Design Evaluation of Microcontroller–Driven Temperature, Humidity and Soil Moisture Control System for the Cultivation of *Pleurotus Florida* Mushroom in a Controlled–Environment Plant Box

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Abstract: The study focused on maintaining the optimal growing temperature, humidity and soil moisture conditions of the *Pleurotus Florida* mushroom contained in a 730 × 510 × 430 mm controlled environment box. The design of the temperature and humidity control mechanism, driven with an estimated first– and second–order transfer function and an on–off control algorithm, is composed of a microcontroller device connected to a DHT22 temperature sensor, a heating lamp, a humidifier, and a cooling fan. The soil moisture control mechanism, driven by its own estimated first– and second–order transfer function and an alternating switching control algorithm, is comprised of the same microcontroller inter–connected between an SEN0193 capacitive soil moisture sensor, and a water sprinkler. At an ambient temperature of 33.4°C, the system was able to increase or decrease (by approximately 4°C) the temperature of the plant box to 27.5°C. At an ambient humidity of 56%, the proposed device was able to reach the 94% relative humidity of the plant box within the duration of about five minutes. This response was observed to have taken place between 11:00am to 3:00pm, and the plant box material took 13 minutes to cool down. The actual maximum increase that the humidifier can achieve is as high as 29% relative humidity. This response took about 5 minutes using the on–off algorithm and has incurred a root–mean–square error of 6.241×10^{-5} or an equivalent 1.0489°C in a 30–minute stabilization duration. Considering a sampling interval of 12 microseconds, the rise time from 10% to 90% of the steady state value was observed to be at 485 microseconds with ±2% overshoot for the first–order approximation and 1,200 microseconds with 2.84% overshoot for the second–order approximation. The final prediction errors of the estimated transfer functions are 1.96×10^{-3} and 7.819×10^{-5} for the first– and second–order approximation respectively. Hence, the desired levels for temperature, humidity and soil moisture for optimal production of the said mushroom cultivated in a controlled–environment box can be simultaneously obtained by these results.

Key Words: *Pleurotus Florida* mushroom; temperature and humidity control; soil moisture control; controlled–environment plant box.

1. INTRODUCTION

Edible mushrooms have been known to contain high amounts of antioxidants that prevent causes of rapid ageing and degenerative diseases (Barros et al, 2007). They have become an integrative part of functional food diets and are considered sources of development of drugs due to their antioxidant properties.

One known species of these edible mushrooms is the *Pleurotus*: *P. florida* Singer, *P. pulmonarius* Quel, and *P. citrinopileatus* Singer (Khatun et al, 2014). These are grown throughout the year in India and are interests of research for their protein and cholesterol content, and antioxidant properties.

Survival and multiplication of mushrooms can be related to the following intrinsic factors such as soil substrate composition, nitrogen source, ratio of carbon to nitrogen, pH level of substance, soil moisture, minerals present in soil, soil particle size, levels of spawning, and surfactant, and also to the following extrinsic factors such as temperature (heat treatment and temperature of culture house), humidity, luminosity, air composition, and envase (Belletini et al, 2016).

The paper focused on the study of growing *P. florida* mushrooms located in Central Luzon of the Philippines. A device installed in a controlled–environment plant box is composed of a microcontroller that facilitates a closed feedback control system that is designed to maintain the ambient temperature, desired humidity and appropriate soil moisture inside the box at optimal growing conditions for a maximum production of the said mushrooms.

2. METHODOLOGY

The proposed design of the controlled–environment plant box (see mushroom box in Figure 1) is made up of plastic with dimensions 730 × 510 × 430 mm. The temperature control system installed in the box for the cultivation of *Pleurotus florida* contained an Arduino Uno R3, DHT22 temperature and humidity sensor (pinout shown in Figure 2a), a soil moisture sensor SEN0193 (pinout in Figure 2b), a heating lamp, a cooling fan (Figure 3a), a humidifier, , and a water sprinkler (Figure 3c). The Oyster mushroom (*Pleurotus florida*) is planted into a substrate, which is the saw dust. The setting of the experimentation will occur in Manila only, where the average temperature is 30°C.

