Simulation of an Energy Saving Egg Incubator

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Abstract

An incubator is a device which is used toturn the fertile eggs hatching successfully at suitable environmental conditions by regulating the temperature and humidity of enclosure. To meet the high demand of poultry production artificial egg hatching is needed. So temperature controls are important factor for incubation process. The source of power in incubator is electrical energy.Energy is limited on earth. So properly use of energy is an important factor. By controlling the temperature and humidity efficiently we can reduce the electrical energy consumption. In this paper we have discussed energy saving technique in hatching incubator which can save energy. The possibility of hatching egg is about 35-40° centigrade but optimum temperature should be kept 37.5° centigrade in 21 days and Below 35° centigrade and above 40.5° centigrade no embryo can be survived for hatching. Cooling eggs for the short time periods says 30-40 minutes out of 24 hours on the regular basis no harmful effect during incubation and probably of profit. So to reduce the energy consumption we introduced a power saving mood which keep the system shut off for 15-20 minutes within 24 hours during incubation. Using fuzzy PID control, we have simulated the system in MATLAB which has improved the temperature rise time and settling time compared to the conventional egg incubator. Calculation shows that this system is energy efficient.

Keywords
Temperature, Humidity, Fuzzy-PID control, Energy saving and Incubator

1. Introduction
An incubator is a machine which provides the good environment for the embryos development of fertilized egg. For the natural brooding, artificial environment allows achieving the necessary temperature, humidity, regular turning of the eggs and ventilation in the incubation system (Peprah and Buadi 2022).Poultry farming helps to sustain the development of village economy and limitation of the urban migration. National population growth is high, so the demand of meat is necessary (Kapen and Foutse2020). Providing the growth of protein, poultry farming is needed for the current purpose, so the farmer and scientist are giving attention to the production of poultry farming development as well.In 2016 the global annual meat production by UN Agricultural outlooks have to be reached 320.7 million tons meat and poultry has reached 12.7 million tons meat total (Mansaray and O.2015).To improve the nutrition and food security for the national demand, poultry farming is the good solution for the sustainable development goal (SDG). It can improve the income capacity for the rural entrepreneurs and contribute to the national economy (Okonkwo and Chukwuezie 2012).Natural Incubation performed by broody hen has low efficiency. For the incubation the fertile eggs properly hatching egg incubator is needed. There are two types of incubator like conventional and automatic egg incubator has been used worldwide. The artificial incubator has two main types like forced air and still air type incubator. Conventional incubator cannot maintain temperature and humidity properly. The poultry farmers cannot hatch the egg properly. Some artificial egg incubators control the temperature and humidity using microcontroller. Lack of electricity in our country is the main problem now a days. Because grid company cannot supply electricity thorough the consumers demand properly due to the lack of economy. The demand of electricity for the domestic line is high, so it is difficult for poultry farmers dependent with connected to the grid. Due to the unreliable and unstable power supply is difficult for egg incubation. So the low cost energy efficient incubator is needed. The possibility of hatching egg within the temperature range 35-40° centigrade but the optimum temperature is 37.5° centigrade. The aim of this paper is to simulate anenergy efficient egg incubator.

For controlling the temperature, there are various kind of techniques have been applied worldwide which are AI techniques such Conventional PID, fuzzy self- tuning PID and Fuzzy logic etc. Fuzzy-adaptive PID control is one kind system which has effective and self-directing control of Fuzzy PID parameters(Jiang and jiang2012).It can sustain, manipulate and control the data of an incubator. FLC is the control system which can use IF-THEN fuzzy rules for decision making. FLC system can determine the error and changing error via the MATLAB simulation.(Rahman and Islam2021).

1.1 Objectives

This paperaims to design the fuzzy based PID temperature control of an egg Incubator. The purpose of this system is to design the temperature control strategy and energy efficient system which is then comparedto the conventional egg Incubator.

