Comparison of IPD and Fuzzy Logic Velocity Control In Two Degree of Freedom DC Motor System

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Abstract- In this study, IPD and Fuzzy Logic Controller (FLC) are applied separately to perform velocity control of the system that has two degree of freedom in real time. IPD controller uses coefficients which are integral, differential and proportional are calculated with Coefficient Diagram Method (CDM). This method is based on polynomial approach and has many advantages such as easy design procedure, an interpretation of settling time, stability and parameter tuning. FLC uses linguistic variables and can be applied easily. IPD and FLC results are compared in terms of current, voltage and velocity for reference input.

Keywords IPD, FLC, CDM, velocity control, reference input.

1. Introduction

DC motors are widely used industrial areas because of the advantages and convert electrical energy into rotational mechanical energy. DC motors have relatively low cost to the other motor types, such as servo, step, brushless DC etc., facility of control with uncomplicated motor drive circuits and can produce high torque in the first operation, operate under heavy loads and reverse direction operation can be done by changing the polarity of the poles.

PID controller is usually used in industrial environments and devices because of its simplicity. PID control design is based on mathematical model so it requires system transfer function. PID means proportional, integral, differential control coefficients and it can be described as controller transfer function. Generally, Ziegler-Nichols method is used to calculate the coefficients of PID. On the contrary, regular PID controller structures can be more efficient by changing structures of IPD in order to have less overshoot. IPD controller is usually used in precise control applications [1 2].

The Coefficients of IPD controller which are integral, differential and proportional can be calculated easily and effectively with using Coefficient Diagram Method (CDM). It is suggested from Shunji Manabe in 1991, since that date it has begun to be used in different control applications. It gives possibilities which are resistance to inner and outer disturbances, lower overshoot of system answer, easy design and implementation, for simple and complex systems [3-5].

Fuzzy Logic Controller was suggested as a new type of controller by A. Zadeh in 1964. It uses not only 1 and 0 but besides them; numbers between 1 and 0 are used, so FLC gives robust control facility. There are many advantages to use FLC. For example, no mathematical equations, capability of using linguistic and numerical variables, possibility of application in all fields [5].Apart from the PID controller structure, PI, PD, PIDP or IPD structures can be used. By comparing these control structures with FLC, it can be decided which one is a better choice for desired conditions. Moreover, a controller can be designed with combinations of FLC and PID or IPD controller [6-10].

In two degree of freedom, systems have two mass or two rotary inertia. One of the motor is source of movement and the other inertia is the load. Strap or coupling machine elements can be used to transfer motion from one to the other [11 12].In this study, the system consists of two DC motors with different inertia pulleys and one of DC motor is chosen as driver and the other one as load. Flexible strap is used for transfer motion and behaves like a spring. Coefficients of IPD controller are calculated with using Coefficient Diagram Method which is polynomial approach. IPD and FLC are applied to experiment system separately then the results are compared.

2. Mathematical Model of The System

DC motor system converts electrical energy to mechanical energy then motion is transferred to the load inertia by elastic belt. The system is shown physical in Fig.1 and block diagram schema in Fig.2

