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Comparison Between Fuzzy Logic and PID Controllers in Temperature Control of Laboratory Incubator

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ABSTRACT: Incubators are very essential equipment that finds wide application in the fields of medical Laboratory and microbiological research organization. This is because Incubator monitors and maintains conducive environment that is suitable for culturing, or growing of micro bacterial and enzymes, for the purpose of clinical diagnoses in Health centres, or process development in manufacturing industries. In this paper, a transfer function model for an incubator was developed upon which a designed Fuzzy logic controller acts to control the incubator Temperature, by computing appropriate Voltage. A PID (Proportional Integral Derivative) controller was also designed and tested on the same model. Findings were that the fuzzy logic controller tracked the optimum Temperatures for culturing of Mesophilic and thermophilic bacterial at 37 ^{0}C and 54.94 ^{0}C respectively. In comparison with the Fuzzy logic controller, the PID controller tracked at 37 ^{0}C and 55 ^{0}C for the two selected set points. In addition, the fuzzy logic controller gave faster rise time (3.30 mS, 3.45 mS and 13.72 mS) and settling time (1.60 mS, 2.04 mS and 5.55 mS) as compared to PID controller which presented longer rise time (53.61 mS, 53.68 mS and 53.62) and settling time (254 mS, 336 mS and 345 mS) for the given set points respectively.

Keywords: PID Controller, Fuzzy logic Controller, Incubator, Mesophilic bacteria, Moderate Thermophilic bacteria, Temperature control.

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1. INTRODUCTION

Temperature control is a cardinal issue that affects human living as well as micro-bacterial survival in their natural habitation. Temperature is an essential physical quantity that is found in most application of home appliances, scientific laboratories equipment and industrial processes. It is the major control parameter in the procedure of industrial manufacturing all over the world [1]. Electrical appliances such as laboratory incubators need their temperature to be controlled accurately within a desired range. The main issue in every temperature control strategy is to monitor and maintain temperature status of a device or facility [2].

There are many types of bacteria in existence; however, this paper centred on monitoring and maintaining temperature range for culturing Mesophilic and thermophilic (moderate) bacteria considering the dominantly warm climate in this part of the World, which favours the survival, and multiplication of these classes, and their resulting economic importance to human existence.

Mesophilic bacteria is a class of bacteria whose growth temperature range from 20^{0}C to 45^{0}C with optimal temperature of 37^{0}C [3][4]. They thrive in moderate temperature (same as human body temperature) hence they are responsible for most human infections[5]. Depending on their growth temperatures range, thermophilic organisms have been arbitrarily divided into three classes: Moderate thermophiles, with optimal growth temperature between 45-65 °C; Extreme thermophiles which grow between 65-90 °C; and Hyper thermophiles, that grow optimally at temperatures over 90 °C [6]. Thermophilic bacterial are those bacterial whose growth temperature range from 45^{0}C to 85^{0}C with optimal temperature at 55^{0}C [3]. Only moderate thermophilic bacteria class is considered in this paper.

2. SYSTEM DESCRIPTION

Basically, a temperature control system comprises of heating element, a controller, a driver (actuator), signal conditioner (amplifier) signal detector (sensor), signal indicator (display), and the environment whose temperature is to be controlled. In this work, the environment whose temperature is to be controlled is an incubator which can be used in Laboratories for the purpose of culturing bacterial, or for preservation of specimen. Figure 1 present a simple block diagram of an incubator temperature control system using fuzzy logic controller.