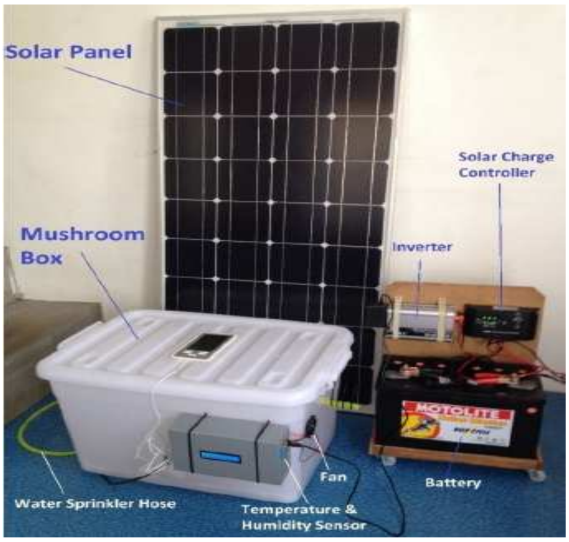


Figure 1. The complete setup for the controlled environment plant box

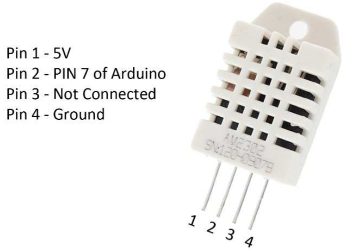


Figure 2a. The DHT22 Temperature & Humidity Sensor

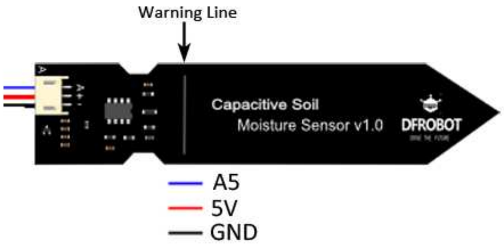


Figure 2b. The SEN0193 Soil Moisture Sensor

According to the book entitled *Small-Scale Mushroom Cultivation* (Oei et al, 2005), the temperature that would give the highest yield for the *P. florida* mushroom ranges from 24°C to 30°C; the desired humidity that would give the maximum production for the *P. florida* mushroom spans from 80% to 90% relative humidity; and the corresponding substrate moisture that would give the optimal yield for the *P. florida* mushroom spans from 60% to 65% soil moisture.

Figure 4a through 4c show the functional diagram of the system for each parameter controlled. The general control loop block diagram is shown in Figure 5, where *SP* is the set point, *PV* is the measured process variable, and e is the error between the two. The specific control system model for the heating and cooling (Figure 6) are then established from the general diagram, (where *TT* is the sensor data and *TC* is the control data). This would be the basis for the control system function that would be estimated to achieve the desired conditions of the growing temperature inside the box.

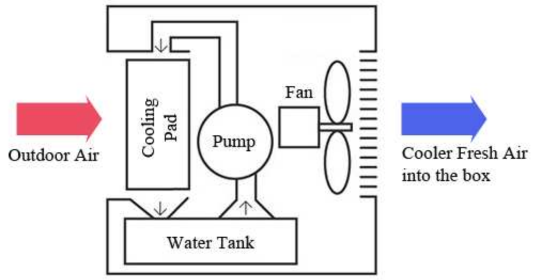


Figure 3a. The Cooling System

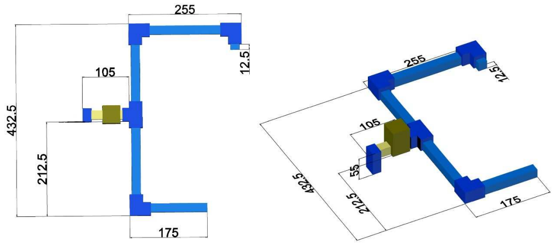
The algorithms are then translated to their respective flowcharts (Figure 7, 8, and 9) where the detailed feedback control function of the system is shown. The function of the system continually checks the temperature of the box and alternately switches on and off if the reading becomes above or below the desired range. This implies that for as long as the reading goes beyond (greater or less than) the accepted range, the activated device remains switched on but it turns off each time it crosses the desired value.

