Comparative Analysis of PI, PID and Fuzzy Logic Controllers for Speed Control of DC Motor

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Abstract

DC motor plays an important role in industry. Thus, the speed control of DC motor is a prime task. This paper gives a comparison of the performance of conventional proportional integral (PI), proportional integral derivative (PID) and fuzzy logic controllers (FLC) for speed control of DC motor. A set of rules have been designed for FLC. FLC is an expert knowledge system which improves the result. Thus the comparison of the graphical results so obtained shows that fuzzy logic approach has minimum overshoot, fast response, and minimum transient and steady state parameters. The results so obtained conclude that FLC is more efficient than PI and PID controller.

Keywords - Fuzzy logic control (FLC), MATLAB/Simulink, PID controller, PI controller, Mamdani fuzzy inference system.

1. Introduction

Different controllers are available now a day in order to get an accurate control in process industries. This paper aims to compare the performances of different controllers for speed control of DC motor. PI and PID control are some of the earlier control strategies in industries. Initially these conventional controllers were implemented in pneumatic devices, followed by vaccum and solid state devices.

PI and PID Controllers are widely used in control applications, but their performance is very poor when applied to certain system. The performance of PI and PID controller is evaluated in terms of rise time and steady state error. The tuning of PID controller is difficult due to insufficient knowledge of the parameters of the system. Sometimes PI and PID controllers make an overshoot. Because of certain demerits of conventional controllers like distributed parameters, large inertia, large time delay, a new and more efficient controller stepped in industry.

Fuzzy logic is a method of rule-based decision making used for expert systems and process control that emulates the rule-of-thumb thought process used by human beings [1].

2. Mathematical model of dc motor

DC motors are highly reliable and flexible because of the several good characteristics like high starting torque, efficient response and linear controllability. The term speed control stand for intentional speed variation carried out manually or automatically. DC motors are most suitable for wide range of speed control and adjustable speed drives[2].

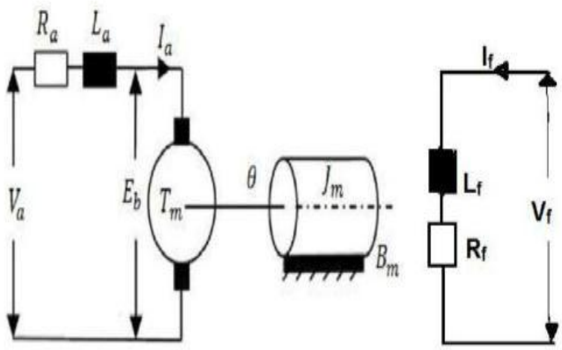

Figure 1. Separately excited DC motor model [2]

The dynamic equations for DC motor are given

$$\frac{d}{dt}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} = \begin{bmatrix}\frac{-b}{J} & \frac{k}{J}\\ \frac{-k}{L} & \frac{-R}{L}\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} + \begin{bmatrix}0\\ \frac{1}{L}\end{bmatrix}u \qquad (1)$$

$$\dot{\theta} = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}\dot{\theta}\\ i\end{bmatrix} \qquad (2)$$

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These equations are in the form of:

$$\ddot{\theta} = A\dot{\theta} + Bu \qquad (3)$$

$$y = \dot{\theta} = C\dot{\theta} + Du \qquad (4)$$

This is converted to a transfer function in order to make the dc motor model similar in terms of transfer function to that of PID in expression(5). Therefore the controlled dc motor has a transfer function of the form in equation (5)[3].

$$\frac{\theta}{V} = \frac{K}{(Js+b)(Ls+R)+K^2} \qquad (5)$$

J is the moment of inertia b is the damping ratio
k is the electromotive force constant
R is the electric resistance L is the electric inductance
θ is the position of shaft i is the armature current

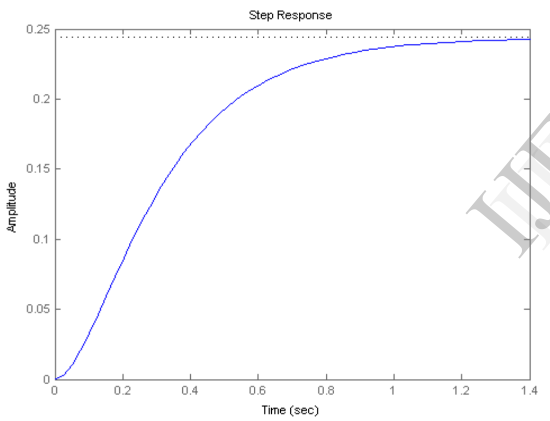

Figure 2. Uncontrolled DC motor response

Fig.2. shows the open loop transfer function behaviour of the dc motor to a unit step input. It is now observed that the motor's response to a unit step input signal is 0.1 rad/sec. This is one-tenth of the desired response. Settling time obtained is 3 sec.

