Development of a Wireless Sensor Network for Oyster Mushroom Environment Monitoring System with Feedback Control Using ANFIS

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***Abstract*— To achieve a fruitful harvest of ouster mushroom, its fruiting phase requires monitoring and maintenance of the environmental factors affecting its growth. This will ensure sustained, larger, and more efficient oyster mushroom production. Despite recent improvements, oyster mushroom farming in our country remains unsatisfactory since the current temperature and humidity preservation method is conventional which is a tedious work. A mushroom environment system automated by using wireless sensor network was designed so that there is control in environmental factors of the oyster mushroom. Factors of production in these systems include temperature, humidity (DHT11), carbon dioxide (MQ-135), and light (TSL-2561). Four actuators are the system's output. The exhaust fan, misting system, LED light, and the thunder-sound speaker comes next. Two data processing algorithms were devised and applied to automate the system. Fuzzy Logic Control (FLC) is programmed using linguistic values. Second, the Adaptive Neuro-Fuzzy Inference System (ANFIS) trains FLC data for output prediction. Last is the conventional method, where proponents monitor and maintain parameters manually. Results show that the system stabilized mushroom house parameters. ANFIS showed faster results in stabilizing and producing harvest than Fuzzy logic control and the uncontrolled technique. Thus, it is a better alternative option.**

Keywords—Oyster Mushroom, Pleurotus ostreatus, Fuzzy Logic Control, ANFIS, ANOVA

I. INTRODUCTION

Agriculture is a major industry in the Philippines and plays a significant role in the economy. Researchers have been studying a new approach to agricultural development with new research methods, including oyster mushroom cultivation. Other tropical countries grow oyster mushrooms in forests. In the Philippines, oyster mushrooms are produced in a mushroom farm or greenhouse for food.

According to the Philippine Statistical Authority, there has only been a 7.18 percent increase in mushroom production in the Philippines from 2019 to 2020, with 671.10MT in 2019 and 721.16MT in 2020. According to Troza, a Department of Agriculture researcher, 90% of mushrooms consumed by Filipinos are imported. Most of the mushrooms consumed were imported from Southeast Asia. Still, only 10% of the total consumed mushrooms are locally cultivated because only 0.5% of Filipinos eat vegetables and mushrooms, according to Food and Nutrition Research Institute (FNRI). Filipinos do not eat mushrooms due to a lack of fresh mushrooms in local markets, causing growers to be dissatisfied and suffer a low return on investments, affecting supply and demand in the market. The Philippines' lowest production volume was 463 metric tons [1]. There are large amounts of agro-industrial waste in the Philippines to produce mushrooms, but the existing crop is diminished because of insufficient authority intelligence and support. Mushrooms have the advantage over other plants because they don't need soil and can be grown from organic waste. Mushroom growing is viable and attractive to rural and peri-urban farmers because no land is needed. After cultivation, the bio-waste substrate can be used as a soil conditioner [2].

II. RELATED STUDIES

Fuzzy Logic-based Controlled Environment for the Production of Oyster Mushroom

In 2019, Amen et al. of MAPUA University developed a study on a Controlled Environment for mushrooms using Fuzzy Logic Based system. This study created a controlled environment with a temperature sensor and humidity sensor utilizing Arduino-Uno Microcontroller using Fuzzy Logic algorithm and integrating sound with Wireless Sensor Network (WSN) to determine the productivity of the oyster mushroom. The researcher used analysis of variance (ANOVA) to determine the productivity of the three treatments. Findings revealed that the desired temperature for growing oyster mushrooms in a controlled environment is 22 to 29ºC, and humidity is 70% and above. The automatic control system and human control were compared. The automated control system possessed more efficiency in controlling humidity than the latter. [6]

An Automated Temperature Control System: A Fuzzy Logic Approach

In 2018, The De Lasalle University of Manila had developed a study using a fuzzy logic approach to monitor and control the temperature inside a Bamboo-style greenhouse for growing lettuce crops. Five digital humidity and temperature sensors were installed inside the chamber to monitor and control the inside air temperature. The readings from five sensors were calibrated and compared to commercially available room temperature. Based on the calibration results, temperature sensors have a 3.75% mean difference only. [7]