The actual data gathered from the results of the system test would be compared to the theoretical results of the simulation using the same estimated control transfer function. The statistical validation used is the root-mean-square error formula:

$$RMSE = \sqrt{\frac{\sum (x_a - x_t)^2}{n}} \qquad \text{(Eq. 1)}$$

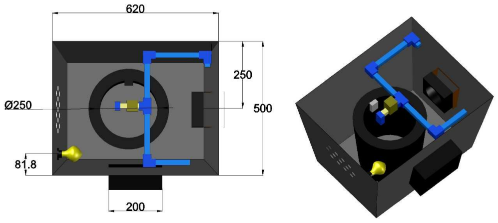
where

x_a = actual data points
x_t = simulated (theoretical values)
n = total number of points



Top View Isometric View

Figure 3b. The Piping System (units in mm)



Top View Isometric View

Figure 3c. Humidifier Assembly (units in mm)

The study made use of bag mushroom cultivation. (Figure 10) The spawning bags can only give yield through a small opening atop the sealed bags. These bags are then arranged inside a basket, cut in height to fit the storage bag, fixed inside the storage box by screws. The basket is an ordinary laundry basket with medium sized rectangular holes around and drilled with holes at the bottom. The said holes are intended for water drainage if or when there is water overrun during watering by the system.

