scale farmers. Our research presents a low-cost IoT-based system for smart mushroom cultivation that was created and tested using simulation. This system includes environmental sensors, a microcontroller control unit, and automated actuators to keep optimal growth conditions ideal. This prototype uses preset logic to control factors like temperature, humidity, and CO_2 levels, which are continuously monitored and adjusted by actuators. IoT connectivity allows real-time data presentation and remote monitoring, enhancing decision-making while reducing human error and labor. This prototype was simulated to evaluate its functionality and control performance under varying environmental conditions. The results demonstrated effective coordination between the sensing, processing, and actuation units, enabling stable environmental conditions while improving quality, and consistent yield. These outcomes show that the proposed system is a low-cost and scalable solution for small and medium-scale mushroom cultivation. The proposed IoT-based system promotes sustainable farming by combining low cost, automation, and remote monitoring. Through the integration of smart technologies, it enhances mushroom cultivation by maintaining optimal growing conditions.

2. LITERATURE REVIEW

Recent advancements in the Internet of Things (IoT) have significantly improved automation in agricultural practices, particularly in mushroom cultivation. **Chanreng Sey Nhim *et al*.** proposed a smart mushroom cultivation system integrating sensors for temperature, humidity, and CO_2 along with feedback-based control algorithms[1]. The system successfully maintained environmental conditions across different growth stages; however, sensor delays and inconsistent humidity readings required manual intervention, indicating the need for more reliable sensing and control mechanisms. **Novi Azman *et al*.** developed an IoT-based monitoring and control system using NodeMCU ESP8266, incorporating sensors, actuators, and the Blynk mobile application for real-time monitoring [2]. Their system maintained optimal temperature (30–35°C) and humidity (80–90%), reduced labor, and accelerated the harvest cycle. However, the system lacked integration with advanced techniques such as Machine Learning and was not validated for large-scale deployment. **Zhikai Zhou *et al.*** introduced an intelligent environmental monitoring system using LoRa technology and STM32 microcontrollers [3]. The system enabled long-distance, low-power communication and improved environmental control precision. Despite its effectiveness, the study did not explore predictive analytics or scalability under diverse environmental conditions. **R. Manikandan *et al.*** designed an IoT-enabled smart mushroom cultivation system integrated with solar power [4]. The system achieved real-time monitoring and enhanced energy efficiency, making it a cost-effective solution. However, it lacked long-term validation, scalability analysis, and integration of intelligent data-driven optimization techniques. **Ammar A. M. Al-Talib *et al.*** developed an IoT-based smart mushroom cultivation kit for home and urban users using ESP32 and multiple sensors [5]. The system reduced harvest time and improved yield while



maintaining environmental accuracy. Nevertheless, it was limited to small-scale applications and lacked advanced environmental control mechanisms. **W. A. Salim *et al.*** **i**mplemented an IoT-based system integrated with Fuzzy Logic to regulate substrate conditions [6]. The system improved environmental stability and reduced energy consumption compared to conventional methods. However, it lacked adaptive learning capabilities and required further real-world validation. Overall, these studies demonstrate that IoT-based systems enhance mushroom cultivation through automation, real-time monitoring, and improved productivity. However, key challenges remain, including limited scalability, absence of advanced intelligence such as machine learning, insufficient long-term validation, and the need for more accurate and responsive sensing systems.

3. METHODOLOGY

Simulation Framework: Wokwi simulations were used to thoroughly build and evaluate the proposed IoT-based smart mushroom cultivation system. This system aims to monitor and adjust the environmental conditions needed for optimal mushroom growth. Sensing, processing, actuation, and cloud integration are the four interconnected subsystems that make up the modular simulated design. In order to maintain the ideal environmental conditions for mushroom growth, it automatically modifies control parameters in response to simulated sensor feedback. The simulation environment enables the testing of system logic, adaptability, and reliability prior to being implemented in the real world.

A. Sensing Subsystem (Simulation Model)

The sensing subsystem in the simulation uses virtual sensor models that simulate inexpensive and energy-efficient sensing technologies to collect environmental data. The model evaluates the CO_2 concentration, relative humidity, and ambient temperature. These virtual sensors provide continuous environmental monitoring by supplying periodic data samples at predetermined intervals. The simulation model incorporates calibration factors to enhance data stability and reduce measurement variances. The generated data is used as the primary source for decision-making and automated control actions.

B. Processing and Control Unit (Simulation Logic)

In the simulation environment, the processing and control functions are implemented as embedded control logic. Using modular software routines, the system carries out data collection, parameter evaluation, decision-making, actuator triggering, and Internet of Things communication. Predetermined ideal thresholds for mushroom development are continuously compared with detected environmental conditions using a rule-based control algorithm. The control logic produces the proper signals to restore environmental stability when deviations take place. The simulation verifies that this control method is effective in a variety of virtual environments.

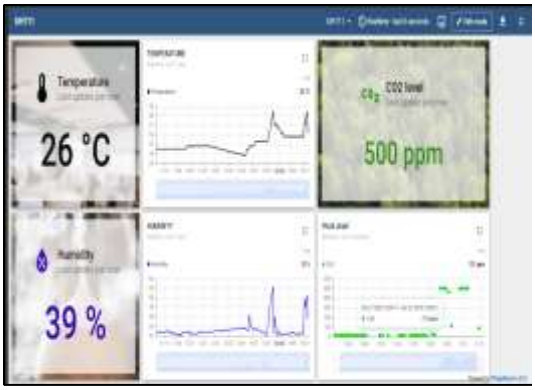
C. Actuation Subsystem (Virtual Control Mechanism)

The simulation uses virtual environmental control elements to represent the actuation subsystem. The system includes a humidity regulation module, an air circulation mechanism for CO_2 control, and a lighting control device to manage illumination cycles.