On Applications of Wireless Sensor Networks

The main focus of this paper is on practical applications in the trade and possible future use of WSNs. Further advancement in wireless communication technology has resulted in habitat and environmental protection, buildings and property health, oil and gas plant, mines and tunnels, emergency medical services and military applications. [9]

Study on Precise Mushroom Cultivation Based on Feedback Perception

To precise control the planting process and monitor mushroom growth in real time online, the design scheme of the environment monitoring system based on Internet of things was put forward on the main environmental parameters that affect the growth of mushroom and according to the mushroom environment characteristics, the appropriate sensor and sensor placement were chose. By using RS-485 bus technology the information acquisition module, display module, communication interface and control interface monitoring terminal were built up. For the wiring is not conducive to the place in the mushroom room, its environmental information precludes the use of wireless sensor networks. [10]

Fuzzy Logic-based Controlled Environment for the Production of Oyster Mushroom

Mushroom is one of the most promising agricultural products adapting to the market as farmers are benefitted. Presently, the mushroom cultivation is just being executed in a conventional way. In upgrading facilities, mushroom yield can increase through an application of a microcontroller using fuzzy logic algorithm. With all this, the researcher developed a controlled environment with temperature sensor and humidity sensor utilizing Arduino-Uno Microcontroller using Fuzzy Logic algorithm and integrating sound with Wireless Sensor Network (WSN) to determine the productivity of the oyster mushroom. The experimental design and action research serve as a guide in conducting the study. [6]

Wireless sensor network for agricultural environment using raspberry pi-based sensor nodes

Another study was conducted by Carlo N. Cabaccan et al. in growth chamber located in State University Science City of Muñoz Nueva Ecija leads the use of an effective system framework for farming condition monitoring. Various sensors were incorporated for gaining information on three fundamental condition boundaries develop inside the Lettuce (Lactuca Sativa) environmental chamber. The utilization of Raspberry Pi as the primary part in structuring the sensor hubs gives an ideal stage for solid yet minimal effort remote sensors organize the monitoring system. Every sensor hub is outfitted with light, temperature, and humidity sensors for the information procurement of the environment status. A continuous clock was additionally introduced to monitor the current date and time, and a Raspberry Pi load up was utilized for the preparation of the assembled data; the information gained by the sensor hub was remotely sent through Wi-Fi in the base station, which has a database organizer which stores the acquired data by the sensor hubs and a graphical UI that fills in as an observing application for the light, temperature and dampness state of the farming condition**.** [11]

III. METHODOLOGY

*A. **Design System***

The system requires knowledge of Arduino, Raspberry Pi, NodeMCU, C# programming, sensor calibrations (particularly temperature, humidity, and CO_2). The sensor will be able to monitor and maintain the important parameters as shown in Table 1 at their optimal level with the use of Arduino and Raspberry Pi in the system. When it comes to maintaining the environmental parameters of the mushroom home, a dual system comprised of two different actuators will be used. This will be accomplished with two distinct algorithms to process the data. (1) Fuzzy Logic Algorithm and (2) Adaptive Neuro-Fuzzy Inference Algorithm. The measured parameters will be analyzed and transmitted to a database for storage. The measured parameters will be displayed by the system via a web and mobile application.

Table 1. Threshold Values for the Environmental Growth Parameters of Oyster Mushroom

Parameter	Setpoint Value
Temperature	22-29 C°
Humidity	80% - 90%
Light Intensity	500-1000 lux
CO_2 Level	400 - 600 ppm

Table 2. Separate condition to activate thunderstorm sound

Condition	Result
IF Humidity is >80% AND temperature drops from original value into its 60-80% value, speaker will turn on.	Thunder sound will trigger.
Stop IF humidity drops <80% AND if temperature stabilizes to its 60-80% value.	Sound will stop.
Else	Speaker will turn off.