2. Literature Review

Various authors haveproposed their method in different ways. The various kinds of work are Arduino, grid, solar, biogas and battery powered egg incubator. Olubiyi, olasunkanmi had proposed 480 egg capacity dc power incubator based on GSM. They had used PIC18F4550 microcontroller, DHT11 sensor and M1306B GSM modem for communication. 4* 57.6 W filaments bulbs (12V) as heat source for the temperature control(Akintade and Olasunkanmi2015).S.Zareen and GulfamBibi et al, proposed their hatching incubator with 80 watt light bulb which was installed in the box as the heat source. They used digital temperature control circuit which consist of a temp sensor, a relay which switch on and off a 220V ac bulb and CPU fan and a display unit to set desired temp. Humidity was controlled manually with a soaked cloth. The hatching was completed on 22 days(Zareen and Rehman2016).Z-Aldeen& S. A.Rahman, had proposed the smart incubator based on PID controller. In his research he used Arduino board ATmega1280 and Atmel AVR brain. DHT-11 sensor was used for humidity sensing and LM35 for temperature sensing. In his research he had used PWM technology for PID output voltage for the humidity and heat source. The author set the temperature in 37 degree centigrade. And humidity was set to be 62%. In experimental period total current is drawn by the controller was 148mA (Aldeen and Rahman2017).S.Ganiyat, I.R.Afolake had proposed a design of a portable solar powered incubator. The authors used 200W, 12V battery, DC to AC converter and solar system. Two pieces tungsten 100 Watts electric bulb including portable fan and egg turning trays which holding 30 eggs are used. The experiment result shows that, the authors tried to regulate the temperature 37° centigrade to heat up the eggs during hatching (Ganiyat and Afolake2020).F.Kyeremeh and ForsonPeprahproposed design and construction of an Arduino Microcontroller based EGG Incubator. In their research they made an incubator designed which can operate 14000 quail eggs or 4500 equivalent chicken eggs hatching. The system were designed via Arduino micro controller which used 4 * 100 watt incandescent bulbs as heat source, 16*2 LCD display, fan for air circulation and water tray used for humidity control inside the incubator. Turning trays were used through the relays(Kyeremeh and Peprah2017).A.A Sunday, O.A Ogunbode et al proposed design and construction of automated eggs incubator for small scale poultry farmers**.** The authors in his research had used 100 eggs capacity hatching incubator systems for small scale farmers. They had used 89C51 Micro-controller. LM35 was used for sensing the heat inside the incubator. Stepper motor was used for rotating the egg position through iron rod. Fan was used for the proper air ventilation inside the incubator and humidity control entire the system. Water tray was used in bottom line for humidity control of the entire system. The authors were set the temperature and humidity between 37°-39°C and 55% respectively. The ambient temperature and humidity were 33°C and 42% (Sunday and Olusoji2020).M.J.P Mariani, R.U Wacas, R.J Padre et al. proposeddesign modification of a cost-efficient microcontroller-based egg incubator. The authors were used Arduino Uno R3, AT Mega 328 Microcontroller. Two incandescent bulbs (25 watt) were used inside the incubator. Fan was used for circulating the air inside the incubator. DHT11 sensor was used for the temperature and humidity control. The authors were used the number of duck and chicken fertile eggs 60(both)(Mariani and Ronald2021).PallaviBhosale and J. Tripathiet al had proposed development of smart egg incubator system using Arduino. 20-25 eggs were hatched in smart egg incubator. In this system Arduinouno board and two tungsten bulbs 40W were used. DHT11 sensor was used for measurement the temperature. Temperature was regulated between 35-37°C. When the temperature exceeds 37 degree the bulb automatically turns off and the fan is on. When the temperature is below 35 °C, then the bulb automatically turns on and the fan is off. The author used micro SD card. Dc motor was used for rotating the iron rod for positioning the egg (Bhosale2018).P.T Kapen, M. Youssoufa,et al had proposeddesign and prototyping of a low-cost, energy efficient eggs incubator in developing countries: A case study of Cameroon. The authors were used 600 capacity based incubator. Theyused Arduino Mega 2560 board. Ultrasonic humidifier was to generate humidity. DHT 22 sensor was used for temperature and humidity sensing of the system. Maple software was used for numerical simulation of the system. The result showed that eggs were incubated through 37°C temperature and

