Internet of Things (IoT)-Based with Solar Panel-Powered Wattage Management Environmental Monitoring and Control System for Mushroom Cultivation and Mushroom Yield Production Optimization

Cherry Mae Bunag
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
cherrymae.bunag@tup.edu.ph

Ivy Buscar
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
ivy.buscar@tup.edu.ph

Geuel Darvie Cuevo
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
geueldarvie.cuevo@tup.edu.ph

Jeffrey Equipaje
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
jeffrey.equipaje@tup.edu.ph

Zyrine Lagman
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
zyrine.lagman@tup.edu.ph

Jomer Catipon
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
jomer_catipon@tup.edu.ph

Jessica Velasco
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
jessica_velasco@tup.edu.ph

John Peter Ramos
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
johnpeter_ramos@tup.edu.ph

Elmar Francisco
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
elmar_francisco@tup.edu.ph

Mark Melegrito
Department of Electronics Engineering
Technological University of the Philippines
Manila, Philippines
mark_melegrito@tup.edu.ph

***Abstract* —This study introduces the MushBloom system, a cutting-edge IoT-based solution powered by solar energy, designed to enhance mushroom cultivation in urban agriculture. By incorporating ESP8266 microcontrollers and a suite of sensors, the system continuously monitors and adjusts critical environmental parameters such as temperature, humidity, CO2 levels, and substrate moisture. The solar-powered setup ensures sustainable operation, aligning with modern eco-friendly practices. The findings reveal that the MushBloom system significantly boosts mushroom yields and improves growth characteristics for both button and oyster varieties. Detailed statistical analysis confirms these advantages over traditional methods, highlighting the system's effectiveness and reliability. This innovative approach underscores the potential for integrating advanced technologies in agriculture, promoting sustainability, and meeting the demands of urban farming.**

Keywords—Urban Farming, Urban Agriculture, Internet of Things (IoT), Solar Energy

I. Introduction

Food, essential for sustaining life, should be consistently available in both quality and quantity over extended periods. However, the world, especially humanity, has grappled with food shortages in recent years, resulting in insufficient agricultural production in terms of both quality and quantity. This issue has been exacerbated by factors such as the expanding urban population, climate change, and the depletion of natural resources [1]. With the current global population standing at 7.6 billion and projected to reach 9.2 billion by 2050, there is a consensus that global agricultural production must increase by 60%-70% to meet the heightened food demand [2]. Consequently, urban agriculture is gaining traction due to its potential to mitigate shortages by utilizing unused community spaces and increasing income through local food production [3].

The cultivation of mushrooms in the Philippines dates back to the 19th century. Despite this long history, the Philippines meets just 10% of its local mushroom demand, largely due to a lack of awareness about mushroom farming among Filipinos [4]. Recently, there has been growing interest and potential in the mushroom cultivation market. However, cultivating mushrooms poses challenges, requiring specific conditions and continuous monitoring, despite its environmental benefits in reducing agricultural waste [5]. Mushroom cultivation is gaining popularity, underscoring the significant role that the Internet of Things (IoT) can play in advancing this field and promoting innovation. IoT technology enables farmers to access real-time environmental data, facilitating prompt interventions to address any issues [6]. This technology utilizes sensors and actuators to monitor the necessary environmental conditions for mushroom cultivation and farming.

This research aims to develop an enclosure equipped with an IoT-based monitoring system to oversee and manage the environmental needs of mushrooms. Additionally, it seeks to investigate the growth behavior of mushrooms under optimal environmental conditions. The study will integrate a solar panel to regulate the system's power consumption, emphasizing its eco-friendly nature and significant environmental benefits.

II. Related Works

The incorporation of IoT into agricultural practices is transforming multiple facets of farming, including mushroom cultivation. Numerous studies have investigated various strategies to improve mushroom farming through technological advancements:

Rahman et al. [7] proposed architectural design integrates IoT and machine learning (ML) for smart mushroom farming. This system integrates IoT and ML technologies to offer a comprehensive solution for automating mushroom cultivation. It aims to provide mushroom growers with insights and predictions to optimize their cultivation processes and boost their yield.

Azimi et al. [8] developed an automatic environmental control system to improve mushroom production. This system uses a water dripper and mist device to regulate temperature and humidity effectively.

Chong et al. [9] introduced a new IoT-based system for environmental control and monitoring for mushroom cultivation. They assessed the accuracy of four sensors against respective laboratory instruments and facilitated remote monitoring and control of mushroom growing conditions through mobile and web applications.

