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Fuzzy Logic Controller for Temperature Regulation Process

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Abstract: A closed loop control system incorporating Fuzzy logic controller has been developed for a temperature regulation process. A unique Fuzzy logic controller structure with an efficient realization and a small rule base that can be easily implemented in temperature control process. MATLAB simulations are carried out and responses are obtained for PID and Fuzzy Logic Controller.

Key words: Fuzzy logic controller % PID controller % Ziegler-Nichols technique

INTRODUCTION

Temperature is the most often-measured environmental quantity. This might be expected since most physical, electronic, chemical, mechanical and biological systems are affected by temperature. Some processes work well only within a narrow range of temperatures. Certain chemical reactions, biological processes and even electronic circuits perform best within limited temperature ranges. When these processes need to be optimized, control systems that keep temperature within specified limits or constant are often used [1].

In modern control theory Fuzzy logic control has been rapidly gaining popularly among engineers. Fuzzy logic provides a powerful vehicle that allows engineers to incorporate human reasoning in the control algorithm. Fuzzy Logic Control can cope with such complex problems. It does not depend on precise mathematical values and equations as the PID control does. Fuzzy Logic Controller (FLC) is good for most situations without any modification. The controller designed using Fuzzy logic implements human reasoning that can be programmed into Fuzzy logic language (membership functions, rules and rule interpretation).

Control of temperature is an important process and common task in process industries.For example, considering the control of the temperature in the tank. Too high or too low temperature in the tank can result in problems. It is important to maintain the temperature of liquid as close as possible to the required set point. Liquid temperature control finds wide applications in process industries [2].

In this paper, we concentrate on Fuzzy logic control as an alternative control strategy to the current proportional integral- derivative (PID).

System Modeling:

System Model: The closed loop liquid temperature control system is shown Fig.1. G(s) = is system transfer function and e^{-sJ} is time delay. C(s) is the controller.

The transfer function for the temperature Process control is

$$G(s) = T_e(s)/T_{ec}(s)=K\,e^{-sJ}/s/a+1 \quad (1)$$

Where Te= tank temperature; 9= time delay and a=1.K=gain

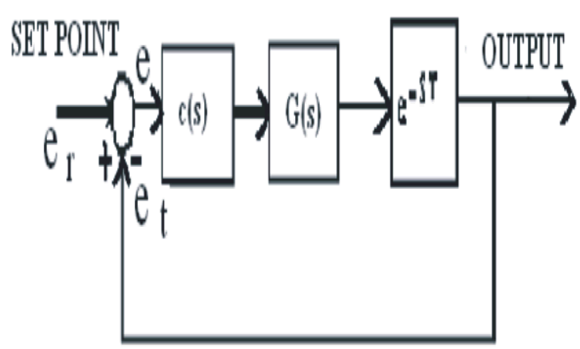

Fig 1: Closed Loop control system

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This voltage is subtracted from the reference voltage e_r to generate the error signal

$$e = e_r - e_t \quad (2)$$

The temperature T of the out flowing liquid is measured by a temperature sensor which produces an output voltage e_t is proportional to T

$$e_{=} k*T$$

This in turn regulates the heating rate Q by means of a power MOSFET. The power MOSFET controls the heating rate by varying the point in the AC power cycle in which the heater is connected to power line [2-9].

Controller Design: Different types of controller which can be applied to temperature control process are listed below

- Fuzzy Logic Controller (FLC)
- Proportional Integral (PI)
- Proportional Integral derivative (PID)
- Neural networks.
- Adaptive Neuro

This paper analyses the PID, Fuzzy Logic Controller as applied to a temp regulation process.

Fuzzy Logic Controller: A rule-based system is characterized by a set of rules that were defined by antecedents and consequents. Inference rules were made by a simple logic. The input variables in a control system are in general mapped into sets of membership functions known as sets. The process of converting a crisp input value to a value is called fuzzification. Controllers are very simple conceptually. The Fuzzy logic control is flexible and can model nonlinear function of arbitrary complexity. The block diagram of Fuzzy logic controller is shown in Fig.2.

A control system is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 0 or 1.

The FLC developed here is a two-input single-output. The two inputs are the deviation from set point error, e (k) and error rate, 9e (k).