45.5% of humidity (Kapen2020).W.S. MadaSanjaya, M.A Aziz et al,were used 490 quail eggs for hatching through incubator. The incubator box was designed with 100*70*43 dimension. 4 pcs 5 watt lamps, 2 pcs blower fan were used inside the incubator. 2 pcs DHT11 sensor were used for sensing the temperature and humidity data. Temperature and humidity range were 36.5°C to 38.5°C & 55%-65%RH accordingly.(sanjaya2018).Susmita M. Chougule, V.B. Desai et al. proposed a smart egg incubator. In their research they used ArduinounoAT mega168/AT mega328p, LM35. HS220 is used for temperature and humidity measurement. The systems was controlled with IOT. Temperature and humidity ranges were 98°F-102°F & 85-89% accordingly. The author used 490 quail eggs during 21 days of incubation process.(Chougule2021). Fasanmiet al, proposed development of an automatic electric egg incubator. In their research they made 540 hatching capacity egg Incubator. They had used 4 filament bulbs (60watt) for heating source for the incubator. Humidity was set 58%-60% and temperature 37°-39° centigrade during 18 days. But, 37.5° centigrade was set for best result until hatching. Adam Faroqi et al. proposed their method and used Arduinouno AT mega328 microcontroller, DHT22 for temperatureand humidity sensing and PIR sensor was used for measurement of the body temperature.In this system temperature ranges 38°C - 40°C and humidity was around (60-70) %(Faroqi and Ismail2020). Dr. Sunitha H D et al used Arduinouno Atmega328P and 2 filament bulb of 60 watt as heat source. DHT 11 sensor was used for temperature and humidity measurement. A low speed dc motor was used for rotating the egg trays at 45° angle. Temperature range was 36°C - 37°C and humidity was kept 57% in first 18days and then increased to 70% during last 3 days of incubation.Okpaguet al proposed a model for temperature control in smart egg incubator. In their research they used AT89C52 Microcontroller, two 60 watt bulbs, LM35 sensor and four relays of 5v to control the temperature. Temperature was kept 35-40° centigrade but optimum temperature was kept 37° centigrade(Okpagu2016).

3. Methods

This paper mainly aims to simulate the energy efficient egg incubator. In this research we can control the temperature through fuzzy-self tuning PID algorithm. We have used fuzzy PID method combined with conventional PID and fuzzy logic. The time error "e" and changing time error "ec" are the input and K_P, K_I, and K_D are the output of this fuzzy control system. In PID controller, voltage is the input and temperature is the output parameter. The fuzzy rules for tuning K_P, K_I, and K_D can be constructed with multiple requirements on the PID monitoring process.Here, 37.5 degree centigrade is the optimum set temperature and 1 second used as transport delay to regulate the system. This design monitors the temperature control process of this system. And reduce the fluctuation and minimize the overshot and improve the rise time and settling time and save the energy consumption of this system compared to the conventional egg incubator.

In Figure 1, temperature is used as feedback sensor. The difference between set temperature and sensor temperature is the error 'e' and dividing the error by a fixed time we can get the changing error rate 'ec'. Error 'e' and changing error rate 'ec' enter on the fuzzy inference system and after defuzzification, the value of K_P, K_I and K_D enters in PID control system.