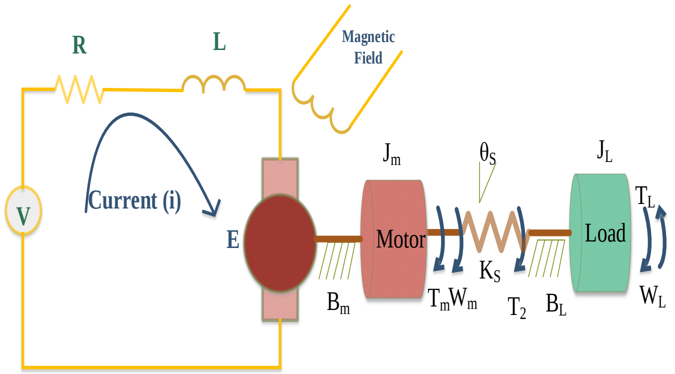

Fig. 1. The system schema

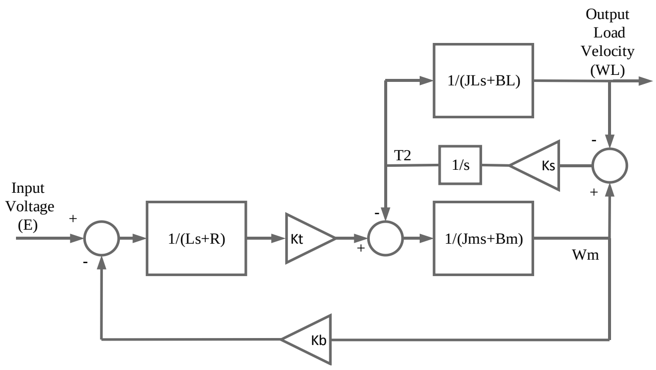

Fig. 2. The system block diagram

Table 1. System Variables

Symbol	*Definitions*	*Units*
K_b	Electromotive Force	V.s/Rad
K_t	Motor torque constant	N.m/A
B_m	Motor friction	N.m.s/rad
R	Armature resistance	Ohm(Ω)
L	Inductance of armature	Henry (H)
J_m	Motor inertia	Kg.m^2
E	Back EMF	Volts (V)
J_L	Load inertia	Kg.m^2
i	Armature current	Current (A)
θ_s	Angular position	Radians
W_m	Motor Angular speed	Rad/s
W_L	Load Angular speed	Rad/s
B_L	Load friction	N.m.s/rad
K_S	Flexible strap	N.m/rad
T_m	Motor torque	N.m
T_L	Load torque	N.m
T_2	Strap torque	N.m
V	Input voltage	Volts (V)

Transfer function of system is given in Eq. (1) with respect to input voltage (V) and load angular velocity (W_L).

$$\frac{W_L(s)}{V(s)} = \frac{K_t * K_s}{((J_m s+B_m)*(Ls+R)+K_t*K_b)*(J_L s^2+B_L s+K_s)} \quad (1)$$

3. Designing of IPD Controller

The IPD controller ensures more stability with using CDM which gives the coefficients of IPD. The IPD controller structure is given in Fig.3. Expression of letter are reference input R(s), output Y(s) and transfer function of system G(s).

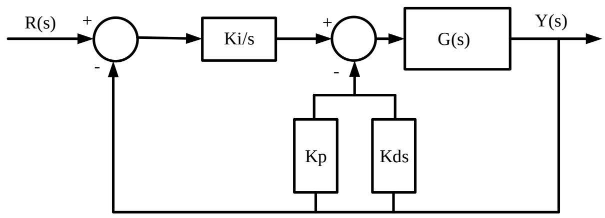

Fig. 3. IPD Controller structure

Substituting IPD to Eq. (1), closed loop transfer function of system with controller are obtained and given Eq. (2)

$$TF = \frac{K_i K_s K_t}{A+B+C} \qquad (2)$$

Where;

$$A = J_m J_L L s^5 + +J_m J_L R s^4$$

$$B = (J_m L K_s + J_L K_b K_t)\, s^3 + (J_m R K_s + K_d K_s K_t) s^2$$

$$C = (K_p K_s K_t + K_b K_s K_t) s + K_i K_s K_t$$

Characteristic polynomial is obtained from Eq. (2)

$$KP = A + B + C \qquad (3)$$

Characteristic polynomial coefficient is used with Manabe Form which is given in Table 2.

Table 2. Standart Manabe Form

	n	γ_i	γ_{i+1}	γ_{i+2}	γ_{i+3}	γ_{i+4}
Manabe Form	4	2.5	2	2		
	5	2.5	2	2	2	
	6	2.5	2	2	2	2

By using Manabe form and characteristic polynomial, time constant (τ), index (γ_1, γ_2) equations are obtained and given below.

$$\tau = \frac{a_1}{a_0}\;;\; \tau = \frac{(K_p K_s K_t + K_b K_s K_t)}{K_i K_s K_t} \qquad (5)$$

$$\gamma 1 = \frac{{a_1}^2}{a_2 * a_0};\, \gamma 1 = \frac{(K_p K_s K_t + K_b K_s K_t)^2}{(J_m R K_s + K_d K_s K_t)*(K_i K_s K_t)} \qquad (6)$$

$$\gamma 2 = \frac{{a_2}^2}{a_3 * a_1};\, \gamma 2 = \frac{(J_m R K_s + K_d K_s K_t)^2}{(J_m L K_s + J_L K_b K_t)*(K_p K_s K_t + K_b K_s K_t)} \qquad (7)$$