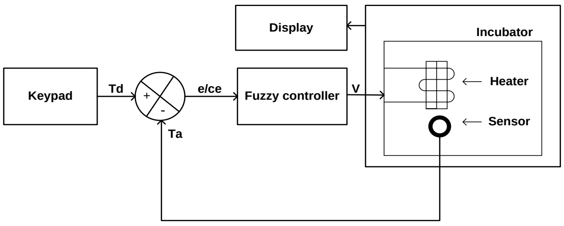


Figure 1. Simplified block diagram of a Temperature control system

The heater element is a major component of the incubator because it produces the heat which is distributed into the incubator by convectional flow of the air molecules within the incubator chamber. Desired temperature (Td) is inputted through the keypad, and the display show both the desired (Td) and the Actual temperature (Ta). The fuzzy logic controller simply takes in error (e), and change in error (ce) as an input variable; and then make use of the fuzzy set to modify the temperature. If the actual temperature is less than the desired temperature, the controller compute voltage which is the control signal, so as to increase or reduce the temperature to the required set point. The sensor, which is usually placed inside the incubator, picks up the actual temperature in the incubator and feed this value back to the comparator. The comparator computes the error, and the change in error, which is again given to the controller to act in a manner that will balance any offset by sending the appropriate signal that will correct the error, and ultimately drive the system's process (incubator temperature) to the desired set point, or as close as possible.

3. SYSTEM MODELLING

The heating system is modelled as a first order plus dead time (FOPDT) system, similar to the model presented by [7]. The general equation representing FOPDT is given in equation (1):

$$G(s) = \frac{Ke^{-\theta s}}{Ts+1} \qquad (1)$$

Where G(s) is the transfer function of the system, K is the process gain, θ is the delay and T the time constant.

The process model was obtained as shown in equation 2.

$$G(s) = \frac{7.72}{15.78s+1} \qquad (2)$$

Equation (2) is the transfer function model, representing the heating system in the incubator, where 7.72 is the process gain, 15.78 seconds is the time constant, and the dead time of 2.6 seconds.

4. DESIGN OF FUZZY LOGIC CONTROLLER

Design of a fuzzy controller involves Fuzzification process, the knowledge base, which is the combination of the data base and the rule base, and Defuzzification of the output of the controller. The fuzzy controller shown in Figure 2 accepts error E as the input variable. This input is fuzzified in accordance with the membership function that is provided in the data base. The controller then applies the rules in the data base; and selects the ones that are applicable as a consequent to the antecedent under consideration at a time. The result, which is the consequent of the rules so fired, is reshaped by the application of appropriate implication method. The result of the implication process is then aggregated and fuzzified into a single crisp value corresponding to the control action acting on the gain of the heater to either reduce or increase the temperature of the incubator.

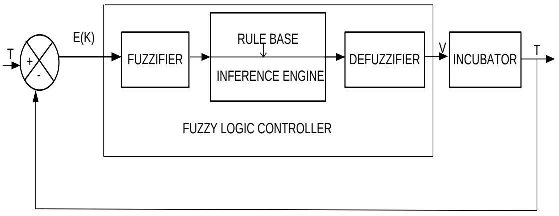


Figure 2. Fuzzy logic Controller in a closed loop syste

4.1 Fuzzification

Fuzzification is the process of converting crisp values of process variables into fuzzy sets. Figure 3 show the membership function for the Fuzzification of input variable to the fuzzy controller, which is Error.

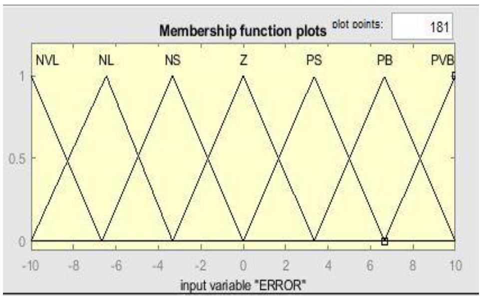


Figure 3. Input membership function ERROR

4.2 Data base

The data base is a store which provides relevant information that enables the controller to perform an operation. It contain input variables, output variables, the universe of discourse for each variable, the demarcation of the universe of discourse into sub sets or fuzzy sets with or without overlap and the membership function assigned to each fuzzy set. the output variable is assigned seven (7) linguistic terms, each representing a membership function as follows: Very- Very Small (VVS), Very Small (VS), Small (S), Moderate (M), Big (BG), Very Big (VBG), Very-Very big (VVBG) within domains [-39.97 24.85], [24 96], [66.85 128.2], [87.44 163], [120 197.1], [154 231.5], and [197.2 277.3] respectively.