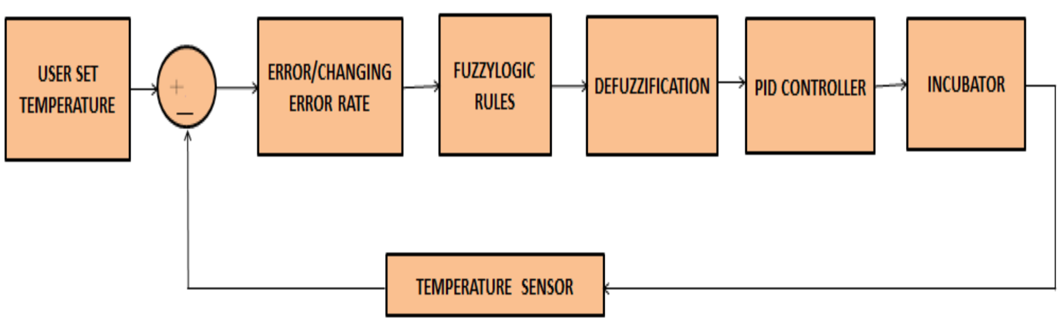


Figure 1. Simplified block diagram of the proposed system

The law of traditional PID controls is given below

$u(k) = Kpe(k) + Ki\sum_{i=0}^{k} e(i) + Kd\{e(k)-e(k-1)\} + u(0)$ ……………………………….(1)

The main parameters of PID controller are:

(1) when **'e'** is big, K_P is big but K_D is little

(2) when **'e'** and **'ec'** are moderate then the overshoot is small

(3) when**'e'** and **'ec'**are little, then K_P, and K_I are big.
(4) when**'ec'** is small then K_D is big.
(5) when 'ec' is big then K_D is little.

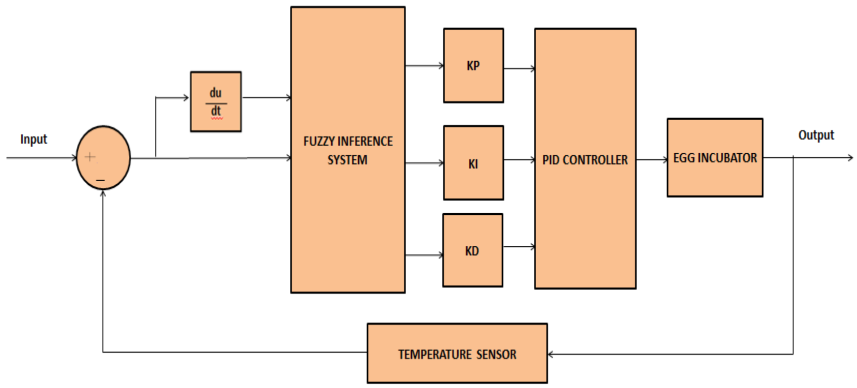


Figure 2. The schematic diagram of Fuzzy adaptive PID monitoring process

Here in Figure 2,supply voltage is used as input connected on the fuzzy inference system. Temperature sensor is used as feedback sensor. The difference between set temperature and sensor temperature is the error 'e' and dividing the error by a fixed time we can get the changing error rate 'ec'. Error 'e' and changing error rate 'ec' enter on the fuzzy inference system and after defuzzification, the value of K_P, K_I and K_D enters in PID control system. After simulation we get temperature as output of this system.

The output of the fuzzy estimation data which are controlled with fuzzy PID can operate the fuzzy table. The design of a fuzzy logic rule are given with following list
1. The input and output of this system is clear
2. Input and output variables fuzzy logic are defined with fuzzy sets
3. Obtaining the fuzzy rules are putting on the list.

In this system, the error "e" and changing error "ec" are calculated with fuzzy-pid controller through different parameters of FLC system.The fuzzy monitoring table K_P, K_I, K_D is calculated by the error and changing error rate via fuzzy inference system.