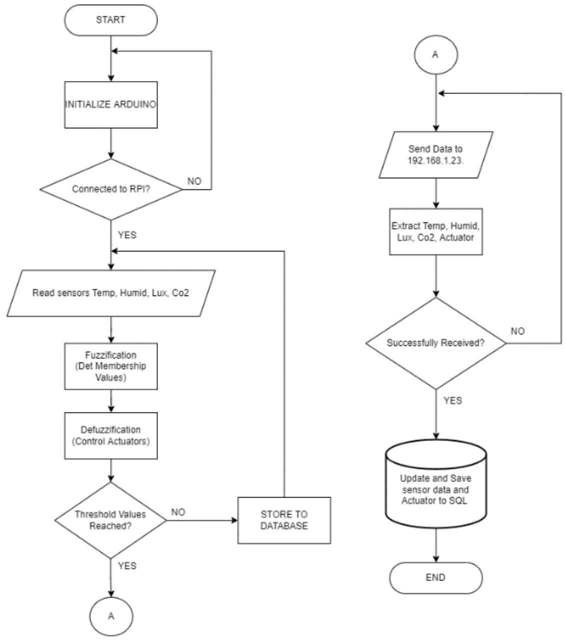

Figure 1. Fuzzy Logic Control System Flowchart Monitoring and Control

The system flowchart for the Fuzzy Logic Control system; it starts by initializing the Arduino and establishing a connection with the Raspberry pi via the same network. Once the connection is established, the Arduino will send the sensor readings temp, humid, lux, and for Fuzzification where the actions are to be determined from the membership values and will proceed with the Defuzzification where the Actuators either activate or not. Once the threshold is met, it will store immediately on the FLC server. Else, it will store data in the database and repeat until it reaches the threshold value

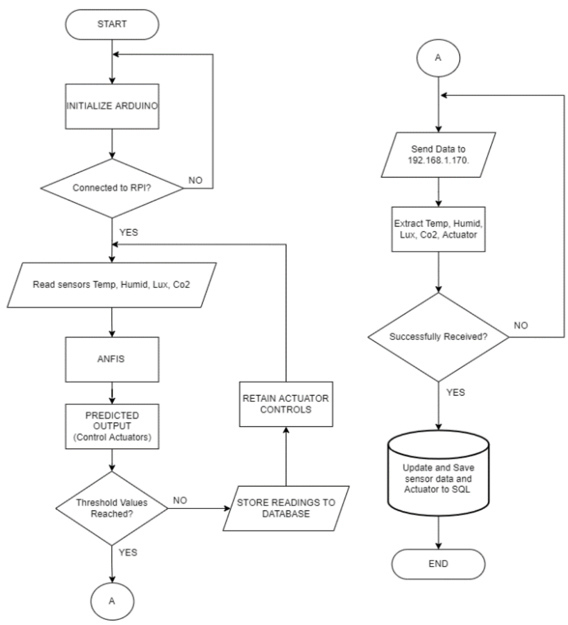

Figure 2. Flowchart of Adaptive Neuro-Fuzzy Inference System

After the training of datasets from Fuzzy logic control, a different microcontroller and computer will be integrated for ANFIS. The output from the predicted values will send a command to activate the actuators. When the threshold values are achieved, it will store the readings and actuator actions in the database. Else, if the threshold values are not met, it will still store data in the database and retain the actuator action until threshold values are achieved.

B. Hardware Design

The proposed set-up of comparison for Feedback controls between FLC and ANFIS method in a Wireless Sensor Network monitoring environment used at least 20 square meter Mushroom growing house and divided into two sections with the same sets of sensors and actuators arranged proportionally to obtain a good response and accurate results.

The Rooms are installed with two rows of iron bars 2.5 meters from each other and a 1-meter distance from a wood frame placed in the middle of the two iron bars, as shown in figure 3. The wood frame holds the electronics hardware of the system, such as the four sets of sensors, microcontrollers, actuators-LED lights, and the Iron bars that carry the Oyster Mushroom fruiting bags. A 55-gallon water barrel is used as the water source for the Misting system. The proponents then installed bidirectional fans above the iron bars to facilitate fresh air exchange and holes at the bottom of the walls with net filters for additional ventilation.

