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Performance Evaluation of Fuzzy Controllers Applied to Speed Control of DC Shunt Motor

NARMADHA T.V., SHOBA E.S.R.,
Department of Electronics and Instrumentation Engineering,
St.Joseph's College of Engineering, Anna University,
Jeppiaar Educational Trust, Jeppiaar Nagar,
Chennai, Tamil Nadu
INDIA

Abstract : - In this paper , performance of fuzzy PD , fuzzy PI , fuzzy PD+I , fuzzy PID controllers are evaluated and compared. The comparison is based on their ability of controlling the speed of DC shunt motor, which merely focuses on performance index of the controllers, and also time domain specifications namely rise time, settling time and peak overshoot. The experiments showed that the fuzzy PID controllers are the best performing candidates in all aspects. The Fuzzy PI controller exhibited null offset but suffers from poor stability and high peak overshoot, whereas the fuzzy PD controller exhibited fast rise time , with no overshoots but has a higher value of IAE. Thus, the comparative study recommends fuzzy PID controller but it is usually associated with complicated rule base and tedious tuning . To circumvent these problems, I this paper, the fuzzy PID controller is implemented in two simpler methods.

Key words : Motor control , Fuzzy controllers, Performance index ,Performance specifications ,servo control, regulator control

1 Introduction

In control or robotic engineering, motor control plays a major role and is an unavoidable part, regardless of whether it is speed or position control. The effectiveness of a controller can be justified by performance objectives such as settling time, rise time , peak overshoot and IAE.

In the last three decades fuzzy logic control has evolved as an alternative or complementary to the conventional control strategies in various engineering areas. Fuzzy control theory usually provides nonlinear controllers that are capable of performing different complex nonlinear control actions.[1] In this paper the major fuzzy control schemes are used to perform a comparative study. The candidate controllers are fuzzy PD , fuzzy PI, fuzzy PD+I and fuzzy PID controllers .The detailed derivation of these fuzzy controllers is referred to [2],[5].

The organization is as follows. Section II presents the various schemes of fuzzy logic control. Section III is devoted to a brief introduction of DC shunt motor and its transfer function model. In section IV the proposed fuzzy controllers are applied to speed control of DC shunt motor and the conclusions are drawn in section V.

2 Fuzzy Logic Control

Unlike conventional controls, designing a fuzzy logic control does not require precise knowledge of the system model such as the poles and zeroes of the system transfer function. Imitating the way of human learning, the trial error and the rate of error are two crucial inputs for the design of such fuzzy control scheme.

The general structure of fuzzy logic controller is given in figure (1).In the fuzzification module, the inputs position error, and velocity error are scaled to some real number in the interval [-1 1] and are mapped to linguistic variables by the fuzzfication operator. The knowledge base of fuzzy logic controller is composed of data base and rule base. The data base provides the necessary information for the proper functioning of fuzzification module, rule base and defuzzification module.

The rule base represents in a structured way, the control policy of the system in the form of set of rules such as

'IF error is PB AND derror is PB THEN mv is PB'

The defuzzication module converts the controller output into crisp value which is then denormalised to map onto its physical domain.

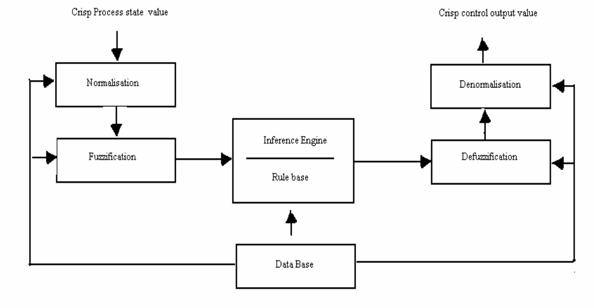

Fig 1 : Structure of fuzzy knowledge base controller

2.1 Fuzzy PI Control

The fuzzy PI controller is shown in figure(2).[4] From the figure, the output of digital fuzzy PI controller in the discrete time domain can be given by

$$U_{PI}(nT)= U_{PI}(nT-T) +Ku_{PI}\, \Delta\, U_{PI}(nT) \qquad (1)$$

Where T is the sampling time , Kp,Ki are the proportional and integral gains respectively, and Ku_{PI} is the fuzzy control gain. If $e_p(nT)$ is the position error at the n^{th} sampling time, $e_v(nT)$ is the velocity error then the incremental control output is given by