Solving Eq. (5, 6, 7), Ki, Kp and Kd coefficients are calculated and given in Eq. (8, 9, 10).

$$K_i = \frac{(J_m * L * \gamma_1^2 * \gamma_2 * K_s + J_L * \gamma_1^2 * \gamma_2 * K_b * K_t)}{(\tau^3 * K_s * K_t)} \qquad (8)$$

$$K_p = \frac{(J_m * L * \gamma_1^2 * \gamma_2 * K_s - \tau^2 * K_b * K_s * K_t + J_L * \gamma_1^2 * \gamma_2 * K_b * K_t)}{(\tau^2 * K_s * K_t)} \qquad (9)$$

$$K_d = -\frac{(J_m * L * \gamma_1^2 * \gamma_2 * K_s - J_m * R * \gamma_1 * \gamma_2 * K_s + J_L * \gamma_1^2 * \gamma_2 * K_b * K_t)}{(\tau * \gamma_1 * K_s * K_t)} \qquad (10)$$

Control system parameters can be obtain by using Manabe Form; time constant and index where; τ =0.12, γ_1= 2.5, γ_2=2 . System characteristic values are given in Table 3. Afterwards, substituting values in Eq. (8, 9, 10) coefficients are obtained as Ki =5.4, Kp=0.5, Kd=-0.0048.

Table 3. System characteristic values

Motor	***Value***	***Unit***
K_b	0,155	Vs/Rad
K_t	0,137	Nm/A
B_m	0,00095	Nm/rad/sec
R	3,592	Ohm
L	0.1	Henry
J_m	0.001	Kgm^2
Load		
J_L	0.0001	Kgm^2
B_L	0,00086	Nm/rad/sec
Flexible Strap		
K_S	1.09	Nm/rad

The system's open loop roots are shown in Fig. 4. When the roots are examined, it seems that they are marginally stable. In addition, the closed loop root placement graphics determined by the Coefficient Diagram Method, IPD controller is shown in Fig.5, and the marginally stable roots are replaced as stable roots.