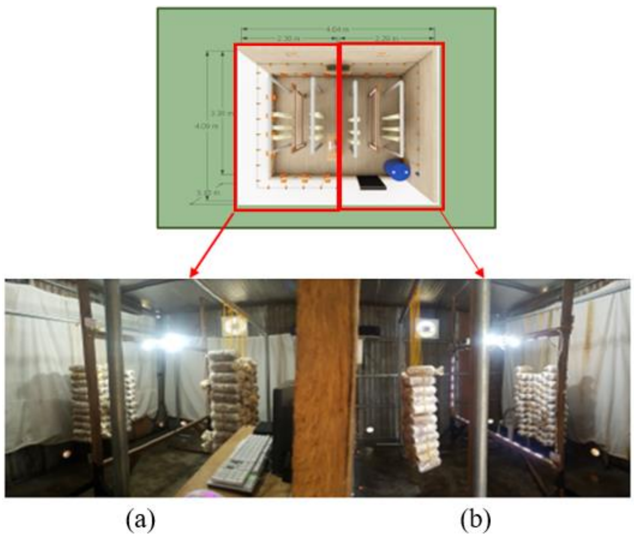

Figure 3. Actual Oyster Mushroom House with Label FLC side

The house is divided into two rooms. As shown in Figure 3, the Left side is for the (a)Adaptive neuro-fuzzy inference system, and the Right side is for (b)Fuzzy logic control system implementation. The entire house is enclosed with cloth and surrounded by a misting system. The Placement of sensors and actuators is proportionally arranged to obtain a good response and accurate results. A 2.5 meters x 2 meters wood frame is used in each room to hold the microcontrollers. The four sets of sensors are mounted in every corner of the wood frame. Each room includes the installation of a sound system and a Bidirectional fan as shown in figure 4.5. All actuators are connected to a 12v relay module and 12DC power supply.

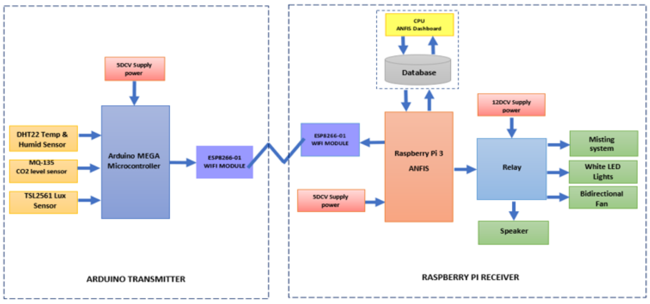

Figure 4. Block Diagram of the System

Figure 4 shows the block diagram of the research prototype. It consists of two systems. The first system is tasked to monitor the environment of the mushroom house and sends data to the second system. The second system corrects the environmental parameters such as temperature, humidity, Carbon Dioxide, and luminosity of the mushroom house based on the averaged data from the Arduino and sensors. The Arduino microcontroller is the transmitter, and the Raspberry Pi is the receiver, where an ESP8266 Wi-Fi module acts as a communication medium. Four sensor sets (DHT22, MQ-135, and TSL2561) are connected directly to the Arduino Mega 2560, powered by a 5V DC power supply. The data received is processed by the Raspberry Pi Receiver, linked to the misting system, white LED strips, and bidirectional exhaust fan. A CPU will act as database storage for monitoring the status of the whole mushroom house setup. Under special conditions, a speaker system will initialize when a triggering value has reached a certain threshold.

C. Calibration Data

To ensure that the sensors provided are in good working condition, they will be calibrated using industry-grade sensors. Table 3 shows that data will be collected three times a day until actual sensor and industrial-grade sensor and instrument values are practically identical for five consecutive days. Figure 3.14 shows the industrial-grade sensors used to calibrate the study's sensor modules. The proponents calibrated only the MQ135 sensor to match the industrial-grade CO2 sensor. The DHT22 and lux sensor are automatically calibrated when placed on the mushroom housing. It also shows the oyster mushroom house's calibration.