$$\Delta\, U_{PI}(nT)= F\{Kp *e_v(nT), Ki *e_p(nT)\} \qquad (2)$$

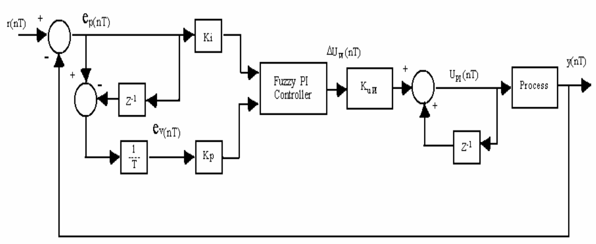

Fig 2: Fuzzy PI Controller

2.2 Fuzzy PD Controller

Similarly the fuzzy PD control output can be derived from figure (3) as

$$U_{PD}(nT)= Ku_{PD}*F\{Kp* e_p(nT), Kd*e_v(nT)\} \qquad (3)$$

where Ku_{PD} is the fuzzy control gain and Kd is the derivative gain.

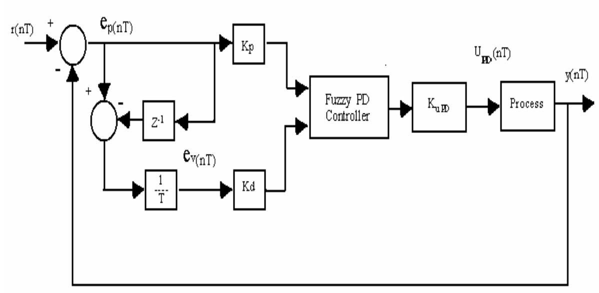

Fig 3: Fuzzy PD Controller

2.3 Fuzzy PID Control

There are several methods available to implement fuzzy PID controller. One of which utilizes the three inputs error , derivative error and integral error . This method leads to too many rules and its realization in practice is difficult to implement and tune. One of the alternatives is to realize fuzzy PID controller as a parallel combination of fuzzy PI and fuzzy PD controllers as shown in figure(4).[5] The combined output U(nT) is given by

$$U(nT)= U_{PI}(nT) + U_{PD}(nT) \qquad (4)$$

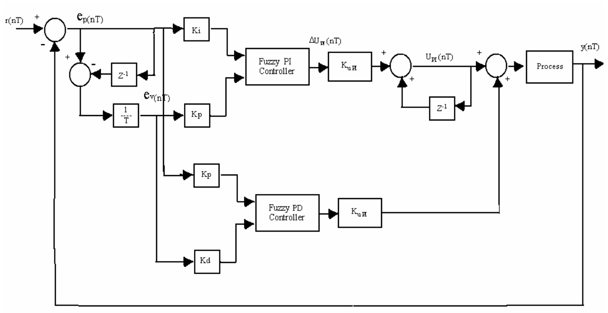

Fig 4: Fuzzy PI+PD controller

2.4 Fuzzy PD +I Control

However the rules concerning the integral action are troublesome , another solution to realize the fuzzy PID is to separate the integral action as fuzzy PD + I (FPD+I) controller shown in Fig. (5).[2],[7] The controller output is computed as

$$U(nT) = Ku*F\{Kp*e_p(nT), Kd*e_v(nT)\}+ Ki*e_i(nT) \quad (5)$$

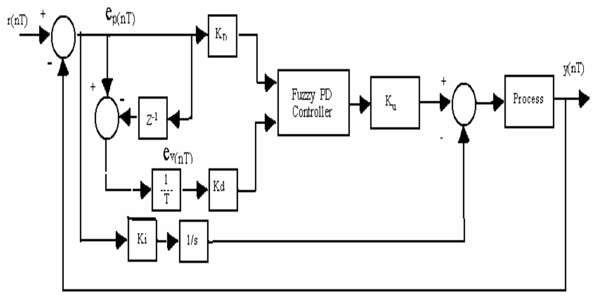

Fig 5 : Fuzzy PD + I Controller

3 DC Motor

The speed of dc motors changes with the load torque. To maintain a constant speed, the armature voltage should be continuously varied. Most industrial drives operate as closed loop feedback systems, as they have the advantages of improved accuracy, fast dynamic response, and reduced effects of load disturbances and system non linearities.[6]

The motor speed is adjusted by setting reference voltage v_r. Assuming a linear power converter of gain K_2, the armature voltage of the motor is

$$v_a= K_2 v_r \quad (6)$$

Assuming that the motor field current I_f and the back emf constant Kv remain constant during any transient disturbances, the system equations are

$$e_g = K_v I_f \omega \quad (7)$$
$$v_a= R_m i_a + L_m\, di/dt + e_g \quad (8)$$
$$T_d = K_t I_f i_a= J\, d\omega/dt + B\, \omega + T_L \quad (9)$$

where e_g is the back emf , ω is the speed of the motor, R_m, L_m is the armature resistance and armature inductance respectively, i_a is the armature current, T_d is the driving torque, K_t is the torque constant, J is the inertia of the load ,B is the friction coefficient of the load and T_L is the load torque

The aim is to alter the armature feed voltage to make the motor track the desired speed.