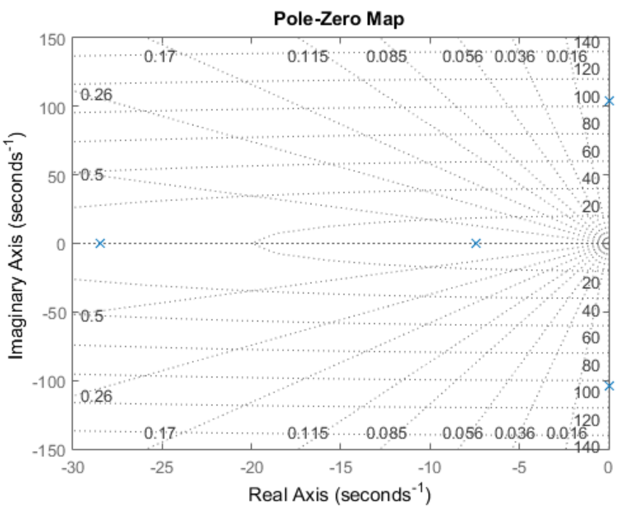

Fig. 4. The roots of open loop

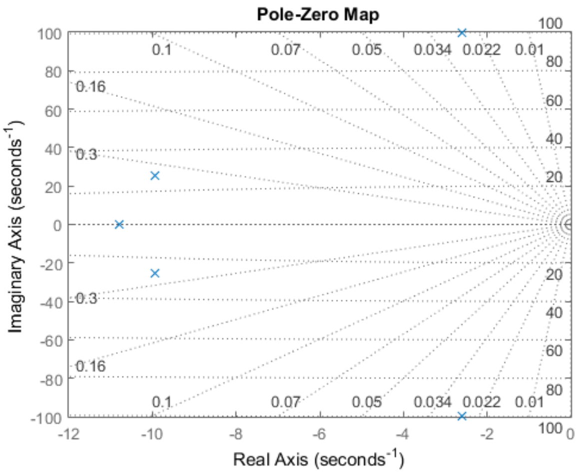

Fig. 5. The roots of closed loop

4. Designing of Fuzzy Logic Controller

The fuzzy logic controller is designed by analyzing the behavior of the system without mathematical model subsequently, based on knowledge as If-Then rules.FLC If-Then statements are associated by membership functions are prepared for inputs and outputs. The more membership functions are defined, the more successful of control of system becomes possible, and so controller system rules are designed as 7x7. The Linguistic variables defining the rule base for the fuzzy logic controller are given in Table 4. Membership ranges are named NB, NM, NS, Z, PB, PM, PS represent “Negative big”, “Negative medium”, ”Negative small”, ” Zero”, “Positive big”, “Positive medium”, “Positive small”, respectively.

The fuzzy logic control is achieved fuzzification operation and output value is determined by FLC decision operation after the specified rules. FLC uses Linguistic variable instead of numerical variable. The numerical variables are converted to linguistic variables, which is named fuzzification. FLC inference engine decide output with using Fuzzy rules. Linguistic variables give output in numerical by defuzzification operation. This condition is stated in Fig.6. In Fuzzy Logic Controller structure, error and error change are applied to FLC as input, thereafter; it gives voltage to the system as output. The designed FLC is given in Fig.7.

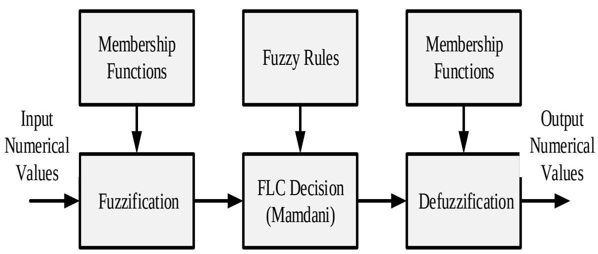

Fig. 6. Fuzzy Logic Controller structure

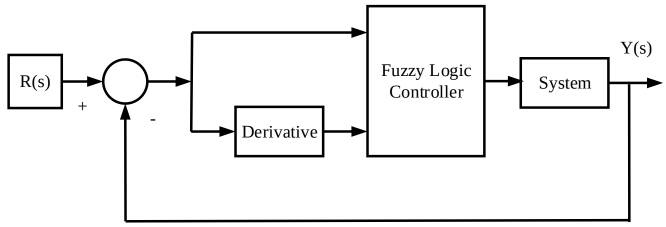

Fig. 7. Application Form FLC to system

Velocity error, derivative of velocity error and output membership functions are given respectively in Figures (8-9-10). Surface graph generated by input and output membership functions is shown in Fig.11.Velocity error and derivative of velocity error rules are matched to output rules, which are given in Table 4.