Date and Time	Industrial Grade Sensor Readings				Actual Sensors Readings			
	Temperature (deg C)	Humidity (%)	CO2 Level (ppm)	Lux (lux)	Temperature (deg C)	Humidity (%)	CO2 Level (ppm)	Lux (lux)
2021-04-03T03:00:06	32.711	60.22	161.353	305.92	31.1	61.87	151	322.25
2021-04-03T07:00:25	32.155	65.72	141.623	345.35	33.5	64.97	147	327.5
2021-04-03T11:00:07	31.988	65.73	142.009	281.99	35.3	65.33	148	284.5
2021-04-03T15:00:35	31.988	69.22	146.756	252.23	30.3	56.57	142	221.75
2021-04-03T19:00:19	32.711	63.22	144.323	407.86	31.58	45.5	141	424.25
2022-04-03T23:00:33	32.988	65.72	145.442	359.99	33.5	63.05	135	380.5

Figure 5. Calibration Data

D. Conventional Farming for Uncontrolled Set-up

In addition to the two systems, the proponents created a standard setup for the operation. The conventional farming room is in the same area in Pasong Buaya II, Imus Cavite, as the mushroom house. The room's environment is maintained every three hours, which depends on the parameters at the time of the monitoring that the proponents perform. Every parameter is listed whenever the proponent observes the mushroom chamber. The average harvested mass acquired from the room is gathered for comparison with the two different configurations.

IV. TESTING AND DATA ANALYSIS

A. Readings of Enviromental Parameters

Figures 6 to 9 show the daily average readings of the environmental parameters inside the mushroom house and the conventional farming room. The temperature ranges from 28 to 32 degrees Celsius, close enough to the upper limit of the ideal setting for the temperature at 29 °C. The data gathering started during the dry season. Based on the history of measurement readings from Imus Cavite from the world-weather report, the average temperature from April to August 2021 ranges from 30 to 33 degrees Celsius. This still shows that the monitoring and control system is working and viable for oyster mushroom cultivation. For the humidity, it ranges from 90% and above, compared to the range of 75% to 87% from last April to August 2021. The CO2 level and lux readings inside the mushroom house are maintained in ideal condition.