4. Membership function

The membership function of fuzzy control system mappings the set of input variable is called fuzzy sets and the value of fuzzy set is called fuzzification. The Fuzzy subsets were defined with different crisp sets. The fuzzy sets are completely perceived by the membership functions. FLC method can also organize the analog inputs which are 0, 1 into its fuzzy operation that can either one or another value .The fuzzy sets were classified into two input variables like error 'e' and changing error 'ec' and the temperature is defined the output variable of this egg incubator system. The input and output domains are defined with seven fuzzy subsets, Errors are: [NB, NM, NS, ZO, PS, PM, PB]. Change in error are: [NB, NM, NS, ZO, PS, PM, PB] and the domain outputs are [NB, NM, NS, ZO, PS, PM, PB]. The value of input and output parameters were fuzzified by converting the membership function corresponding to the seven subsets. All of the membership functions in FLC were taken straight line which is triangular shape. The input value range of (K_P, K_I, K_D) range is [-20 40] & the output value range of (K_P, K_I, K_D) is [0 40]. The fuzzification and defuzzification method of a fuzzy function has been used to quantify the linguistic terms which can plotted with changing the temperature.

In Figure 3, the membership function of KP, KI, KD has two input like Error 'e' and Changing Error 'ec' which range is [-20 40] and output which range is [0 40]. Seven fuzzy subsets are taken which are NB, NM, NS, ZO, PS, PM, PB. All the membership function are triangular shape. In Table 1 the Membership functions are given.