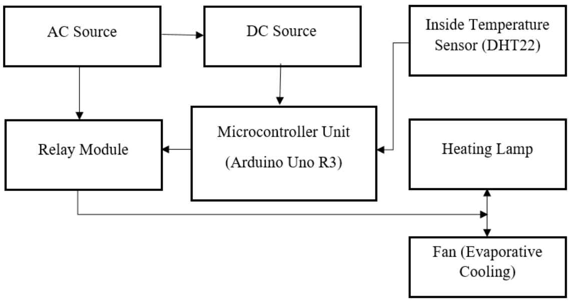


Figure 4a. Temperature Functional Block Diagram

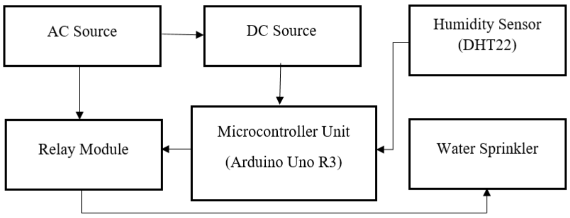


Figure 4b. Humidity Functional Block Diagram

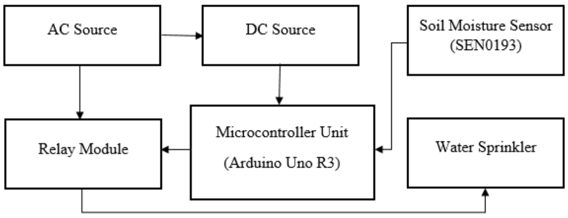


Figure 4c. Soil Moisture Functional Block Diagram

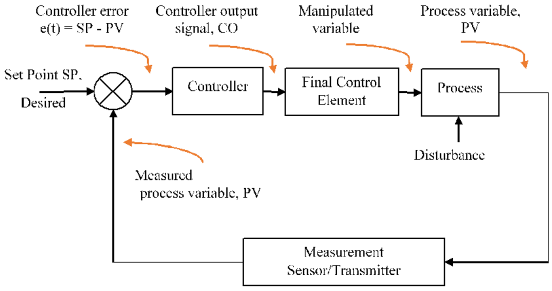


Figure 5. General Control Loop Block Diagram

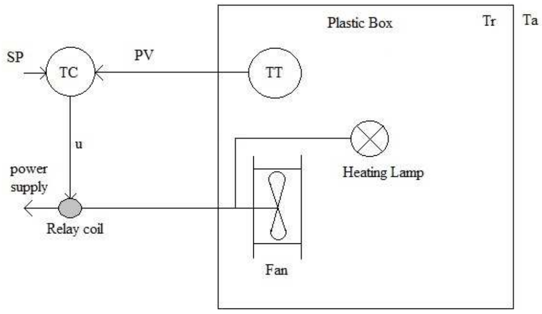


Figure 6. Box Temperature Control Model (Heating and Cooling)

3. RESULTS AND DISCUSSION

3.1 Temperature Control

At 33.4°C ambient temperature, actual testing was done and data were collected. To validate the gathered measured readings, an estimation of the control transfer functions must be implemented. The system identification of MatLab® was used to generate an estimate of the linear time-invariant (LTI) control system transfer function based on the results generated after testing the prototype. After 20 iterations and using 2,000 sample points, the following transfer function models were estimated:

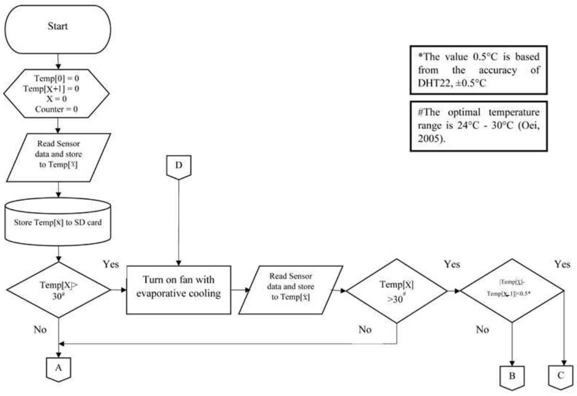
$$X(s) = \frac{0.253s + 0.005206}{s + 0.005222} \qquad \text{(Eq. 2)}$$

$$X(s) = \frac{0.01493s + 8.016\times10^{-5}}{s^2 + 0.02784s + 8.001\times10^{-5}} \qquad \text{(Eq. 3)}$$

where Eq. 2 and Eq. 3 are the first- and second-order approximations, respectively. The step responses are then shown in the following Figures 12 and 13.

The actual measured output is then graphed simultaneously with the first- and second-order to observe the differences in behavior (Figure 13). The resulting root-mean-square-error for both approximations is 4.715×10^{-4} for the first-order and 6.241×10^{-5} for the second-order approximation.

Figure 14 shows the observed difference between the actual and theoretical responses.

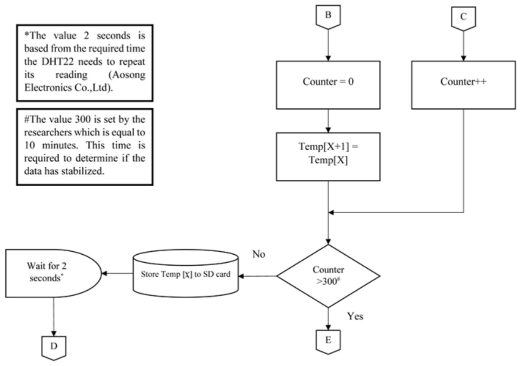


*The value 0.5°C is based from the accuracy of DHT22, ±0.5°C

#The optimal temperature range is 24°C - 30°C (Oei, 2005).

Note: This system flowchart is based from the actual response obtained by the researchers.