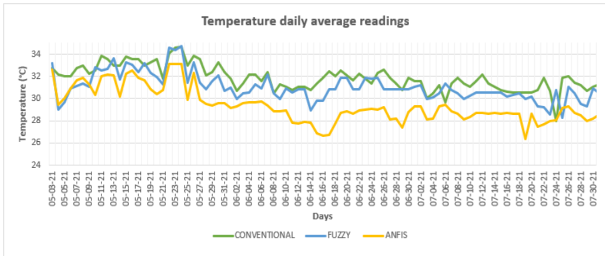

Figure 6. Temperature daily average reading

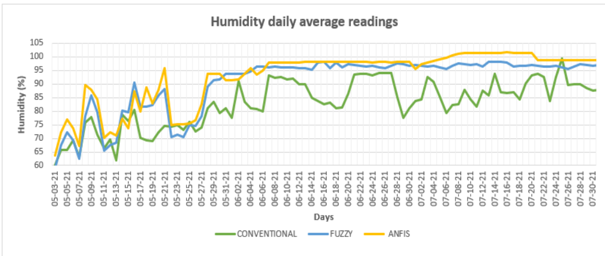

Figure 7. Humidity daily average reading

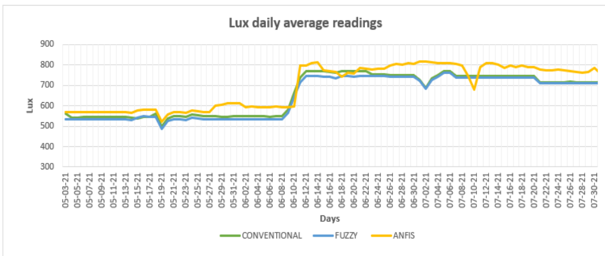

Figure 8. Lux daily average reading

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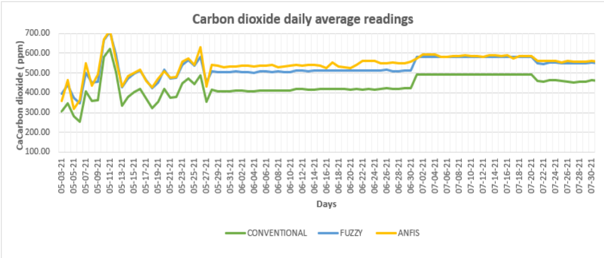

Figure 9. Carbon dioxide daily average reading

B. Data Harvest Evaluation

The harvesting for three setups occurred every day from May through July. Figure 4.25 illustrates the harvesting of mushrooms from a fruiting bag and the following weighing of the total mass of the gathered mushrooms. The information the proponents acquired will be listed as a table for quantitative comparison between the three different configurations.

Figure 10 (a) Proponent Harvesting Oyster Mushroom (b) Measuring Mass of the Harvested Oyster Mushroom

Figures 11 and 12 show the Bar graph of the production of Oyster mushrooms in three methods. ANFIS produced a total of 43,652 grams, the Fuzzy logic method had 36379 grams, and the Conventional way was 17378 grams. ANFIS method produced an 86.10% increase in Oyster mushroom production than the conventional method and an 18.18% increase from the Fuzzy logic control method.

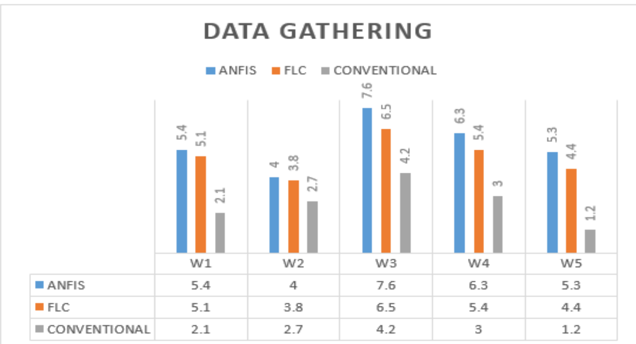

Figure 11. Week 1 to Week 5 Data Harvested Bar graph

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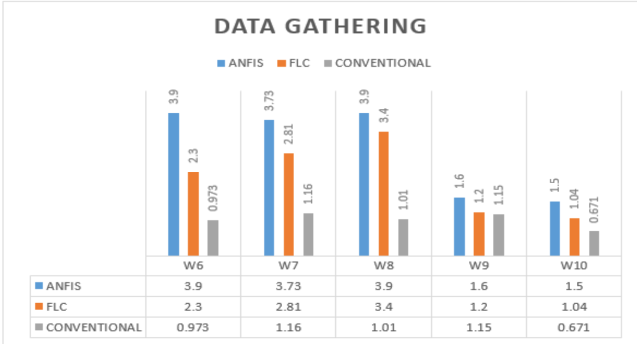

Figure 12. Week 6 to Week 10 Data Harvested Bar graph

C. Statistical Analysis

The Analysis of Variance (ANOVA) is used to statistically treated the collected data parameters to assess the significant difference between the three methods used in growing of Oyster mushrooms. Table 4, 5,6, and 7 Shows the summary of the analysis for Temperature, Humidity, Lux, and Carbon dioxide with an alpha level of 0.05. The F-statistical value is 136.9919 for Temperature, Humidity has an F-statistical value of 42.6641, The Lux has an F-statistical value of 8.35189, and Carbon dioxide has an F-statistical value of 145.014. All the F-statistical values of each parameter are greater than the F-critical value of 3.02123. Hence, the null hypothesis for Temperatures, Humidity, Lux, and Carbon dioxides of each method is rejected because of the extremely unlikely sample relationship, and the Alternative hypothesis is accepted.

