Neuro-fuzzy humidity control for white oyster mushroom in a closed plant production system

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Abstract. Oyster mushrooms grow optimally in relative humidity of 80-90%. As a tropical country, Indonesia is very suitable for oyster mushroom cultivation, but relative humidity must be controlled. The usual effort is ineffective by spraying water to mushroom inside kumbung (mushroom cultivation building) every morning and evening. A building called a Closed Plant Production System (CPPS) equipped with a control system needs to be developed as a solution. The purpose of this study was to design and do a performance test of a neuro-fuzzy based relative humidity control system inside CPPS for white oyster mushroom (Pleurotus ostreatus) cultivation. The main components consist of Arduino Mega 2560 microcontroller, SHT11 sensor, and diaphragm pump connects with mist nozzle as an actuator. The performance test was carried out by running neuro-fuzzy based control system and giving disturbance inside CPPS room. As a result, this control system was able to reach a steady-state condition within 5 minutes. The highest relative humidity error was 0.73%, and the lowest error was 0.09%—the recovery rate of relative humidity inside CPPS when disturbed was 2.25% per minute.

1. Introduction
White oyster mushroom is one type of horticultural product known as a functional food. The advantages of oyster mushrooms do not contain cholesterol and lots of fiber to prevent the onset of high blood pressure, heart disease and reduce weight [1,2]. The nutritional content is quite a lot in white oyster mushrooms is protein, which is 3.5-4% (wb) [3].

Kumbung is a special house built to be used for cultivating consumption mushrooms and serves to protect the mushroom growing media (baglog) from rainwater and other unwanted contaminants of fungal spores. The mushroom kumbung can be adjusted using certain materials and constructions to resemble the original conditions in the mushroom growing environment [4]. However, mushroom farmers face obstacles in controlling the temperature and humidity of the mushroom kumbung daily. The usual effort is considered less practical, namely using a sprayer that is sprayed on the mushroom kumbung every morning and evening. Another drawback with this method is that if the temperature and humidity conditions fluctuate throughout the day, such as at the change of seasons, it is not enough to just spray with a sprayer every morning and evening. Fluctuations in temperature and humidity become very high, and this causes crop yields to be disrupted. So that a building with the term Closed Plant Production System (CPPS) needs to be developed as a solution and replace the conventional oyster mushroom kumbung. CPPS can relatively create the conditions required of a high-sustainability system.
for the production of functional plants such as leaf vegetables, medicinal plants, and transplants, for which CPPS is superior to greenhouses.

Oyster mushroom is the easiest to cultivate compared to other mushrooms. It is the most tolerant/weather resistant (can grow in various seasons), the most productive, can grow in various media, high productivity yields, and can be built with small capital. Oyster mushrooms grow optimally in a temperature range of 28-30°C and 80-90% humidity. So in terms of temperature conditions, Indonesia, as a tropical country with an average temperature of 25-32°C, is very suitable for oyster mushroom cultivation. Still, humidity must be controlled so that moisture can be fulfilled optimally [5]. Research that has been done [6] showed the advantages of neuro-fuzzy logic are as follows: (1) improves fuzzy if-then rules to describe complex system behavior; (2) does not require prior human expertise, which is often required in fuzzy systems, and may not always be available; (3) presents a wider selection of membership functions to use; (4) produces a speedy convergence time.

In other research, a prototype design of an automatic control system of temperature and humidity for oyster mushroom cultivation based on fuzzy logic has been developed [7]. The results of the automated control system of temperature and humidity generated by the system can reach a steady state within 5 minutes. With the highest temperature error of 3.70% and the lowest error of 0.89%, the highest humidity error is 0.78%, and the lowest error is 0.11%. The fuzzy system developed in other research [8] can control the essential parameters in a custom-built pilot-scale indoor aeroponics model designed for lettuce (Lactuca sativa), such as temperature, relative humidity, and light intensity with high accuracy. It was observed that the errors for relative humidity were maintained at less than ±5% from the setpoint were relatively high. Other research determined the fuzzy value of temperature control and humidity of plant factory that converted to PWM (Pulse Width Modulation) by primary data collection, the formation of fuzzy sets, the basis of fuzzy rules, defuzzification, and conversion of defuzzification to PWM [9]. The PWM output value at the temperature and humidity control is 628.8515 with a setpoint of temperature is 28°C and humidity is 75%. Fuzzy approximation method compared to the other, Tsukamoto fuzzy methods are very appropriate for temperature and humidity control. It is simple and the value is easily adjustable. Control of temperature and humidity are very sensitive and easy to change the value.

In this study, the purposes were to build CPPS building equipped with neuro-fuzzy humidity control systems and to know the effectiveness of a neuro-fuzzy humidity control system for white oyster mushroom cultivation in CPPS compared with Fuzzy humidity control system. The effectiveness of that control system was tested by running it inside the CPPS room within 60 minutes and tested by running it, then gave disturbance for 15 minutes by opening the door and all windows.