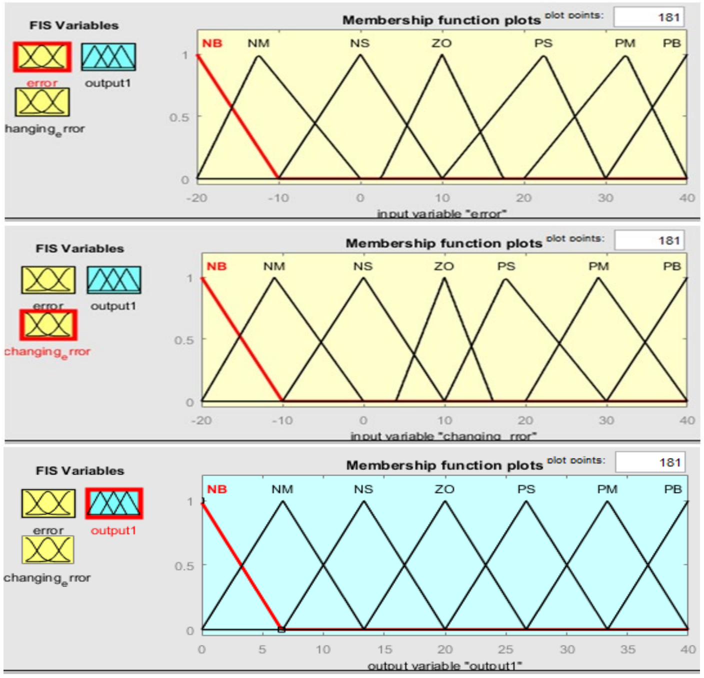


Figure 3. Membership function (a) KP, (b) KI, (c) KD

Table 1. Table of the Membership Function

	Membership function	**Error ‘e’**	**Changing error ‘ec’**	**Output**
	NB	[-30 -20 -10]	[-30 -20 -10]	[-6.773 -0.104 6.56]
	NM	[-20 -12.5 0.0025]	[-20 -11 0.0025]	[0 6.665 13.33]
	NS	[-10 0.0025 10]	[-10 0.0025 10]	[6.665 13.33 20]
K_P	ZO	[2.5 10 17.5]	[4 10 16]	[13.33 20 26.67]
	PS	[10 22.5 30]	[10 17.5 30]	[20 26.67 33.35]
	PM	[20 32.5 40]	[20 29 40]	[26.67 33.35 40]
	PB	[30 40 50.02]	[30 40 50.02]	[33.35 40 46.68]
	NB	[-30 -20 -10]	[-30 -20 -10]	[-6.773 -0.104 6.561]
	NM	[-20 -12.5 0.0025]	[-20 -11 0.0025]	[0 6.665 13.33]
	NS	[-10 0.0025 10]	[-10 0.0025 10]	[6.665 13.33 20]
K_I	ZO	[2.5 10 17.5]	[4 10 16]	[13.33 20 26.67]
	PS	[10 22.5 30]	[10 17.5 30]	[20 26.67 33.35]
	PM	[20 32.5 40]	[20 29 40]	[26.67 33.35 40]
	PB	[30 40 50.02]	[30 40 50.02]	[33.35 40 46.68]
	NB	[-30 -20 -10]	[-30 -20 -10]	[-6.773 -0.104 6.561]
	NM	[-20 -12.5 0.0025]	[-20 -11 0.0025]	[0 6.665 13.33]
	NS	[-10 0.0025 10]	[-10 0.0025 10]	[6.665 13.33 20]
K_D	ZO	[2.5 10 17.5]	[4 10 16]	[13.33 20 26.67]
	PS	[10 22.5 30]	[10 17.5 30]	[20 26.67 33.35]
	PM	[20 32.5 40]	[20 29 40]	[26.67 33.35 40]
	PB	[30 40 50.02]	[30 40 50.02]	[33.35 40 46.68]

4.1 Fuzzy logic Rules

FLC method consists of an input term, processing term and output term of system. The input term of a FLC system is the error ‘e’ and the changing error ‘ec’. The output term is temperature of the system and processing term is based on fuzzy logic rules if-than statement where if statement is known as ‘precursory’ and then statement is known as 'pursuant'(Okide and Anazia2012).In the fuzzification process we can get fuzzy sets and defuzzification process we get three parameters with improvement PID operation. FLC rule is familiar with manufactured the output variables K_P K_I K_D to this system. The fuzzy logic rules are demonstrated below in Table 2, Table 3 and Table 4.

Table 2. Fuzzy logic Rules for [K_P]

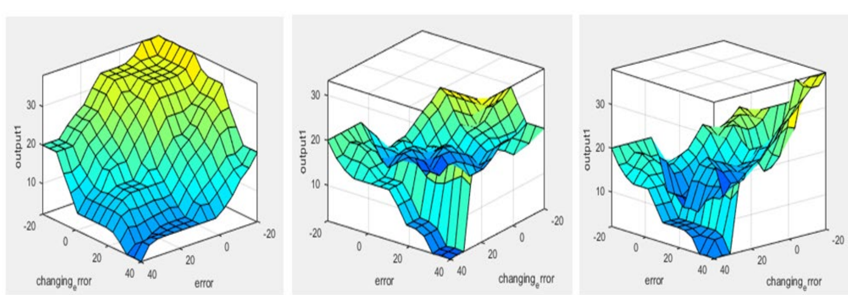
E/EC	**NB**	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	NM	PB	PB	PM	PM	ZO	ZO
NM	PB	PM	PM	PS	PS	ZO	NM
NS	NM	PM	PM	PS	ZO	NS	NM
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NS	NS	PM	PM
PB	ZO	PS	NM	NM	NM	NB	NB

Table 3.Fuzzy logic Rules for [K_I]

E/EC	**NB**	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	NB	NM	NM	PS	ZO	ZO	ZO
NM	PS	NB	NS	NS	NS	ZO	NS
NS	NM	NS	PS	NS	ZO	NS	NS
ZO	NM	NS	NS	ZO	PS	NS	NS
PS	NS	NS	ZO	PS	PM	NM	PM
PM	ZO	NS	PS	PS	PB	NB	NB
PB	ZO	PS	PM	PM	PM	NB	NB

Table 4.Fuzzy logic Rules for [K_D]

E/EC	**NB**	**NM**	**NS**	**ZO**	**PS**	**PM**	**PB**
NB	NB	NS	NM	NM	ZO	ZO	ZO
NM	NM	NS	NB	PM	NS	ZO	NS
NS	PS	NS	NM	NS	ZO	NS	NS
ZO	ZO	NM	NS	ZO	PS	NM	NM
PS	PS	PB	NS	PS	PM	PM	NB
PM	PM	PB	NS	PS	PM	PM	NB
PB	PB	PB	PM	PM	PM	NB	NB



K_P K_I K_D

Figure 4. Surface view of K_P, K_I, K_D

After the fuzzification the surface view of K_P, K_I, K_D is given in Figure 4. In surface view according to error and changing error rate, the output (values of K_P K_I and K_D) are shown.