3. PI Controller

The closed loop transfer function between the output C(S) and the input R(S) is given in equation(6) below.

$$C(s)/R(s) = [\{K_m\ (sK_p+K_i)\}/\{T_m s^2+(1+K_m K_p)s+k_m k_i\}] \quad (6)$$

Where Ki and Kp, are the integral and the proportional gains of P-I or I-P controller, Tm, is the mechanical time constant of motor, and Km, is the motor gain constant[4].

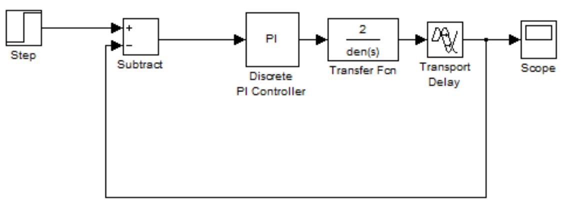

Figure 3. PI controlled system

When the circuit connections shown in fig.3 are done in MATLAB/simulink, then the graphical result so obtained is shown below in fig.4.

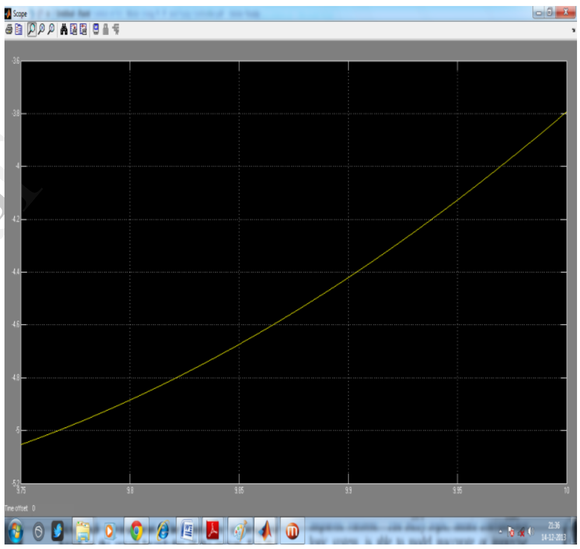

Fig.4: Response of a tune PI controlled system

4. PID Controller

A simple strategy which widely used for industrial control is PID controller. But the parameter selection for the Kp, Ki and Kd gain is always difficult. Many tuning algorithms are developed, but it is still difficult to select particular algorithm for designing PID gain values for the particular system for particular process control. Fig.5 shows the circuit connections of PID controlled system.

Thus in order to provide an improvement to the performance of the DC motor, a PID controller is introduced. The set up of PID controller in MATLAB/simulink environment is shown below in fig.5[3].

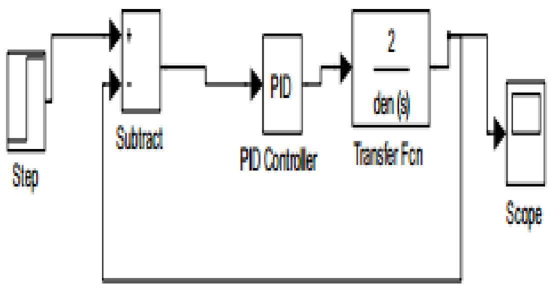

Figure 5. PID controlled system in MATLAB/Simulink

A simple feedback control theory is utilized to represent the overall PID controlled system[3].

This PID controller has the transfer function of the form:

$$K_p + \frac{K_I}{s} + K_D S = \frac{K_D S^2 + K_P S + K_I}{s} \quad (7)$$

It is observed that when the proportional gain and PI are chosen alone(arbitrarily), then the response of the motor is not satisfactory. This problem also continues when the integral gain and the derivative gain alone are concentrated on.