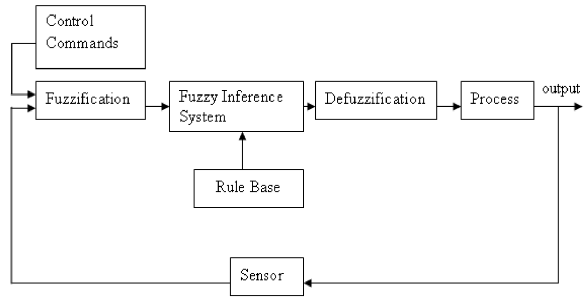

Fig 2: Block diagram of Fuzzy logic controller

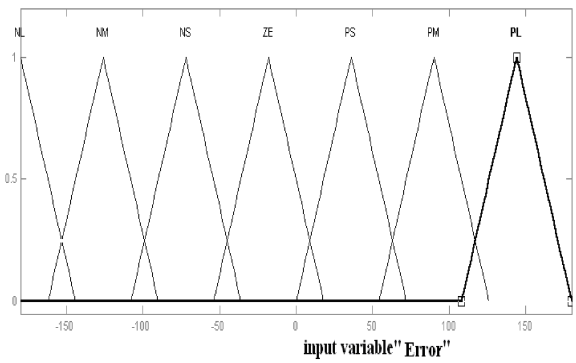

Fig 3: Error membership function

Fuzzification: The input variables in a control system are in general mapped into by sets of membership functions similar to this, known as "sets". The process of converting a crisp input value to a value is called "fuzzification".Fuzzification translates a numeric value for the error, e(t), or error rate,) e(t), into a linguistic value such as positive large with a membership grade.

Membership Function: The crisp variables are converted into linguistic variables with a process fuzzification. The input and output variables are divided into seven different ranges, each range corresponds to a linguistic variable. The FLC membership functions are defined over the range of input and output variable values and linguistically describes the variable's universe of discourse. The triangular input membership functions for the linguistic labels zero, small, medium and large, had their membership function are shown in Fig3 and Fig4. The universe of discourse for both *e* and) *e* is normalized from -1 to 1. The left and right half of the triangle membership functions for each linguistic label was chosen to provide membership overlap with adjacent membership functions. The straight line output membership functions for the labels very low, low, medium moderate, high, very high and full are defined as shown in Fig.5

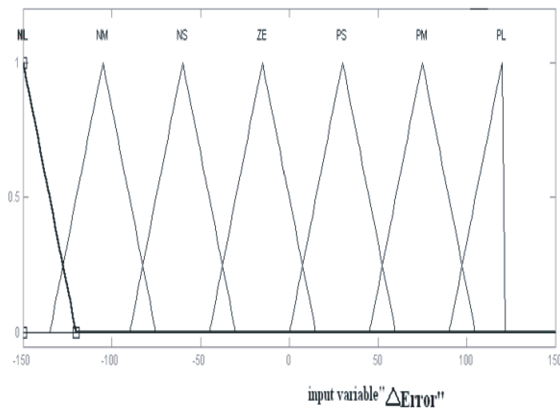

Fig 4: Change in error membership function

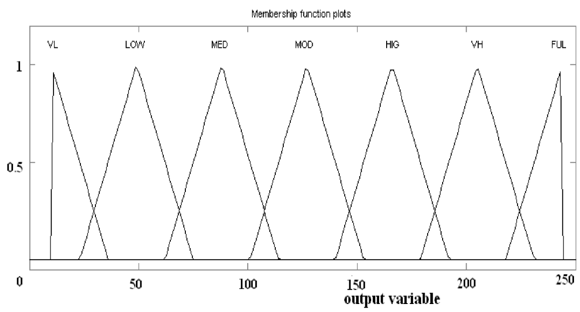

Fig 5: Output membership function

Rule Development: The rule table is prepared which is based on the expert's knowledge. This rule base is the backbone of this system according to which the whole system is operated and the temperature is controlled.

Our rule development strategy for systems with time delay is to regulate the overall loop gain to achieve a desired step response. The output of the FLC is based on the current input e and ?e (t); the main idea is that if the FLC is not designed with specific knowledge of mathematical model of the plant, it will not be dependent on it. The rules developed in this paper are to compensate for varying time delays by tuning the FLC output membership functions based on system performance.