The control logic triggers the associated virtual actuators when the simulated environmental parameters vary from the intended range. This closed-loop feedback technology allows for autonomous environmental adjustments, resulting in stable growth conditions with minimal human involvement.

D. Cloud Integration and IoT Communication (Simulated)

The ThingSpeak/ThingsBoard platform is used to create the cloud integration subsystem, which allows for remote access, real-time data monitoring, and visualization. Standard IoT communication protocols are used in the simulation environment to send sensor data, including temperature, humidity, and CO2 levels, to the cloud. For ongoing monitoring, the platform offers an intuitive dashboard with graphical displays of environmental information. Additionally, ThingSpeak/ThingsBoard facilitates data logging and analytics, enabling the storing of previous data and trend analysis for improved decision-making. When environmental parameters surpass predetermined thresholds, the system can also produce notifications. Furthermore, by allowing users to transmit commands from the cloud interface back to the system, the simulated arrangement facilitates remote control and guarantees efficient two-way communication. This integration shows that a scalable, cloud-connected smart mushroom farming system with improved automation, monitoring, and data-driven optimization capabilities can be implemented.

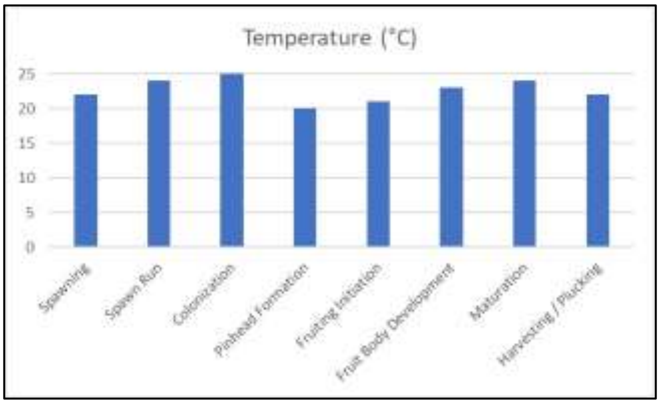


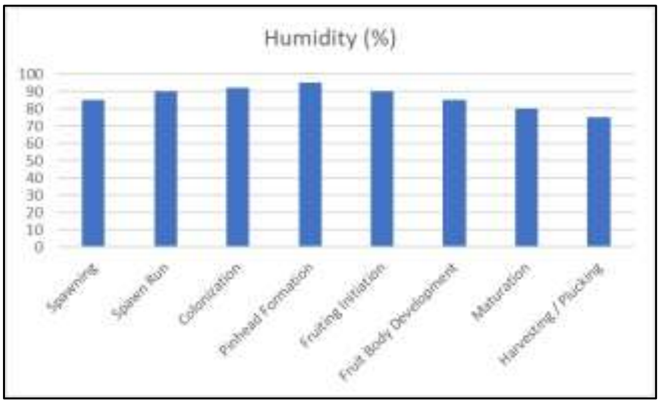
4. EXPERIMENTATION

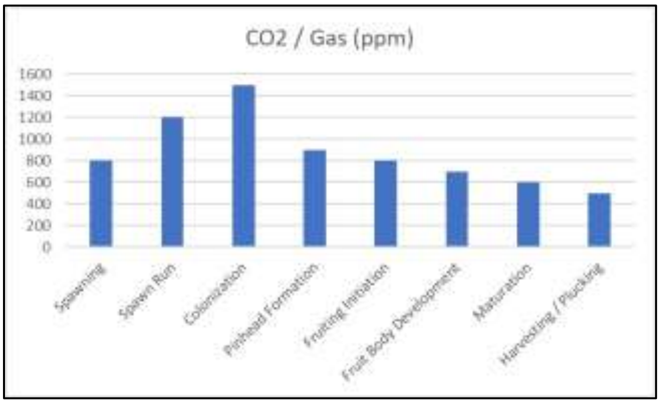
Table -1: Experimental Results of Environmental Control

Stage	Temperature (°C)	Humidity (%)	CO2 / Gas (ppm)
Spawning	22	85	800
Spawn Run	24	90	1200
Colonization	25	92	1500
Pinhead Formation	20	95	900
Fruiting Initiation	21	90	800
Fruit Body Development	23	85	700
Maturation	24	80	600
Harvesting / Plucking	22	75	500

5. **Experimental Result Plots**







6. CONCLUSION

The simulation and implementation of the IoT-based environmental monitoring system for oyster mushroom cultivation were successfully completed. The designed framework effectively integrated both simulation and hardware components to ensure controlled growth conditions throughout the cultivation cycle.

During the simulation phase, key environmental parameters such as temperature, humidity, and CO2 were modeled and analyzed. The simulated results provided a clear understanding of the optimal ranges required for different stages of mushroom growth, including spawning, pinhead formation, and harvesting. Subsequently, the hardware system was developed and tested using appropriate sensors and microcontroller-based interfacing. The real-time data obtained from the hardware setup closely matched the simulated values, validating the accuracy and reliability of the proposed system. The sensors demonstrated consistent performance, and the system responded effectively to environmental variations.

The comparison between simulated and experimental results confirms that the designed framework is robust, scalable, and suitable for practical implementation. The successful alignment of simulated parameters with real-time measurements highlights the effectiveness of the IoT-based approach in precision agriculture. Overall, the system provides an efficient solution for automated monitoring and control of mushroom cultivation environments, leading to improved yield, reduced manual intervention, and enhanced consistency in production.

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