The universe of discourse for error is between [-10 10]; and has seven (7) membership functions in domains represented as [-13.334 -6.66], [-10 -3.332], [-6.666 0], [-3.33 3.348], [0 6.654], [3.348 10], and [6.654 13.37]; carrying linguistic variables as: Negative Very-Large (NVL), Negative Large (NL), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Large (PL) and Positive Very Large (PVL) respectively.

Figure 4 present the output membership function for the fuzzy logic controller.

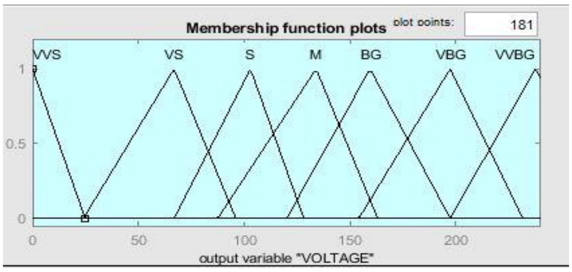
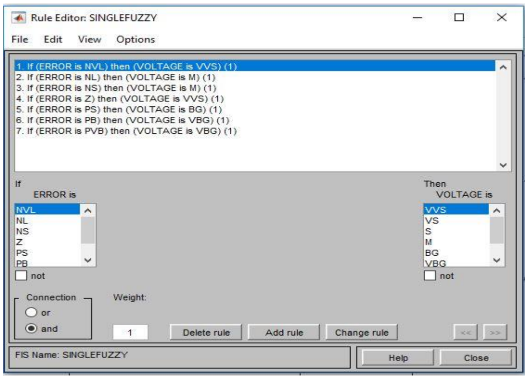


Figure 4. Output membership function

4.3 Rule base

In the operation of the fuzzy controller, the IF THEN rules are used to represent the antecedent and the consequent part respectively. The rules that govern the action of the fuzzy controller are presented in Figure 5.



1. If (ERROR is NVL) then (VOLTAGE is VVS) (1)
2. If (ERROR is NL) then (VOLTAGE is M) (1)
3. If (ERROR is NS) then (VOLTAGE is M) (1)
4. If (ERROR is Z) then (VOLTAGE is VVS) (1)
5. If (ERROR is PS) then (VOLTAGE is BG) (1)
6. If (ERROR is PB) then (VOLTAGE is VBG) (1)
7. If (ERROR is PVB) then (VOLTAGE is VBG) (1)

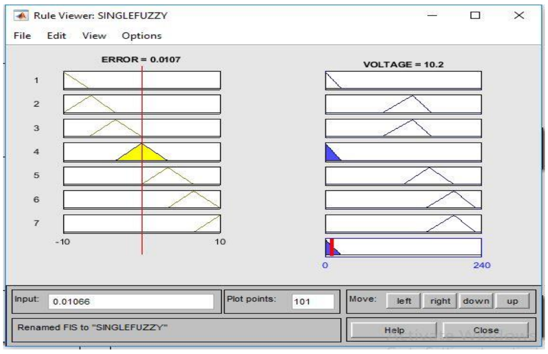
Weight: 1

FIS Name: SINGLEFUZZY

Figure 5. Fuzzy controller rules

4.4 Fuzzy inference engine

The task of the inference engine is to combine the fuzzy IF THEN rules for mapping the set N from the controller input space U to a fuzzy set B’ in the controller output space V using the production rules and the knowledge base of membership function (Ajit, 2012). Figure 6 show the rule aggregation.



ERROR = 0.0107

VOLTAGE = 10.2

Input: 0.01066

Plot points: 101

Renamed FIS to "SINGLEFUZZY"

Figure 6. Fuzzy controller rules aggregation

4.5 Defuzzification method

This is a process by which all the aggregated fuzzy sets are transferred into a single crisp value necessary for the control action to take place.

Equation (3) describes the method of Defuzzification used.

$$Dfz\_V = \frac{\sum_{i=1}^{k} Ai \times xi}{\sum_{i=1}^{k} Ai} \qquad (3)$$

Where x i is a running point in a discrete universe of discourse and *Ai* is its membership value in the membership function.