2. Materials and methods
Some of the important materials in this research were Arduino IDE software for programming coding programs, Arduino Mega 2560 microcontroller as the brain of the control system, motor driver (TLP521&IRF540) as water pump RPM regulator, SHT11 sensor for measuring relative humidity condition inside cultivation room, mist nozzle for spraying water mist to the white oyster mushroom baglog, a diaphragm water pump for pumping water to the mist nozzle, white oyster mushroom as the object of research, baglog as a growing medium for white oyster mushrooms, galvanized hollow iron as baglog racks and window frames, light bricks as a wall of CPPS, and water as a source of the mist that sprayed by mist nozzles.

This research was conducted in two stages. The first stage was making a structural design (building) of a CPPS as a cultivation room for white oyster mushrooms. In addition to installing a functional design, a series of humidity actuators consisted of the diaphragm pump and a mist nozzle set. The second stage was making an electrical design, which consisted of made control system hardware including a humidity control system assembled in an electronic box, installing neuro-fuzzy logic-based software coding on Arduino Mega 2560, and ran a neuro-fuzzy based was compared with Fuzzy based humidity control system testing and a humidity control system that was given a disturbance testing. The overall
research time of the two research stages was carried out within 4 months, starting from April 2021 to June 2021.

3. Results and discussion

3.1. Design of closed plant production system equipped with neuro-fuzzy-based relative humidity control system

The first stage was making a structural design (building) CPPS as a cultivation room for white oyster mushrooms. This first stage was established in the form shown in Figure 1. The dimensions of this CPPS building are length×width×height of the front side×height of the backside (3.5×2×2.75×3.25m). The walls are made of lightweight brick reinforced with cement, sand, and fly ash and coated with a leak-proof coating on the outside, aiming to prevent water vapor from evaporating out. The roof was made of corrugated asbestos, which is also coated with leak-proof paint on the outside. The door was made of PVC, and the windows were made of polycarbonate. The roof frames were made of C-channel galvalume, and the baglog racks were made of galvanized. The ground floors were made of a mixture of cement and sand. The purpose of these frames and shelves was to have a long service life and were hygienic for oyster mushroom cultivation because it was not like the use of wood/bamboo for shelves and the use of the ground floor in conventional mushroom kumbung. CPPS room were equipped with a humidity actuator from the control system in the form of a diaphragm pump and mist nozzle where the action of the actuator depends on the reading value from the SHT11 sensor in the CPPS room (Figure 2). It would be processed according to the neuro-fuzzy based coding program installed on the microcontroller assembled in the control box.

![Figure 1](image1.png)

**Figure 1.** Close Plant Production System (CPPS) building.

![Figure 2](image2.png)

**Figure 2.** Relative humidity actuators of the control system and its components in the CPPS are (a) diaphragm pump, (b) mist nozzles, (c) white oyster mushroom baglogs, (d) galvanized racks, and (e) SHT11 sensors.

![Figure 3](image3.png)

**Figure 3.** Box of electrical components of relative humidity control system.

![Figure 4](image4.png)

**Figure 4.** The electrical circuit of the control box consists of (a) 20×4 LCD, (b) motor drivers, (c) Arduino Mega 2560 microcontroller, (d) control buttons, and (e) RTC.
Meanwhile, inside the different room, a control box (Figure 3) had the electrical design of control systems with critical components such as those found in Figure 4. The entire electrical circuit in the control box was powered by an AC/DC power supply with an AC input voltage of 100-245 Volts at 60 Hz and an output DC voltage of 12 Volts with a resistance of 5A. The cultivation room at this CPPS had a capacity of ±2000 white oyster mushroom baglogs with a tube length of 20cm and a diameter of 10cm. However, in the control system test conducted in this study, only 500 baglogs were filled.

3.2. Automatic humidity control system schematic closed plant production system

The initial step of the second stage was making an electrical design which consisted of made control system hardware which included a humidity control system assembled in an electronic box and installing neuro-fuzzy logic-based software coding on Arduino Mega 2560. A neuro-fuzzy-based system was compared with a fuzzy-based humidity control system testing and a humidity control system that was given a disturbance testing in the next procedure. Arduino Mega 2560 microcontroller was connected to all components. Arduino Mega 2560 was the controller's brain to control the humidity actuator components in the form of a diaphragm water pump and mist nozzle and provides output data displayed by the LCD from the results of processing input data sent by the SHT11 sensor. The component that was given the humidity actuator command was the motor driver (TLP521 and IRF540), which would provide a Pulse Width Modulation (PWM) signal according to the neuro-fuzzy logic coding program that installed on the ArduinoMega 2560 microcontroller (Figure 5).