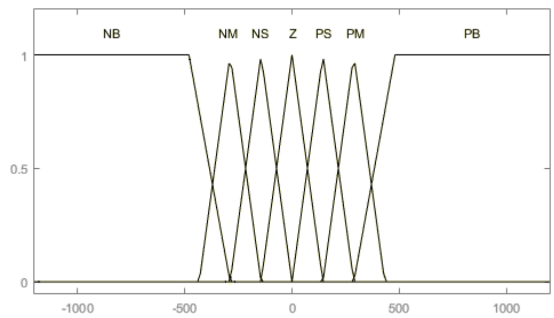

Fig. 8. Velocity Error Membership Functions

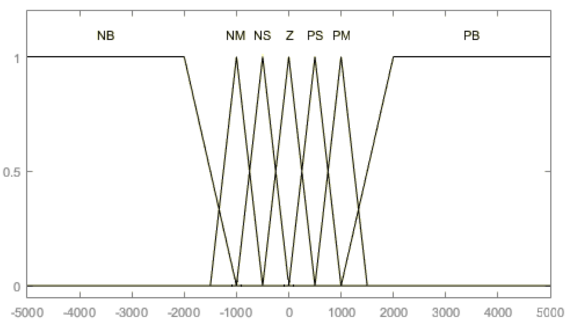

Fig. 9. Derivative of Velocity Error Membership Functions

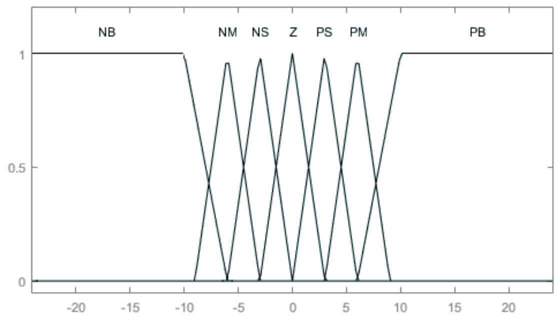

Fig. 10. Output Membership Functions

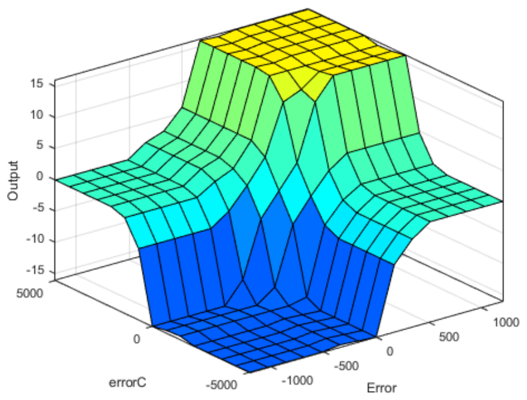

Fig. 11. FLC Surface

Table 4. The system Fuzzy Logic Controller rules table

	Derivative of Velocity Error						
Velocity Error	***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	PS
Z	NB	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PS	PB	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

5. The Experimental System

The The system is designed with two DC motor, 100w DC motor acts as the driver motor and 140w DC motor is used as the load. Flexible strap is used to transfer motion from driver to the load. DC motor velocity information is gained from 140w load motor by attached 360p encoder. To control system, Quanser Q8 data acquisition card (DAQ) is used for sending analog signals and getting encoder signals.

The system is designed by using block diagrams with Matlab-Simulink that also provides communication between computer and DAQ card. When control signal arrived to DAQ card then it sends interpretation of analog signals to H-Bridge Motor driver. In addition, to gain velocity of the load, feedback signal from 360p encoder is used. In other words, DC motor is energized from H-Bridge driver and feedback velocity information is gained from the load encoder. Flexible strap is transferred motion from motor to load. It provides flexible motion and this point differ from other two degree of freedom systems. The goal of this study, if belt stretches under inner or outer disturbances, controller should compensate the affect.