The Simulink model for the fuzzy controller is presented in Figure 7.

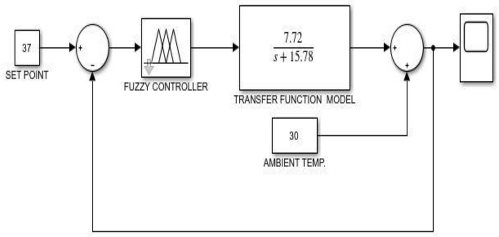


Figure 7. Simulink Block model of the Fuzzy controller

4.6 Design of PID Controller

The design of the PID controller was done using the Ziegler- Nichols rules for tuning PID controllers. Ziegler and Nichols proposed rules for determining values of the proportional gain Kp, integral gain Ki and derivative gain Kd based on the transient response characteristics of a given plant [8]. The determination of these gains is referred to as tuning. Based on the rules the PID controller gains were obtained as shown in Figure 8. The tuned parameters for the gains in Figure 8 are; 2.7341 for the proportional gain (P), 86.2354 for the integral gain (I) and -0.0062922 for the derivative gain (D) respectively.

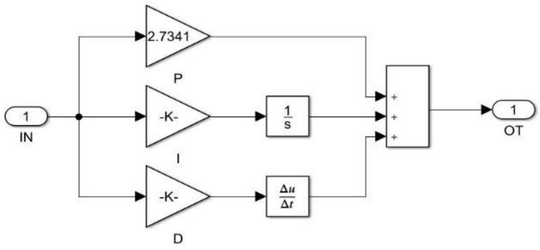


Figure 8. PID controller gains after tuning.

From Figure 8 the point marked IN is the error signal into the PID controller; whereas OT is the controller output (voltage) supplied to the heater. Figure 9 shows the Simulink block diagram of the PID Controller Model.

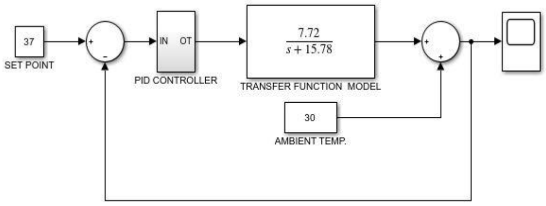


Figure 9. Simulink Model of PID Controller

4.7 PID versus Fuzzy logic Controller

The two controllers were cascaded to view their responses more closely in a single scope. The incubator model was reduced to a sub system and the cascaded Simulink Model of the two controllers, in MATLAB, is shown in Figure 10.

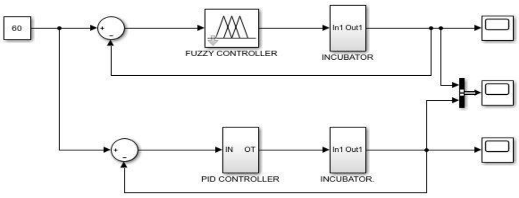


Figure 10. Simulink Model for the cascaded PID- Fuzzy controllers

The middle scope on the right hand side of Figure 10 combines the output from the fuzzy logic controller, as well as the output from the PID controller, to portray clearer view when making comparison between the two controllers.

5. RESULTS AND DISCUSSION

The combined response for the two controllers as viewed at the middle scope, in Figure 10, is presented from Figure 11a to Figure 11c; being the output responses for the two controllers at 35 ^{0}C, 37 ^{0}C and 55 ^{0}C set points respectively.

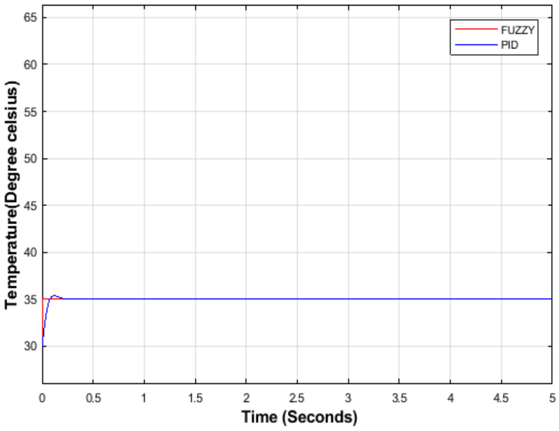


Figure 11a. Controllers Output at 35°C set point.