Table 4 Summary of analysis using ANOVA for Temperature

Groups	*No. of Data*	*Sum*	*Average*	*Variance*
FUZZY	119	3668.905	30.83113	1.431431
ANFIS	119	3485.106	29.28661	1.906939
CONVENTIONAL	119	3792.45	31.86933	1.063104

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	401.9773673	2	200.9887	136.9919	8.64394E-45	3.021227
Within Groups	519.3738575	354	1.467158			
Total	921.3512248	356				

H_{01} : Mean of three methods (ANFIS, FLC, and Uncontrolled) are equal

H_{a1} : Mean of three methods (ANFIS, FLC, and Uncontrolled) are not equal

Table 5. Summary of analysis using ANOVA for Humidity

Groups	*No. of Data*	*Sum*	*Average*	*Variance*
FUZZY	119	10953.8	92.0485	89.7204
ANFIS	119	11195.8	94.0821	81.6496
CONVENTIONAL	119	9992.13	83.9675	68.1471

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6812.51403	2	3406.26	42.6641	2.5114E-17	3.02123
Within Groups	28263.012	354	79.839			
Total	35075.5261	356				

H_{01} : Mean of three methods (ANFIS, FLC, and Uncontrolled) are equal

H_{a1} : Mean of three methods (ANFIS, FLC, and Uncontrolled) are not equal

Table 6. Summary of analysis using ANOVA for Lux

Groups	*No. of Data*	*Sum*	*Average*	*Variance*
FUZZY	119	79056.3	664.339	8218.41
ANFIS	119	84564.3	710.624	8923.2
CONVENTIONAL	119	80292.2	674.725	8070.44

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	140378.829	2	70189.4	8.35189	0.00029	3.02123
Within Groups	2975022.56	354	8404.02			
Total	3115401.39	356				

H_{01}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are equal
H_{a1}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are not equal

Table 7. Summary of analysis using ANOVA for CO_2

Groups	*No. of Data*	*Sum*	*Average*	*Variance*
FUZZY	119	63486.5	533.5	2580.01
ANFIS	119	65351.7	549.174	2831.59
CONVENTIONAL	119	52630.9	442.276	2792.3

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	793117.7842	2	396559	145.014	9.9434E-47	3.02123
Within Groups	968059.9275	354	2734.63			
Total	1761177.712	356				

H_{01}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are equal
H_{a1}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are not equal

Table 8. Summary of analysis using ANOVA for Harvest

Groups	*Count*	*Sum*	*Average*	*Variance*
ANFIS	36	33111	919.75	296775.9
FLC	36	27096	752.6667	233398.5
CONVENTIONAL	36	15397	427.6944	113094.5

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4507709.46	2	2253855	10.51126	6.90098E-05	3.082852
Within Groups	22514410.4	105	214423			
Total	27022119.9	107				

H_{01}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are equal
H_{a1}: Mean of three methods (ANFIS, FLC, and Uncontrolled) are not equal

V. Conclusion

The proponents were able to construct an environmental growth chamber using temperature, humidity, lux, and co2 sensors, as well as actuators such as exhaust fans, misting systems, LED lighting, and speakers. They were interconnected by the microcontrollers Arduino and raspberry pi and the Wi-Fi module.

This system is integrated using Arduino and C# programming, where the program created can monitor, control, and regulate the specific threshold parameters for mushroom development. Based on the graphs of the regulated system's daily average temperature, humidity, CO, and lux of the controlled system, it is evident that the mushroom oyster house is indeed controlling and maintaining the set parameters into its threshold values compared to the uncontrolled system.

Lastly, the mean mass of the harvested mushroom in the controlled and uncontrolled systems was gathered and compared to test and evaluate the study. Based on the average harvest per day and throughout the project duration, the average mass of ANFIS set-up is 4.3 kg, which is much more efficient compared to Fuzzy Logic control with 3.6 kg average mass and uncontrolled set-up with 1.7 kg average mass. To further verify this, the proponents used ANOVA analysis that also says that there is a significant difference between the harvested mass of the controlled and uncontrolled.

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