5. Simulation Result and Discussion

To execute the energy efficient egg incubator temperature control is most important part of this system. For energy saving we proposed temperature control by using fuzzy adaptive PID control of this system via MATLAB toolbox The simulation of MATLAB is the adapting of the arrangement of the membership functions for fuzzy rules. The application of fuzzy-PID is, maintaining the heating and controlling air temperature in the incubator. This system can reduce overshoot and undershoot and give the good response. The transfer function on the Simulink model is:

$$\frac{1}{s^3 + 7s^2 + 15s + 9}$$

Comparing between the simulation of result on the fuzzy PID and the conventional PID control, simulation result shows that it has improved the rise time and settling time and reduced the overshot and under shoot and energy efficiency of system. (Qin and Yanni 2013).

The Simulink block diagram is given in Figure 5.In the Simulink block diagram, the step-response allows the fundamental step signal detecting and the reaction of the progressive system. FLC system is essential to select the appropriate error 'e' and changing error 'ec'. For the better temperature performance of this system, the FLC is used in this system. The error 'e' and changing error 'ec' determines the parameters *Kp*,*Ki and Kd.*

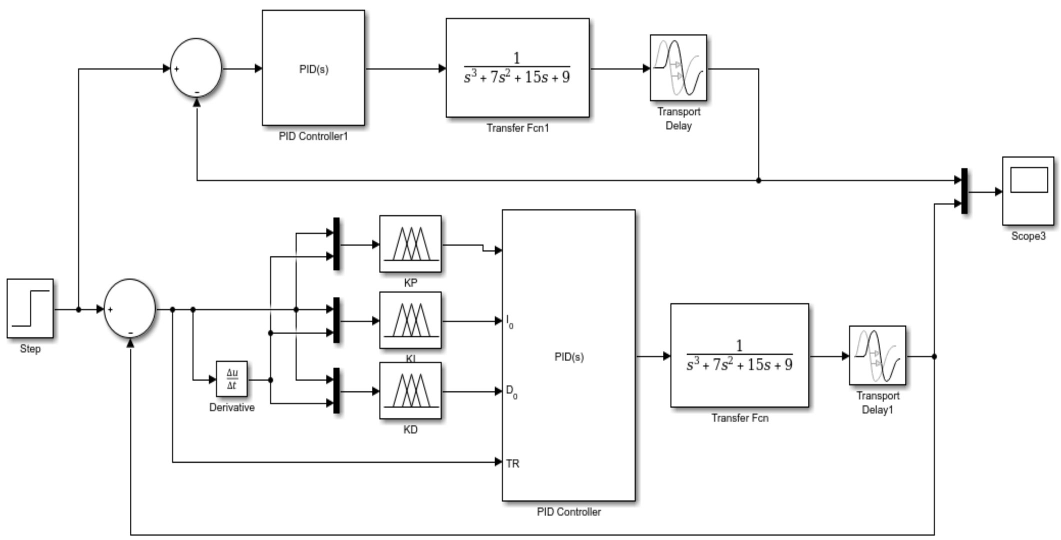


Figure 5. Simulink Block Diagram using MATLAB

If the system error 'e' is big, then overshoot is big and the mode of transition will be extended. If 'ec'is big, then Kd is big. The overshoot will be reduced, the speed reaction will slow. The set temperature is taken 37.5degree centigrade. The step time of the system is 0 and the final value is 37.5 degree centigrade. 100 seconds has taken for the simulation process. And 1 second has been used as transport delay. During the simulation, conventional PID control parameter has been taken asK_P =*10.55,* K_I=*10.12*and K_D=*5.*During the simulation time the rise time and settling time has improved, overshoot is reduced which is energy efficient for this system compared to conventional egg incubator.