Albius et al. [10] designed an automated mushroom cultivation system with remote monitoring and management capabilities, utilizing microcontrollers and IoT-based applications. This system is particularly suited for cultivating white Oyster mushrooms. Their recommendations included improving security, better greenhouse location, adding sensors, and further research on light effects.

Dela Cruz [11] created a mushroom cultivation system using solar power and an automated system, which produced up to 250 grams of mushrooms every other day from a single box. Sterilizing with ultraviolet light and stacking boxes is recommended to increase yield.

III. Methodology

A. Conceptual Framework

Fig. 1 illustrate the overall plan for the enclosure, developing hardware, data processing, and a web and mobile application. It showcases several sensors, such as the MH-Z19C, DHT-22, and the Capacitive Soil Moisture sensor. These sensors collect crucial real-time data necessary for monitoring oyster mushroom growth environments. NODE MCU ESP8266 microcontroller is integrated with these sensors to handle data processing and regulate components such as the Thermoelectric Cooler (TEC1), exhaust fan, humidifier, and LED strip light. Once finished, the system displays real-time environmental parameter values on the Blynk Dashboard through the Blynk app. This setup provides a user-friendly interface for monitoring and maintaining optimal conditions, thereby promoting ideal Oyster mushroom growth.

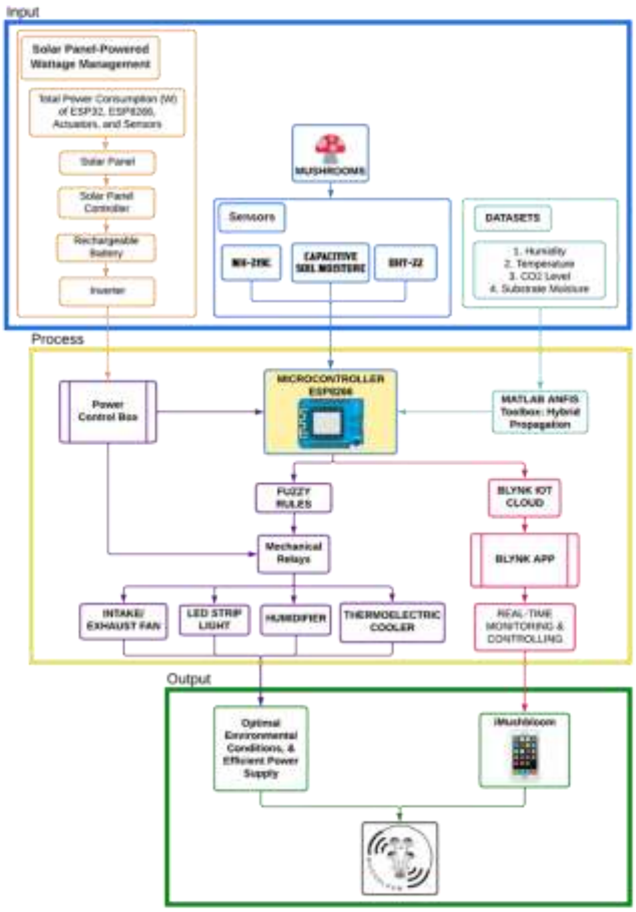

Fig. 1. System Block Diagram

B. Hardware Construction

Fig. 2 illustrates the connection of components within the system of each layer. Each layer includes an LCD display, thermoelectric coolers, exhaust and intake fans, a humidifier, a DHT22 sensor for temperature and humidity, a capacitive soil moisture sensor, an MH-Z19C CO_2 sensor, an ESP8266 microcontroller, and two 4-channel relay switches. All actuators are connected to the relay switches for automation, while the sensors, LCD, and relay switches are connected to the ESP8266 microcontroller for data acquisition and control. The differences in configuration highlight the specific variations in each layer while maintaining a core set of common elements across the system.