Fuzzy logic rules in the form of IF-THEN statements, where the IF part is called the "antecedent" and the THEN part is called the "consequent". Typical control systems have 49 of rules are shown in table 1 Consider a rule for a thermostat:

IF (temperature is "cold") THEN (heater is "high")

Defuzzification: Defuzzification takes the output of the rules and generates a crisp numeric value used as the control input to the temperature regulation process.

Table 1:Rule development

ΔE \ E	NL	NM	NS	ZE	PS	PM	PL
NL	VL	VL	VL	VL	VL	VL	LOW
NM	VL	VL	VL	VL	VL	LOW	LOW
NS	VL	VL	MED	LOW	LOW	VL	VL
ZE	VL	LOW	LOW	MOD	MED	MED	MOD
PS	MED	MED	MOD	MOD	HIG	HIG	VH
PM	HIG	HIG	HIG	VH	VH	FUL	FUL
PL	VH	VH	FUL	FUL	FUL	FUL	FUL

The output of a process can be logical union of two or more membership functions defined on the universe of discourse the output value. Max membership function principle used for defuzzification process. The output variable is converted to crisp value by the process of defuzzification. The defuzzified output is the fed to the further circuit to obtain the control signal.

Pid Controller: Proportional-integral-derivative controller (PID) is a generic control loop feedback mechanism widely used in control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then output a corrective action that can adjust the process accordingly. By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements. The block diagram of conventional control system is shown in figure 6.

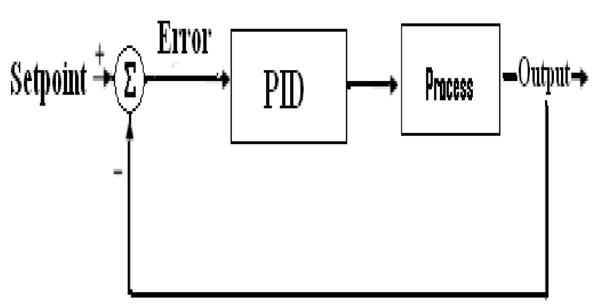

Fig 6: block diagram of PID controller

The proportional term makes a change to the output that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain. The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. It decrease rise time and eliminate steady state error. The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i the rate of change of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. It decreases overshoot and settling time.

The process of selecting the controller parameters to meet given performance specification is known as controller tuning. Here Ziegler-Nichols tuning rule is used for the determination of the values of parameters of $K_p K_i$. K_d.

$$G(s) = K_p + K_i /s + K_d\, s \quad (3)$$

The model for the temperature Process station control is shown in below

$$G(s) = T_e(s)/T_{ec}(s) = K\, e^{-sJ\ d}/((s/a)+1) \quad (4)$$

For a time delay J_d=10, a=1 and system gain k=1

$$G(s) = e^{-10s}/(s+1) \quad (5)$$

Based on the Ziegler-Nichols tuning the proportional; gain, integral and derivative parameters are shown in below

K_p=0.12, K_i=20, K_d=5

The controlled output of the temperature regulation process can be found to be

$$C(s) = G(S)*Gc(s) \quad (6)$$

The PID controller transfer function is

$$C(s) = 5S^2+.12S+20/S. \quad (7)$$

Simulation and Results: The Fuzzy Logic controller for the temperature regulation process is designed and is simulated using MatLab/Simulink. The simulink model for the Fuzzy Logic Controller is shown in Fig.7 for the Temperature regulation process. The simulated performance results using Fuzzy logic controller is shown in Fig 8 which shows the temperature control process for a set point of 50º C.

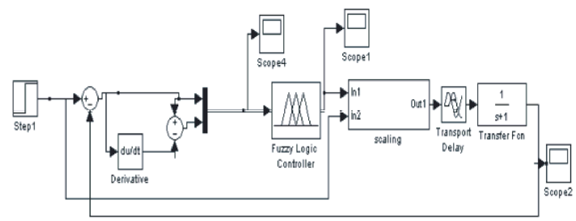

Fig 7: Mat lab simulation for Fuzzy Logic Control

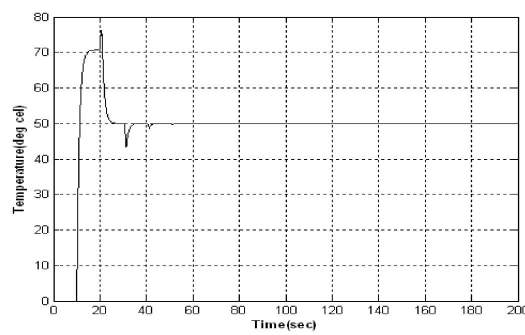

Fig 8: FLC simulation for set point of 50º C.