5.1. Graphical Results

The graphical result is shown in Figure 6. The result shows that PID has a big overshoot which is reduced is fuzzy-PID. The oscillation of PID has been fixed in Fuzzy-PID.

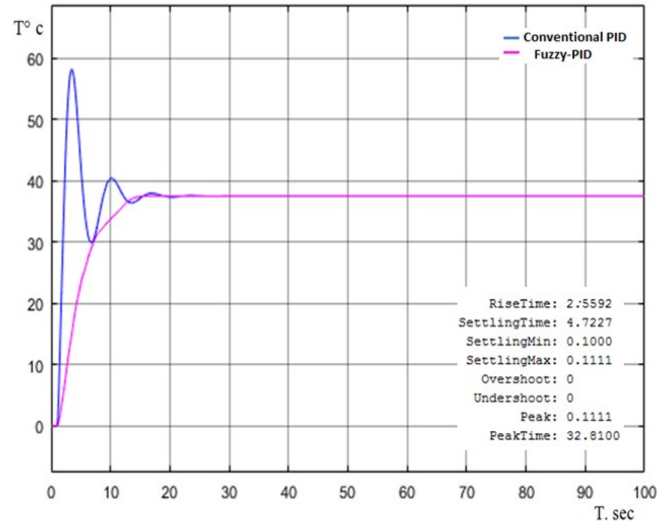


Figure 6. Response Curve of a Conventional PID and Fuzzy-PID

5.2 Energy and powercalculation

Thermal energy, $Q = m_a c_a (T_f - T_i)$ (Agidi and Liberty 2014)
Where,
Q=heat required in incubator
m_a = mass of air
c_a = specific heat capacity of air
T_i=initial temperature
T_f = final temperature of the incubator
The value of parameters which are used in thermal energy calculation are given in Table 5.

Table 5. Value of Parameter

Parameters	Value
m_a	0.097kg
c_a	1005 $Jkg^{-1}\ k^{-1}$
T_i	0^0C
T_f	37.5^0 C

From Figure 6,we see that, at 4 sec, PID temperature increases0^0 to 59^0C and fuzzy-PID temperature increases 0^0 to 19^0C.
Therefore, thermal energy for temperature 0^0 to 19^0C,
$Q = 0.097 * 1005 * ((19 + 273) - (0 + 273))$
$Q = 97.485 * 19$
$Q = 1852.215$ J

And,thermal energy for temperature 0^0 to 59^0C,
$Q = 0.097 * 1005 * ((59 + 273) - (0 + 273))$
$Q = 97.485 * 59$
$Q = 5751.615$J

As we know, Power (W) =$\frac{Q}{t}$
Where, Q=thermal energy/heat required in incubator,

t=time,
Therefore, Electric power consumption in PID control system:
Power (W) =$\frac{5751.615\,J}{4\,sec}$ = 1437.90375W per second.
Therefore, Electric power consumption in Fuzzy-PID control system:
Power (W) =$\frac{1852.215\,J}{4\,sec}$ =463.05375 W per second.

5.3 Proposed improvement

In this proposed system overshoot and oscillation free temperature control has been achieved for egg incubator and also this system could be an advanced temperature control system design in future for various industrial applications and could help to monitor environmental condition of any temperature control system.

6. Conclusion

By controlling the temperature of egg incubator we can conclude that, fuzzy logic is effective method. In this research, fuzzy self-tuning PID response strategically controls the temperature of system and it is easy to demonstrate the philological variables. It can help to control the temperature of this system very effectively. The result shows that fuzzy-PID control is more effective than conventional controller and also it has made the system energy efficient. It can help to reduce the fluctuation and minimize the overshoot and undershoot and improved the settling time. This system is energy efficient than conventional system.

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