![Block diagram of humidity control system on CPPS](image)

**Figure 5.** Block diagram of humidity control system on CPPS.

The control system action in the CPPS was the motor driver of TLP521, and IRF540 would be ordered according to the results and fuzzy logic to the actuator. This actuator would execute the command called by the diaphragm water pump delivered water to the mist nozzle set, which would automatically spray water mist in the form of spraying water mist on the white oyster mushroom baglog. The actual data showed in LCD contains degrees of temperature and percentages of humidity inside CPPS. The schematic humidity control system can be seen in Figure 6.
3.3. Control system testing

It can be seen in Figure 7 and the calculations that the system with fuzzy logic can reach a steady-state within 5 minutes. Meanwhile, from the calculation, the highest humidity error value of 2.08% and the lowest error of 0.21%. This error was still within the tolerance limits of the system specifications, with a maximum steady-state error of 5% for the upper error and 2.5% for the lower error. This test was carried out with the humidity around the environment outside the CPPS of 60%. While in Figure 8 and the calculations, it can be concluded that the system with the neuro-fuzzy logic can reach a steady-state within 5 minutes. While the calculation of the above can be deduced for error steady-state is divided into two, namely the value of the humidity error a high of 0.73% and error lowest at 0.09%. This error is still within the tolerance limits of the system specifications, with a maximum steady-state error of 5% for the upper error and 2.5% for the lower error. This test was carried out with the humidity around the environment outside the CPPS of 60%. So, we can conclude that the neuro-fuzzy humidity control system was better than Fuzzy from the highest and lowest error value. In another paper, a comparison of implementation methods between zero order Sugeno-fuzzy logic controller and feed forward Neural Network (NN) in operation to control the temperature and humidity of oyster mushroom cultivation problem in lowlands based on microcontroller [10]. It can be seen from the results of the testing tool that compares the response time of the application of fuzzy logic and Neural Network application method concerning the value of the initial temperature and humidity. The result shows that NN is more optimal and effective with the average response time for conditioning the ideal humidity was 113.4 seconds from 5 times of repetition.
Calculation of steady-state error (fuzzy)

\[ h_{\text{average}} = \frac{h_{\text{total}}}{n} \]

\[ h_{\text{average}} = \frac{5110.96}{60} = 85.18\% \]

Range \( E_{ss} = 85\% + (2.5\% \times 85.18\%) = 85\% + 2.13\% \)

Range \( E_{ss} = 85\% - (2.5\% \times 85.18\%) = 85\% - 2.13\% \)

Highest Error = \( \frac{85-86.77}{85} \times 100\% = 2.08\% \)

Lowest Error = \( \frac{85-85.18}{85} \times 100\% = 0.21\% \)

Calculation of steady-state error (neuro-fuzzy)

\[ h_{\text{average}} = \frac{h_{\text{total}}}{n} \]

\[ h_{\text{average}} = \frac{5081.34}{60} = 84.69\% \]

Range \( E_{ss} = 85\% + (2.5\% \times 84.69\%) = 85\% + 2.12\% \)

Range \( E_{ss} = 85\% - (2.5\% \times 84.69\%) = 85\% - 2.12\% \)

Range \( E_{ss} = 82.88\% \) until 87.12\%

Highest Error = \( \frac{85-85.62}{85} \times 100\% = 0.73\% \)

Lowest Error = \( \frac{85-84.92}{85} \times 100\% = 0.09\% \)

3.4 Disturbed control system testing

Figure 9 shows that the system with fuzzy logic can overcome the disturbance. The disturbance given by opening all windows and doors for 15 minutes caused the humidity in the CPPS room to decrease by 9%. The recovery time required for the system to return to steady-state was 5 minutes, so this system's humidity recovery speed was 1.8% per minute. It had reached the target by a control system that was expected because of the speed of relative humidity recovery very quickly and accurately. Meanwhile, Figure 10 showed the system with neuro-fuzzy logic can overcome the disturbance. The disturbance given by opening all windows and doors for 15 minutes caused the humidity in the CPPS room to decrease by 9%. The recovery time required for the system to return to steady-state was 4 minutes, so this system's humidity recovery speed was 2.25% per minute. The expected control system achieved the target because the humidity recovery speed was very fast and accurate. Other investigators applied step changes in disturbances of different controller types for temperature and humidity loop (PDF, fuzzy, ANFIS, and GA-based ANFIS) [11]. The Root Mean Square Error (RMSE) as defined was computed for the process outputs for each individual controller for the first 300 min of operation. RMSE value of fuzzy was 2.390E-04, and ANFIS was 6.556E-02.

Figure 7. Response to humidity readings on a fuzzy-based control system.

Figure 8. Response to humidity readings on a neuro-fuzzy-based control system.
Figure 9. Responses of relative humidity values to the disturbed control system (fuzzy).

Figure 10. Responses of relative humidity values to the disturbed control system (neuro-fuzzy).

4. Conclusion
A CPPS design equipped with a humidity control system based on neuro-fuzzy logic for white oyster mushroom cultivation had been successfully developed. The results of the neuro-fuzzy based humidity control system carried out in this study reached steady-state conditions within 5 minutes, with the highest error humidity of 0.73% and the lowest error of 0.09%. The humidity recovery rate in the CPPS room when disturbed was 2.25% per minute. These results were better than the fuzzy-based humidity control system used as a comparison in this study which can reach steady-state conditions within 5 minutes, with the highest error humidity of 2.08% and the lowest error of 0.21%. The humidity recovery rate in the CPPS room when disturbed was 1.8 % per minute.

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