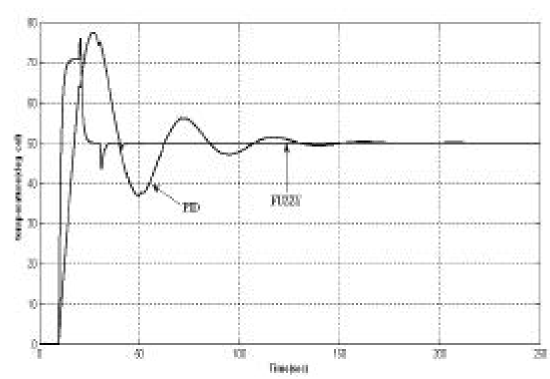

Fig 9: Comparison of Fuzzy vs. PID controller

Comparison to Pid Controller: Controllers based on the PID transfer function are commonly used for process controller applications. Comparing the Fuzzy logic control to classical PID control yields useful insight.

The comparison indicates that the Fuzzy Logic controller is able to achieve faster transient response with less overshoot, more stable steady state response and less dependence of operating point. Since the Fuzzy controller does not require exact mathematical model of, it is not designed based on specific operating point. The time domain specification comparison are tabulated shown in Table 2.

Table 2: Comparison of performance of PID vs. Fuzzy Control for temperature set point 50°C

Time domain specifications	PID controller	Fuzzy Logic Controller
Rise time(sec)	15.5	11.2
Settling Time (sec)	85.3	23.6
Max peak response	78.1	76.2
Oscillation	More	less

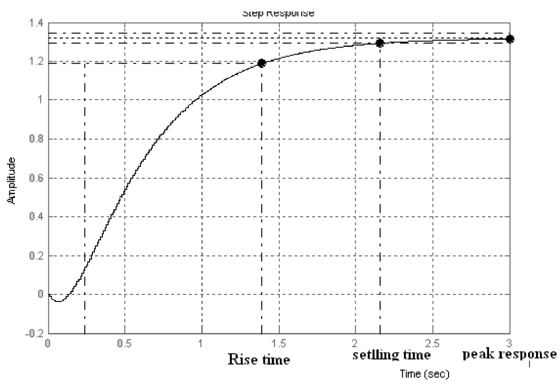

Fig 10: Step response for Fuzzy logic controller

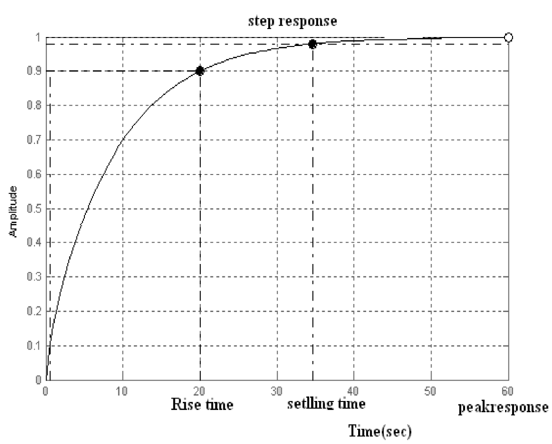

Fig.11.Step response for PID controller

The comparison performance of step response for PID and Fuzzy Logic controller are shown in Fig 10 and 11.

CONCLUSION

FLC was designed for temperature control. The performance of the FLC was evaluated and compared with that of PID controller. PID controller was tuned by stepwise determining the control parameters. This shows that Fuzzy Logic Controller is better compared to the conventional PID controllers. It is observed that the Fuzzy Logic Controller is faster than the conventional PID Controller. The FLC is useful in reaching the set point faster where as the PID Controller is useful for maintaining the process variable value at the set point. Fuzzy Logic Controllers are much closer in spirit to human thinking and decision-making.

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