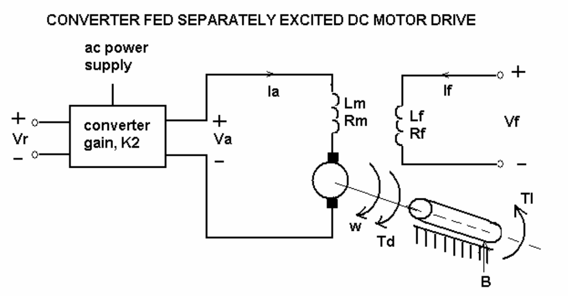

Fig 6: DC motor

4 Simulation Results

In this study, 110 V, 2.5 hp, 1800 rpm separately excited DC motor having the following parameters are used: R_a = 1 Ω, L_a = 46 mH, J = 0.093 kgm^2, B = 0.008 N-m/rad/s, K_v = 0.55 V/rad/s.[3] The dc motor is shown in figure(6). A typical triangular membership function is adopted for fuzzifying the controller inputs and outputs, as shown in figure (7). The rule bases for fuzzy PD and fuzzy PI controllers are made slightly different to achieve greater flexibility during tuning. The bisector method is used as the defuzzification method .The FAM table and control surface of the fuzzy PD controller are shown in table (1) and figure(8) respectively. The FAM table and the control surface of the fuzzy PI controller are shown in table (2) and figure (9) respectively.

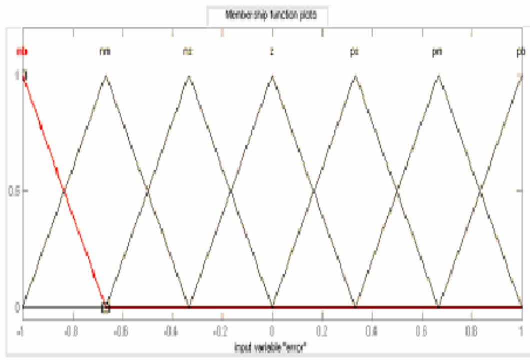

Fig 7: Membership functions for error , derror, controller output

DE/E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 1: Fuzzy Associative Memory for Fuzzy PD Controller

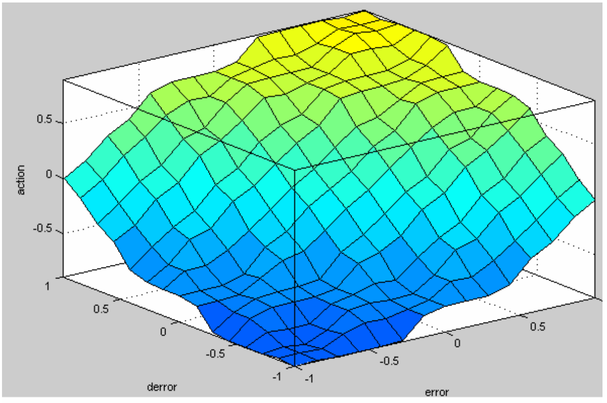

Fig 8: Control surface for Fuzzy PD Controller

DE/E	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NM	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PM	PB	PB	PB

Table 2: Fuzzy Associative Memory for Fuzzy PI Controller

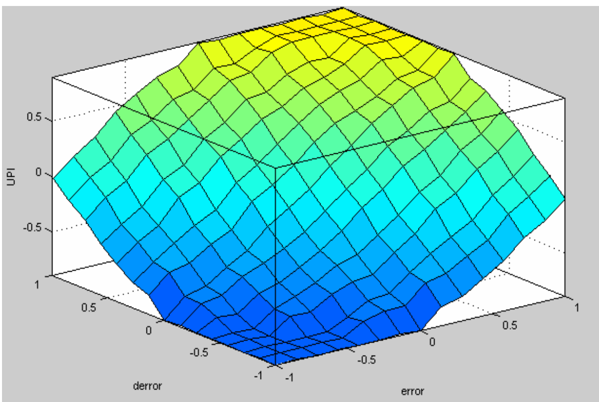

Fig 9: Control surface for Fuzzy PI Controller

To evaluate the performance of the controllers, a step change in set-point is applied at the first instant followed by a step change in load at the tenth second. The simulink models were simulated using fourth order Runge-Kutta method with fixed step size of 10 msec. The figure (10) shows the response of the controllers. Figure (11) and (12) depict the position and velocity errors obtained during aforementioned experiment. Table (3) presents the detailed comparison results of fuzzy controllers.