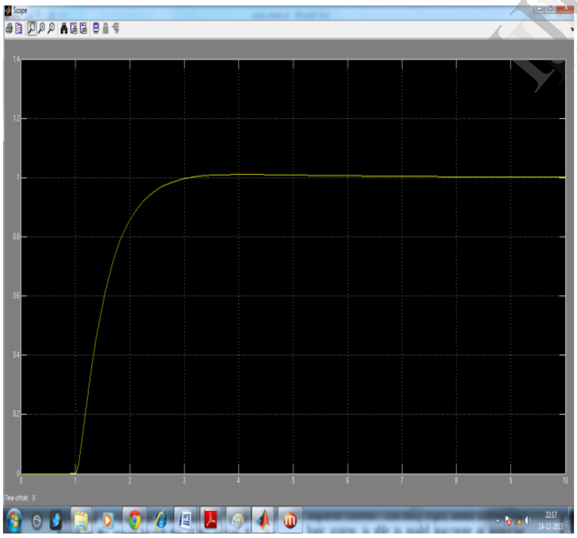

Figure 6. Response of a tune PID controlled system

Therefore, in order to have the desired motor response, the PID controller has to be tuned. Tuning of PID controller using a trial and error method wastes time and if not properly tuned the dc motor could be damaged. To save us a lot of efforts, a tuning guide proposed by Ziegler-Nichols is adopted with the aim of; shortening the rise time,

eliminate/reduce the overshoot, quickening the settling time of the system to a steady state, and reducing to a tolerable value the steady-state error which is the difference between the steady-state output and the desired output [5].

When the PID controller is properly tuned according to Ziegler-Nichols tuning rule applied to a unit step input system, and with proportional gain, Kp = 250, integral gain = 100, and derivative gain = 20, the response or plot so obtained is shown in fig.6.

5. Fuzzy logic controller

1. Principles of fuzzy modelling

The general algorithm for a fuzzy system designer can be synthesized as follows:

A)Fuzzificatin
(a) Normalize of the universes of discourses for the fuzzy input and output vector.
(b) Convert crisp data into fuzzy data or membership function.
(c) Calculate the membership function for every crisp value of the fuzzy input.

B)FuzzyInference
(d) Combine membership function with the rule to drive the fuzzy output.
(e) Calcution of the membership function for every crisp value of the fuzzy input.

C)Defuzzificatin
(f) Calculate the fuzzy output, using suitable defuzzification method.

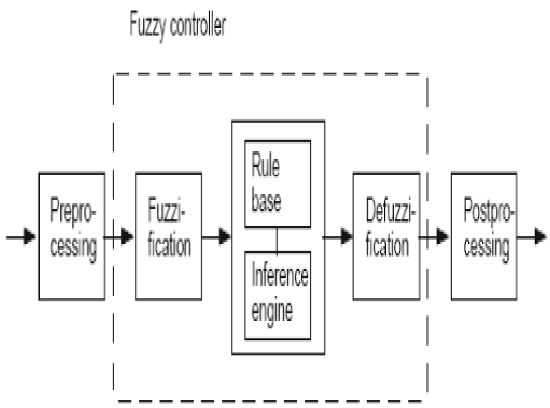

Figure 7. Process blocks of a fuzzy controller

(A) Fuzzy membership function
A membership function for a fuzzy set A on the universe of discourse X is defined as µA: X → [0,1], where each element of X is mapped to a value

between 0 and 1. This value, called membership value or degree of membership, quantifies the grade of membership of the element in X to the fuzzy set A.

(B) Types of inference system

Mamdani-Type Fuzzy Inference- is defined for the toolbox, expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification.

Sugeno-Type Fuzzy Inference- This topic discusses the so-called Sugeno, or Takagi-Sugeno-Kang, method of fuzzy inference. Introduced in 1985, it is similar to the Mamdani method in many respects. The first two parts of the fuzzy inference process, fuzzifying the inputs and applying the fuzzy operator, are exactly the same. The main difference between Mamdani and Sugeno is that the Sugeno output membership functions are either linear or constant.

(C) Fuzzy rules for developing fis

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in the previous sections: Membership Functions, Logical Operations, and If-Then Rules.

2. System design with FLC

The membership functions should be chosen such that they cover the whole universe of discourse.

Now the algorithm is implemented in matlab with a seven Member fuzzy inference system used for the input parameters, that is, error and change in error and also for the output. A Mamdani-type fuzzy inference approach is utilized. The set up is as shown in fig.8.

Table 1 is of Fuzzy Sets and mfs for Input Variable Speed Error (e).

Table 2 is of Fuzzy Sets and mfs for Input Variable Change in Error (Δe)

The membership function is displayed in fig. 9.