Figure 7a. Process Flowchart of the Algorithm



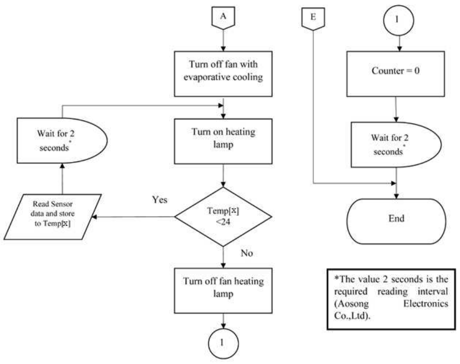
*The value 2 seconds is based from the required time the DHT22 needs to repeat its reading (Aosong Electronics Co.,Ltd).

#The value 300 is set by the researchers which is equal to 10 minutes. This time is required to determine if the data has stabilized.

Note: This system flowchart is based from the actual response obtained by the researchers.

Figure 7b. Process Flowchart of the Temperature Control Algorithm

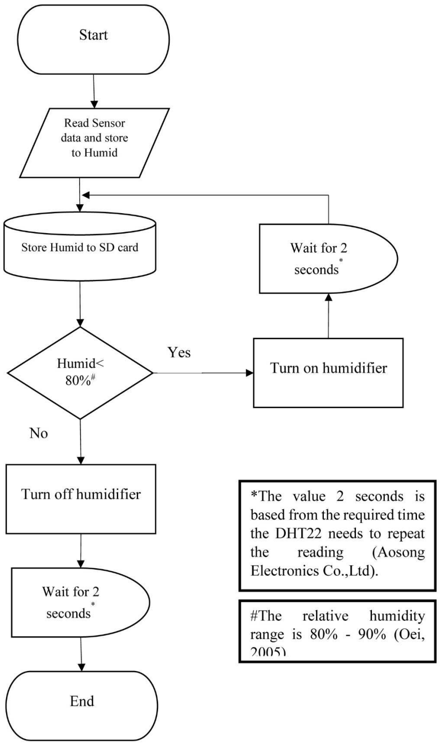
Temperature steady-state can be achieved within 5 minutes based on the actual alternating activation-deactivation of the control system, shown in a 30-minute observation duration. Since the loop function in the algorithm is set to 10 minutes, as the only allowed time for the mushrooms to be immersed under undesirable temperatures, the achieved output has been reached with half the time allotted.



*The value 2 seconds is the required reading interval (Aosong Electronics Co.,Ltd).

Note: This system flowchart is based from the actual response obtained by the researchers.

Figure 7c. Process Flowchart of the Temperature Control Algorithm



*The value 2 seconds is based from the required time the DHT22 needs to repeat the reading (Aosong Electronics Co.,Ltd).

#The relative humidity range is 80% - 90% (Oei, 2005)

Figure 8. Process Flowchart of the Humidity Control Algorithm

3.2 Humidity Control

With an ambient 56% humidity, actual experimentation was done and humidity inside the box was measured. A sample data of humidity between 3:02pm and 4:02pm is shown in Figure 15. The respective switching graph of the humidifier is superimposed on the same sample humidity reading is shown in Figure 16.

As observed on Figure 17, the prototype has successfully maintained the relative humidity (black line) between 80% and 90% when the ambient relative humidity is 65% (green line). Between 3:02 pm and 4:02 pm, the humidifier turned on 5 times (blue line) with the first occurrence at 3:02 pm, second occurrence at 3:14 pm, third occurrence at 3:17 pm, fourth occurrence at 3:37 pm and the last occurrence at 3:49 pm.

The second and third occurrences (see Figure 16) show how effective the humidifier is. Once the sensor reading reached 85%, the humidifier will turn on, averaging for only 2 seconds, resulting to the increase in relative humidity by about 2% - 5%. Stability of the humidification control system is then shown in Figure 17, between 1:25pm to 1:58pm of another afternoon in February 2017.