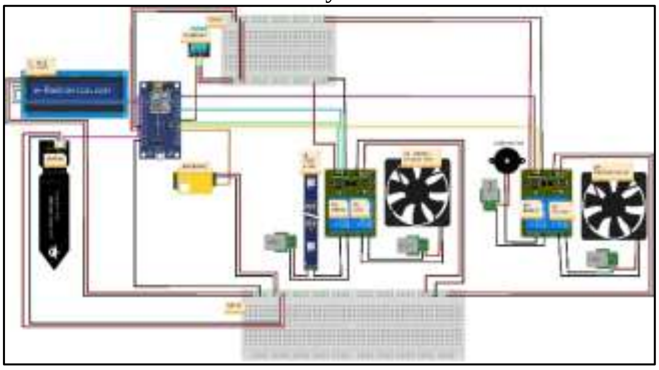

Fig. 2. System Schematic Diagram

IV. Results and Discussion

A. *Statistical Testing*

Compare the MushBloom system's effectiveness and efficiency to conventional methods in increasing mushroom yield, considering the ease of resolving technical issues and the availability of technical support for manual operations. To assess the comparative performance of the traditional and MushBloom systems for each mushroom type, a series of paired T-tests was conducted to analyze various characteristics, including yield, spike count, cap diameter, and stem length.

The analysis results indicated significant differences between each mushroom characteristic's traditional and MushBloom systems. Specifically:

Null Hypothesis (Ho):

There is no statistically significant difference in the specified characteristics between each mushroom variety cultivated in the traditional system compared to the MushBloom system.

Alternative Hypothesis (Ha):

There is a statistically significant difference in the specified characteristics between each mushroom variety cultivated in the traditional system compared to the MushBloom system.

Decisions regarding the acceptance or rejection of the null hypothesis were based on calculating the T-value for each T-test and comparing it against the critical t-value corresponding to the selected significance level (e.g., 0.05)

Table 1 presents the statistical analysis of button mushroom yield for the system's method compared to the conventional method. The analysis indicates that the mean yield of mushrooms from the system's method is significantly higher than that of the conventional method. The computed t-value of 3.66 exceeds the critical t-value of 2.101, leading to the rejection of the null hypothesis.

TABLE I. Comparison of Button Mushroom Yield

	Computed t-value	Critical t-value	Decision	Remarks
MushBloom	3.66	2.101	Reject null	Significant
Conventional				

Table 2 presents the statistical analysis of oyster mushroom yield for the system's method compared to the conventional method. The analysis indicates that the mean yield of mushrooms from the system's method is significantly higher than that of the conventional method. The computed t-value of 2.46 exceeds the critical t-value of 2.101, leading to the rejection of the null hypothesis.

TABLE II. Comparison of Oyster Mushroom Yield

	Computed t-value	Critical t-value	Decision	Remarks
MushBloom	2.46	2.101	Reject null	Significant
Conventional				

B. System Performance Evaluation

Table 3 presents the evaluation results of the prototype's performance in optimizing the mushroom yield production is conducted to reveal its effectiveness across multiple criteria. It demonstrates completeness, correctness, efficiency, and appropriateness in functionality and sustainability, with a mean of 4.48. In terms of reliability, it excels in capacity, availability, ability, sustainability and is highly effective in fault tolerance, with a mean of 3.64. User Friendliness is focused on easiness, learnability, intuitiveness, and operability, with a mean of 4.00. Overall Contribution is highlighted by its effectiveness, user satisfaction, and impact, with a mean of 4.92. Overall, grand mean is 4.24 showcasing the prototype's effectiveness in various aspects potential for practical implementation.

TABLE III. Evaluation of Prototype Performance

Criteria	Weighted Mean	Interpretation
Functionality and Effectiveness	4.48	Very Effective
Reliability	3.64	Effective
User Friendliness	4.00	Effective
Overall Contribution	4.92	Very Effective
Grand Mean	**4.24**	**Very Effective**

**Range of values - 4.21 – 5.00: Very Effective; 3.41 - 4.20: Effective; 2.61 - 3.40: Moderately Effective; 1.81 - 2.60: Ineffective; 1.00 - 1.80: Very Ineffective*

V. Conclusion

The study's findings highlight the remarkable effectiveness of the MushBloom system in optimizing mushroom cultivation. The results indicate that the MushBloom system significantly outperforms conventional methods, showcasing higher yields and improved growth characteristics for both button and oyster mushrooms. Statistical analyses consistently revealed significant improvements, underscoring the practical benefits of this innovative approach. Furthermore, the MushBloom system's integration of IoT technology and solar power demonstrates its commitment to sustainability and efficiency. This system not only proves to be reliable and user-friendly but also aligns with modern agricultural needs by offering a sustainable solution for urban farming. Overall, the MushBloom system exemplifies how technological advancements can be successfully applied to agriculture, paving the way for more productive and eco-friendly farming practices.

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