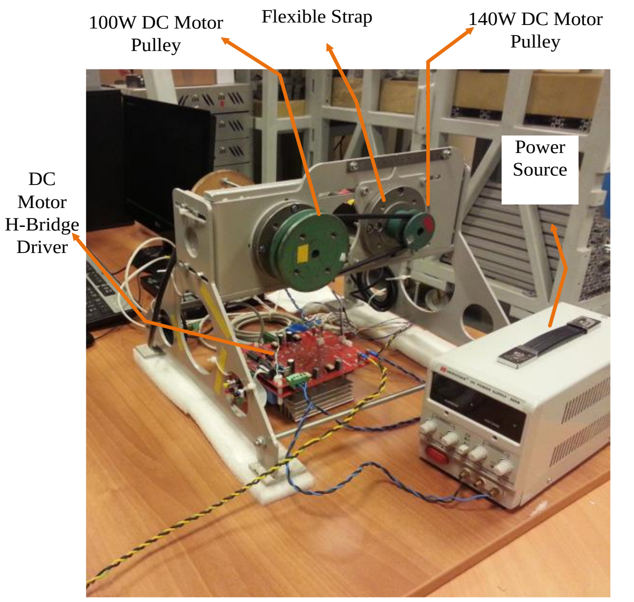

Fig. 12. Experimental System Frontside

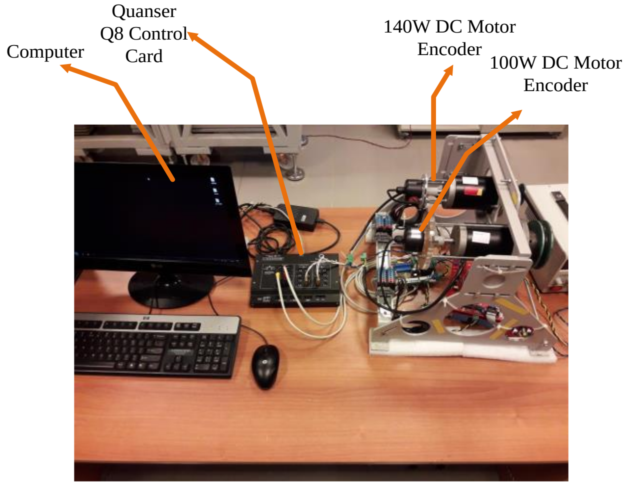

Fig. 13. Experimental System Backside

The results of CDM IPD controller and Fuzzy Logic Controller are compared in terms of current, voltage and velocity for 50 rad/s velocity input value. According to the measurement results, FLC draws more current and voltage than IPD when reference is applied, shown Fig.14 and Fig.15 respectively. When the results are examined, it is clear that FLC achieves to desired values faster than IPD controller (Fig.16). Moreover, in all three graphs, controller responses are shown according to the disturbance torque, applied between fifth and seventh second. It has been observed that FLC responds faster than IPD controller.

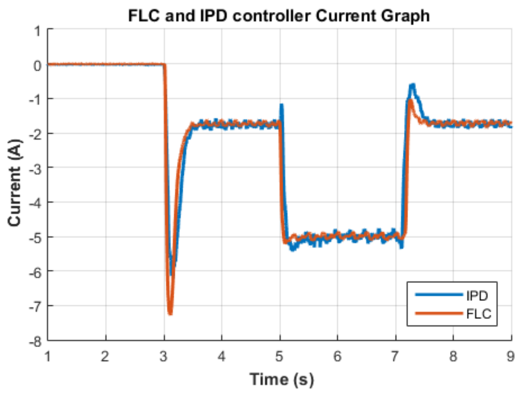

Fig. 14. IPD and FLC current graph in system velocity control

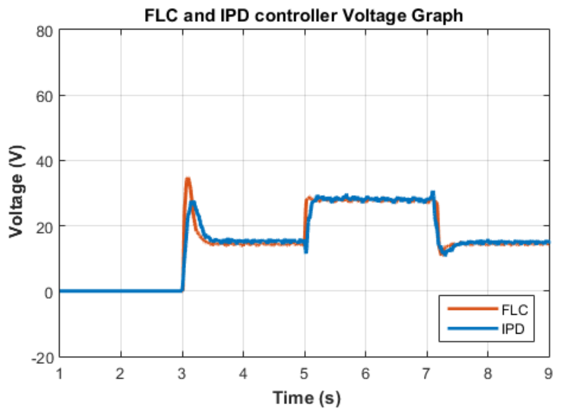

Fig. 15. IPD and FLC volt graph in system velocity control

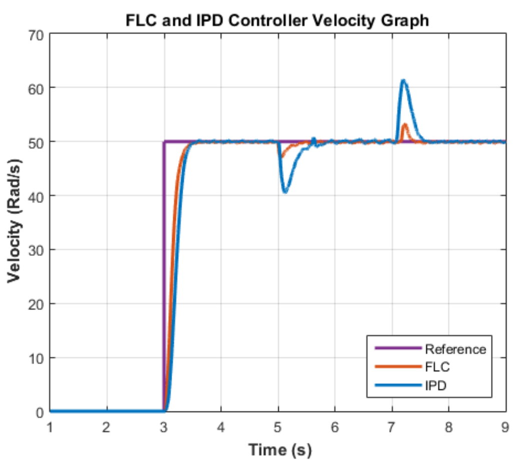

Fig. 16. IPD and FLC graph in system velocity control

6. Conclusion

The Two degree of freedom DC motor system is used in the study. The system transfers motor motion to load by elastic strap. Firstly, mathematical model and transfer functions of the system are obtained. Then, IPD and FLC based active control algorithm are applied to the system experimentally. CDM based IPD controller and FLC are applied for velocity control, then results of controllers are compared. FLC acts faster than IPD controller and performs better even at reference input or against output disturbance.

Acknowledgements

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