3.3 Soil Moisture Control

The actual experimentation was done and substrate moisture inside the box was measured. The sample data gathered was used in the linear time-invariant (LTI) toolbox in Matlab® to estimate the transfer function. Hence, the best estimate is

$$X(s) = \frac{446.5s + 2.154\times10^{-7}}{s^2 + 7051s + 2.208\times10^{-7}} \qquad \text{(Eq. 4)}$$

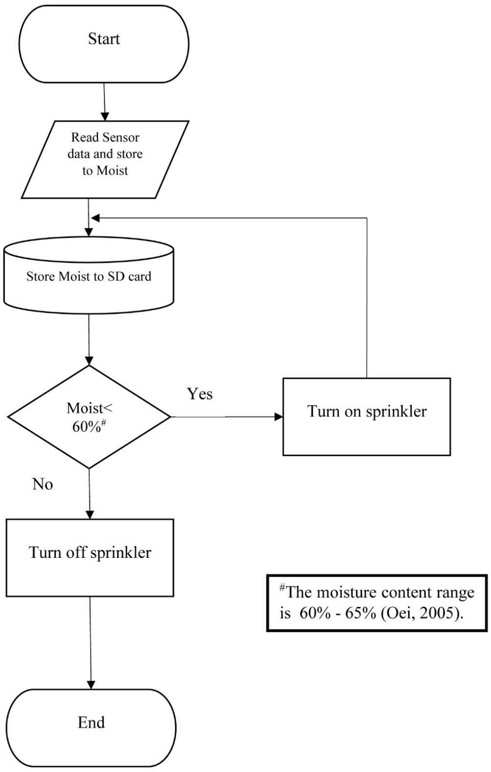


Figure 9. Process Flowchart of the Soil Moisture Control Algorithm

Figure 10. Bag Culture of Mushrooms

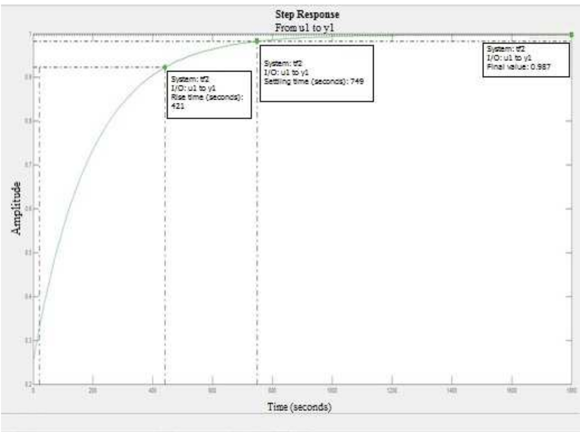


Figure 11. Step Response of the 1st Order Function

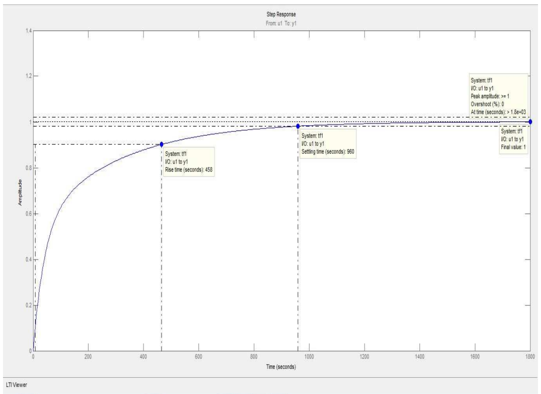


Figure 12. Step Response of the 2nd Order Function

This estimated transfer function is then graphed as shown in Figure 18. The respective first- and second-order estimations against the actual measured data is superimposed in Figure 19.

The rise time, which is the time required for the step response to rise from 10% to 90% of the steady state value, is observed to be 485 microseconds for the first order estimation. The settling time, which is the time required for the system step response to settle to within ±2% of the steady state value, is 1200 microseconds for the second order estimation with 2.84% overshoot at 993 microseconds. However, this estimation has a steady-state value of only 97.5%

The researchers presented the second order estimated transfer because it is closer to the input-output time domain data. First, this is supported by the 97.47% 'fit to estimation data' unlike the 87.10% 'fit to estimation data' of the first order transfer function, and second, the final prediction error (FPE) of the second order estimation, which is 0.00007819, is much smaller compared to the FPE of the first order estimation which is 0.00196. To have a better perception of the results, the researchers overlaid the first order and second order transfer function with the raw output time domain data of SEN0193 and is shown on Figure 20.