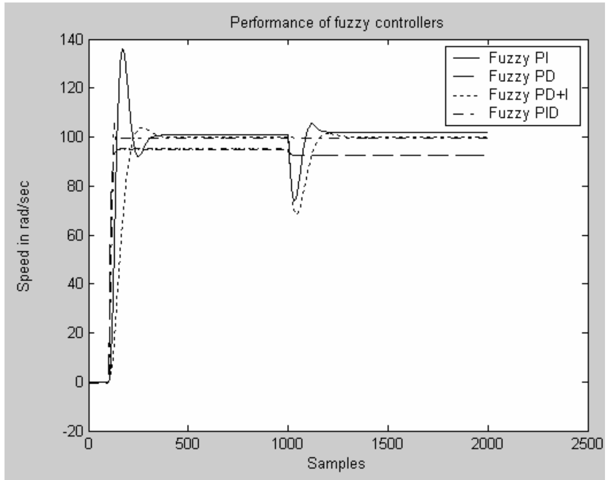

Fig 10: Responses of fuzzy controllers

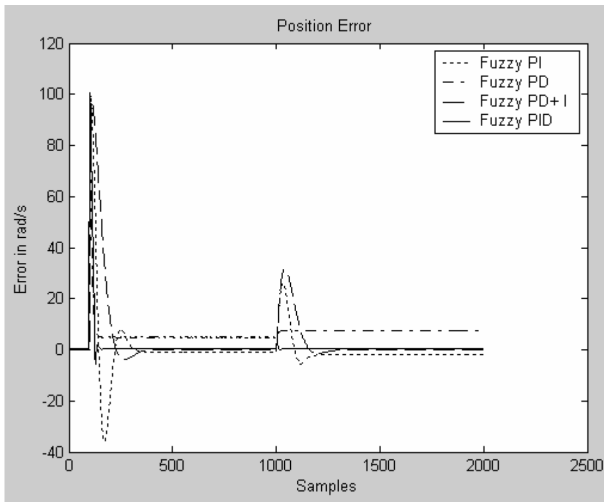

Fig 11: Position error

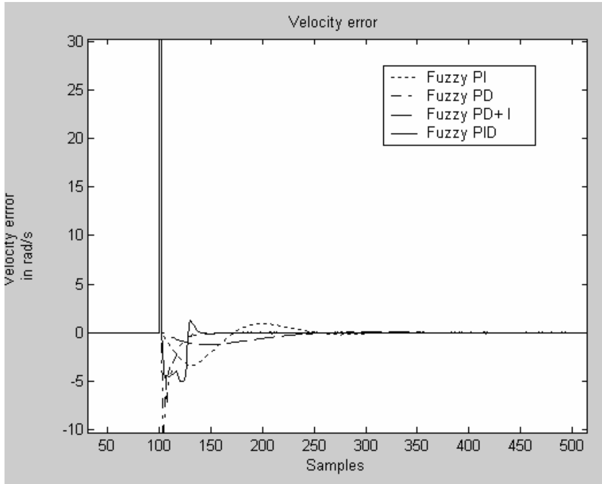

Fig 12: Velocity error

Candidate Controller	**IAE**	**Rise time, t_r (sec)**	**Settling time, t_s (,sec)**	**Peak overshoot %Mp**
Fuzzy PI	84.55	0.43	2.10	36
Fuzzy PD	127.14	0.40	0.40	00
Fuzzy PD+I	89.32	1.25	2.75	04
Fuzzy PID	20.74	0.24	0.50	05

Table 3: Comparison results

5 Conclusion

This paper presents a comparison study of fuzzy controllers of speed control of DC shunt motor. The experiments showed that the fuzzy PID controllers show the best performance in all aspects. It can be noticed that the fuzzy PD+I has a greater rise time and settling time , which could be contributed by the pure integrator employed. Further investigating other candidates ,the Fuzzy PI controller has the highest peak overshoot but with null offset, whereas the fuzzy PD controller exhibited fast rise time , with no overshoots but has a higher value of IAE. It may be concluded that fuzzy PID proves to be better in all points of view. However, it is always worth investigating a simple tuning algorithm for fuzzy PID which would be carried out in near future.

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