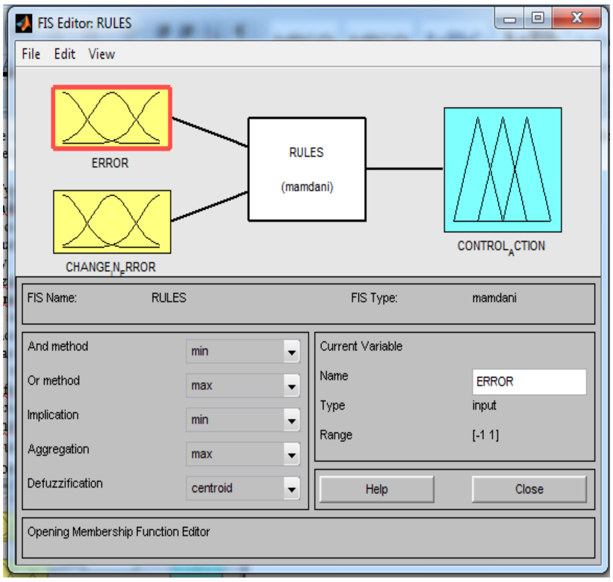

Figure 8. Selection of number of I/O for designing FIS for FLC

Table 1. Fuzzy sets and the respective membership functions for speed error (e)

Fuzzy set or label	Set Description	Range	Membership Function
NL (Negative Large)	Speed error is high in the negative direction.	-1.0 to -1.0 -1.0 to -0.8 -0.8 to -0.5	Trapezoidal
NM (Negative Medium)	Speed error is medium in the negative direction.	-0.8 to -0.5 -0.5 to -0.2	Triangular
NS (Negative Small)	Speed error is small in the negative direction.	-0.5 to -0.2 -0.2 to 0	Triangular
ZE (Zero)	Speed error is around zero.	-0.2 to 0 0 to 0.2	Triangular
PS (Positive Small)	Speed error is small in the positive direction.	0 to 0.2 0.2 to 0.5	Triangular
PM (Positive Medium)	Speed error is medium in the positive direction.	0.2 to 0.5 0.5 to 0.8	Triangular
PL (Positive Large)	Speed error is high in the positive direction.	0.5 to 0.8 0.8 to 1.0 1.0 to 1.0	Trapezoidal

Table 2. Fuzzy sets and the respective membership functions for Change in Error (Δe)

Fuzzy set or label	Set Description	Range	Membership Function
NL (Negative Large)	Speed error is high in the negative direction.	-1.0 to -1.0 -1.0 to -0.8 -0.8 to -0.5	Trapezoidal
NM (Negative Medium)	Speed error is medium in the negative direction.	-0.8 to -0.5 -0.5 to -0.2	Triangular
NS (Negative Small)	Speed error is small in the negative direction.	-0.5 to -0.2 -0.2 to 0	Triangular
ZE (Zero)	Speed error is around zero.	-0.2 to 0 0 to 0.2	Triangular
PS (Positive Small)	Speed error is small in the positive direction.	0 to 0.2 0.2 to 0.5	Triangular
PM (Positive Medium)	Speed error is medium in the positive direction.	0.2 to 0.5 0.5 to 0.8	Triangular
PL (Positive Large)	Speed error is high in the positive direction.	0.5 to 0.8 0.8 to 1.0 1.0 to 1.0	Trapezoidal

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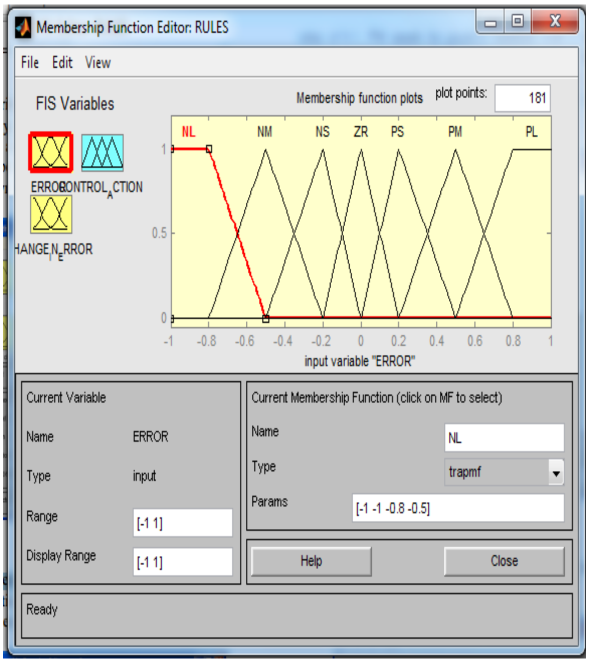