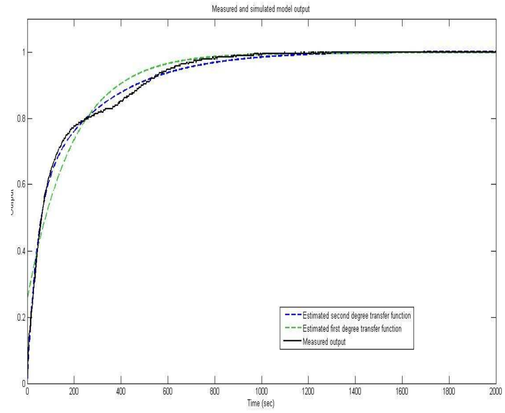


Figure 13. Measured and Simulated Output Models

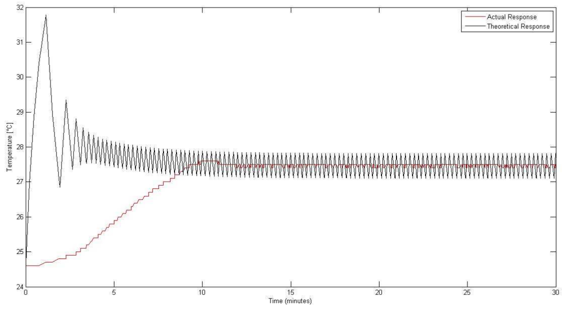


Figure 14. Actual vs. Theoretical Response

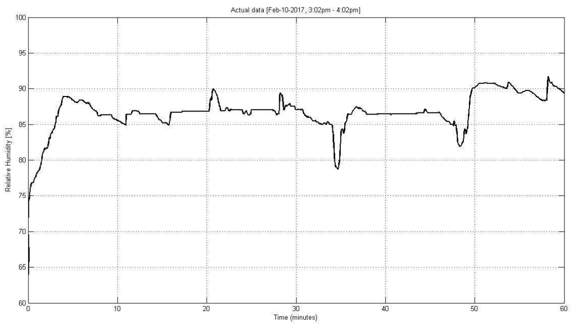


Figure 15. Sample data in an afternoon of February

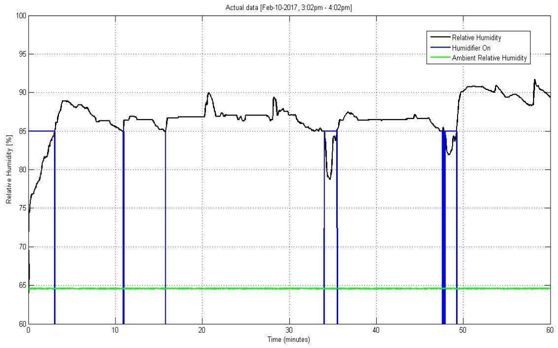


Figure 16. Sample data switching graph of humidifier

4. CONCLUSIONS

With an ambient temperature of 33.4°C, the proposed temperature control system for the cultivation of *P. florida* mushroom was able to fluctuate (by approximately 4°C) the temperature of the plant box to 27.5°C. Such response took about 5 minutes through the on–off algorithm and has incurred a root–mean–square error of as low as 6.241×10^{-5} or equivalently 1.0489°C for the second-order transfer function estimation in a 30–minute observation window.

At 56% ambient humidity, the proposed humidity control system was able to reach the 94% relative humidity of the plant box within approximately 5 minutes. The response was observed to have taken place between 11:00am to 3:00pm, and the controlled-environment plant box material took about 13 minutes to cool down. The actual largest humidity increase that the humidifier can achieve is as high as 29% relative humidity.