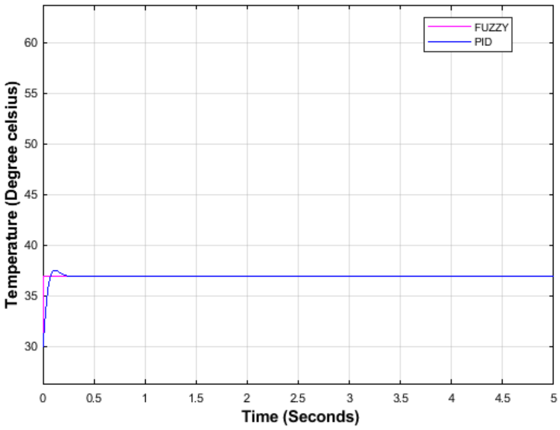


Figure 11b. Controllers output at 37°C set point.

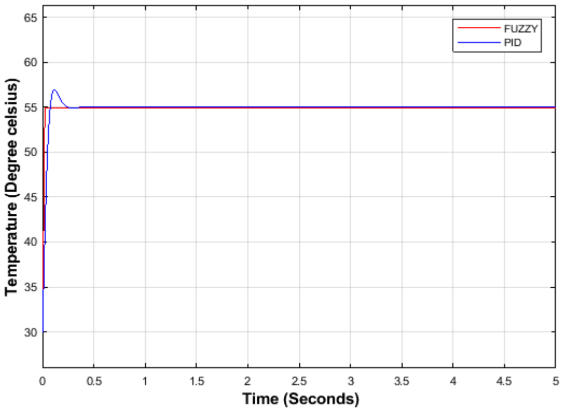


Figure 11c. Controllers Output at 55°C set point.

5.1 Performance Evaluation

Comparison, in terms of the transient responses of the two controllers, is presented in Table 1.

Table 1. Comparison between Fuzzy and PID controller

Tempt. (°C)	Fuzzy Controller			PID Controller		
	Rise time (mS)	Settling time (mS)	Overshoot (%)	Rise time (mS)	Settling time (mS)	Overshoot (%)
35	3.30	1.60	0	53.61	254	5.22
37	3.45	2.04	0	53.68	336	5.98
55	13.72	5.55	0	53.62	345	6.81

In terms of performance, the fuzzy logic controller appears to be better as can be seen in Table 1. Fuzzy logic controller did not give overshoot in all the set points; whereas the PID controller gave a little overshoot in all the set points. The rise time; and the settling time is also less in fuzzy controller response as compared with the PID controller response in all the set points. This shows that the overall transient response of the Fuzzy logic controller is better than that of the PID controller.

6. CONCLUSION

The results from the simulation carried out on the two controllers; have shown that, both controllers performed greatly in terms of set point tracking. However, the Fuzzy logic controller performed better for the fact that in all the set points, the tracking was without any overshoot whereas the PID controller has overshoot in all the set points. In addition, the fuzzy logic controller gave faster rise time (3.30 mS, 3.45 mS and 13.72 mS) and settling time (1.60 mS, 2.04 mS and 5.55 mS) as compared to PID controller which presented longer rise time (53.61 mS, 53.68 mS and 53.62) and settling time (254 mS, 336 mS and 345 mS) for the given set points respectively.

7. RECOMMENDATIONS

In view of the outstanding performance of the fuzzy logic controller over the PID controller, it is recommended that the technique of fuzzy logic be employed more in the design of incubator temperature control which at the moment heavily utilizes the PID control technique. For further research, a hybrid of fuzzy logic controller and any other intelligent controllers such as genetic algorithm can be used to further improve on this one.

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