Fig.9: Membership function of the input to the fuzzy logic controller

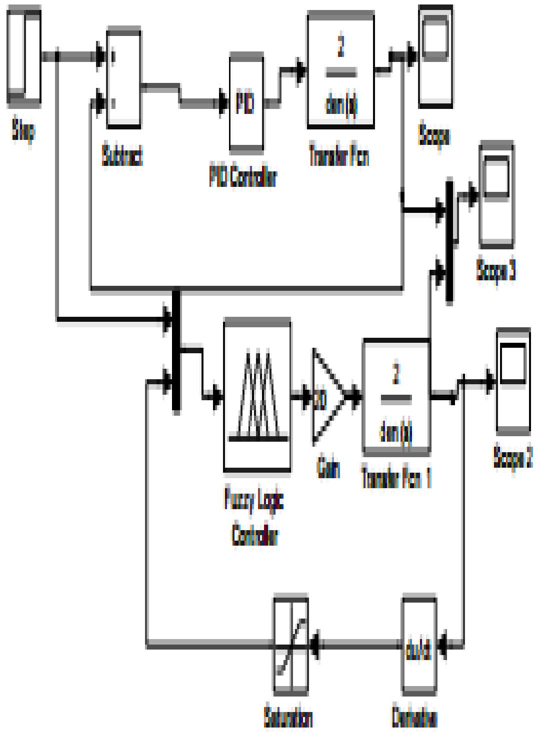

Figure 10. Combination of PID and Fuzzy logic controller

5. Comparison between PIDand FLC

The simplification or linearization of the non-linear system under consideration has to be performed by the conventional control methodologies like PI, PD and PID since their construction is based on linear system theory. Hence, these controllers do not provide any guarantee for good performance [8]. They require complex calculations for evaluating the gain coefficients. These controllers however are not recommended for higher order and complex systems as they can cause the system to become unstable. Hence, a more heuristic approach is required [9] for choice of the controller parameters which can be provided with the help of fuzzy logic, where we can define variables in a subjective way. Thus we can avoid the numerical complicacy involved in higher order systems.

Fuzzy logic provides a certain level of artificial intelligence to the controllers since they try to imitate the human thought process. This facility is not available in the conventional controllers[10].

Now the following matlab/simulink arrangement is utilised inorder to compare the responses of the PID and that of FLC.

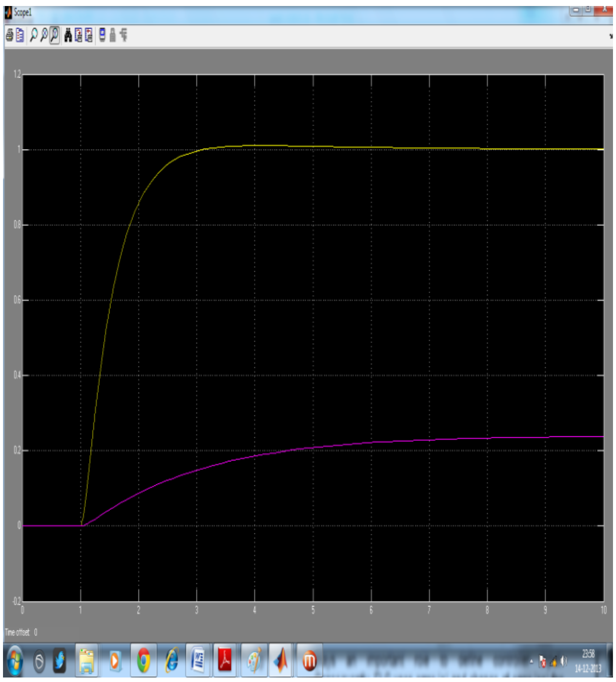

Figure11. PID and Fuzzy logic controller response

CONCLUSION

The performance of a well tuned PI and PID controller is undoubtly ahead in terms of system robustness and predictability. Another way of controlling a dc motor is through fuzzy logic (Mamdani-type) controller which shows an appreciable performance though not optimal. No tuning is required with Fuzzy logic based controller but it has a sluggish response to the input signal and cannot readily predict. The peak overshoot of the system was found to have reduced as compared to the earlier designs of the controllers. Hence the proposed FLC is better than the conventionally used PI and PID controller but it has to be optimized so as to achieve an optimum value for the rise time, settling time and peak overshoot.

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