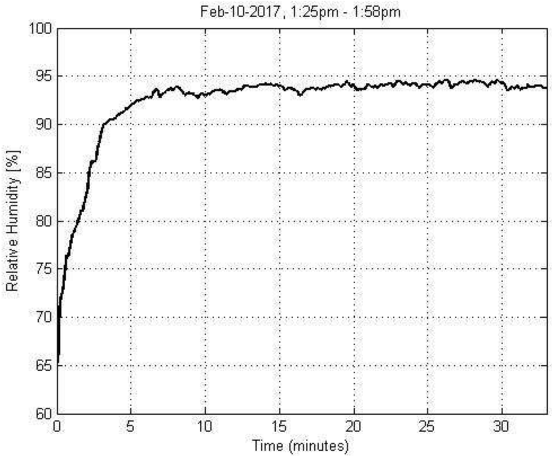


Figure 17. Humidifier response graph

Sampled at an interval of 12 microseconds, the rise time from 10% to 90% of the soil moisture steady state value was obtained at 485 microseconds with ±2% overshoot for the first–order estimated transfer function and 1,200 microseconds with 2.84% overshoot for the second–order estimated transfer function. The final prediction errors (FPE) of the estimated transfer functions are 1.96×10^{-3} and 7.819×10^{-5} for the first– and second–order approximation respectively.

Therefore, the optimal temperature, humidity, and soil moisture content for maximum production of the said mushroom grown in a controlled–environment box can be preferably described by the estimated second–order control transfer function as shown by the findings presented. The system has proven to be effective in achieving these results. However, actual differences in harvest quality of the mushrooms grown inside the box against those cultivated outside are yet to be tested.

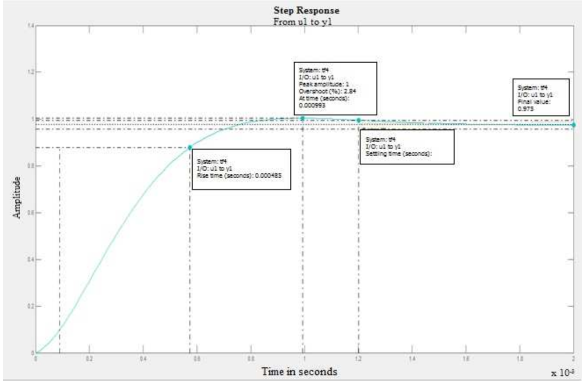


Figure 18. Second order estimated transfer function

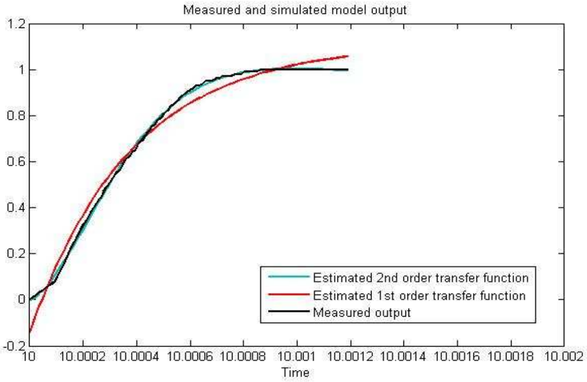


Figure 19. Sample data switching graph of humidifier

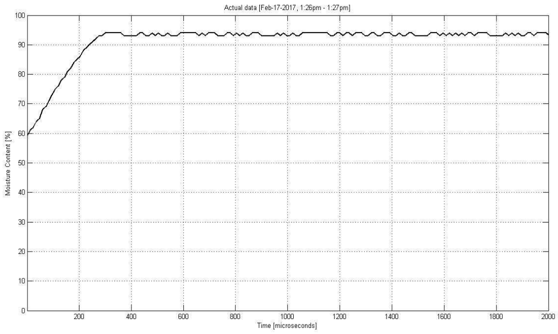


Figure 20. Sample soil moisture response graph

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