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Fuzzy Logic Controller versus PID Controller (DC Motor Speed Control)

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Abstract: The DC motor is a device that can be found in many applications ranging from industrial applications to home applications. In the use of DC motors the need for speed control and position control arises. Various methods could be applied to the control of DC motor speed, but we shall limit this paper to the use of the PID controller and the Fuzzy Logic Controller (FLC). The speed error signal e(t) and the change in speed error Ce(t) are fed as the input into the FLC. In case of PID the speed error e(t) only is input to generate the control signal u(t). We shall utilize simulations from software like Lab VIEW (Laboratory Virtual Instrument Engineering Workbench and also MATLAB in our analysis and to assert which controller is more preferable.

Keywords: DC motor, Speed control, PID controller, Fuzzy, controller.

I. INTRODUCTION

The importance of the dc motor cannot be over emphasized, this is because we can find its use in various applications where speed and position control are desirable e.g. steel rolling mills, electric trains, electric vehicles, electric cranes and robotic manipulators require speed controller to perform their task [1]. The dc motor is favored in industry control area compared to other types of motors because they have many good characteristics for example: high start torque characteristic, high response performance, easier to be linear control etc.[2] The primary property of dc motor is that its speed can be controlled by varying the terminal voltage. The Proportional Integral Derivative (PID) controller has been and is also still in use for controlling motor speed: but the Fuzzy Logic Controller has taken a good ground in the field of dc motor speed control. The PID relies on the exact mathematical model of the motor for control while the FLC can model inaccurate or imprecise models. [2]

In this paper section 2 will be our methodology dwelling on the model and design of the dc motor, the PID model and tuning and also on the FLC. Section 3 will be on simulation and results using the PID and the FLC using Lab VIEW and MATLAB. Section 4 will be our conclusion.

II. METHODOLOGY

We will begin with looking at the basic design and mathematical model of the dc motor.

A. The Dc Motor Model And Design

The speed of a dc motor can be varied either by; varying the armature voltage or inserting a resistance in series with The model of a dc motor is a separately excited device so the armature voltage can be varied without affecting the field voltage.

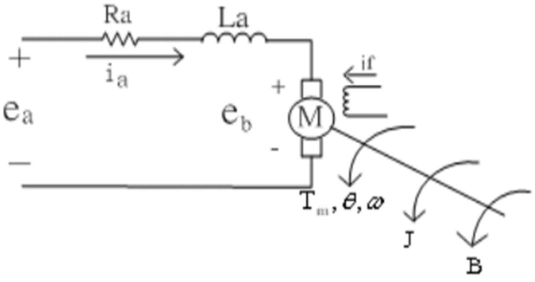


Figure 1. Basic diagram of the model of a dc motor

Where;

R_a : Armature resistance(Ω)

L_a : Armature inductance(H)

i_a :Armature current(A)

i_f : Field current(A)

e_a : Input voltage(V)

e_b : Back electromotive force (EMF)(V)

T_m : Motor torque(Nm)

ω: Angular velocity of rotor

J: rotor inertia (kgm^2)

B : Friction constant (Nms/rad)

K_b : EMF constant (Vs/rad)

K_T: torque constant (Nm/A)

The equation for the back emf is given as:

$$e_b(t) = K_b \frac{d\theta(t)}{dt} = K_b \omega(t)$$

Also Kirchoff voltage law,

$$e_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t)$$

Motor torque can gotten from Newton’s law by

$$T_m(t) = J \frac{d^2\theta(t)}{dt^2} + B \frac{d\theta}{dt} = K_T i_a(t)$$

Taking the Laplace transforms of the following equations

$$E_b(s) = K_b \Omega(s)$$

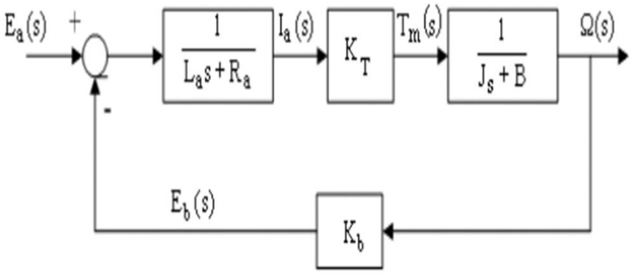
And

$$E_a(s) = (R_a + L_a s) I_a(s) + E_b(s)$$

And also,

$$T_m(s) = B\Omega(s) + Js\Omega(s) = K_T I_a(s)$$

The block diagram of the dc motor model is given below



$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s+R_a)(Js+B)+K_b K_T}$$

Where G(s) is the transfer function of the motor

B. *The Pid Controller Model*

The PID controller, though its application has a history of about 60years, it is still used extensively in our contemporary industrial control processes.[2] Its low cost, ease of application, simple but efficient structure, robust performance, fast and efficient action and comprehensible control algorithms have made it retain its relevance today.[1][3] The control signal is a linear combination of the error signal its integral and derivative.[3] There are three controller parameters in the PID: the proportional gain(K_P), the differential(K_D) and the integral gain(K_I). The controller parameters are to be determined properly and this is done by a process called tuning. Tuning can be done by using the Ziegler-Nichols tuning method.

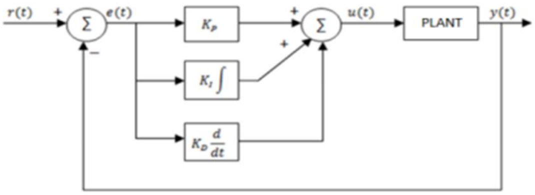


Fig. 2 PID control system.

The mathematical model of the is given below;

$$U(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt}$$

Taking Laplace transform of the equation above, we get;

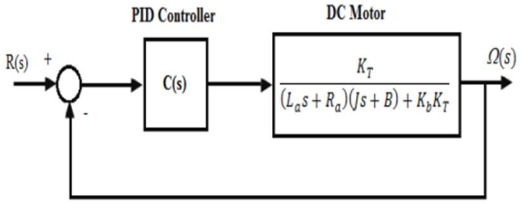
$U(s) = K_D E(s) + \frac{K_I E(s)}{s} + K_D E(s)s$

Dividing through by E(s),we get;

$$\frac{U(s)}{E(s)} = K_P + \frac{K_I}{s} + K_D s$$

Let C(s), the transfer function, be the control signal from the PID controller:

$$C(s) = \frac{U(s)}{E(s)}$$



The transfer function of the model above is given as:

$$G(s) = \frac{\left(K_P + \frac{K_I}{s} + K_D s\right)\frac{K_T}{(L_a s+R_a)(Js+B)+K_b K_T}}{1+\left(K_P + \frac{K_I}{s} + K_D s\right)\frac{K_T}{(L_a s+R_a)(Js+B)+K_b K_T}}$$

$$= \frac{(K_D s^2 + K_P s + K_I)K_T}{L_a J s^3 + (R_a J + BL_a + K_D)s^2 + (R_a B + K_b K_T + K_P)s + K_b K_T}$$

C. Ziegler-Nichols Tuning Method Of Pid Controller

In 1942 Ziegler and Nichols published a paper showing how to obtain P-, PI-, and PID parameters for tuning the controllers.[4] In this method the process is brought as close as possible to the specified operating point of the control system, by manually adjusting the control variable with the controller in manual mode, until the process variable is close to the approximate setpoint. Then set $K_P = 0$, $T_I = \infty$ (i.e.$K_I = 0$) and $T_D = 0$ (i.e.$K_D = 0$), where T_I and T_D are integral time period and derivative time period respectively.

Then vary K_P incrementally until you observe sustained oscillations in the response of the control system which have a constant amplitude, record the gain K_P at that point as the ultimate or critical gain K_U .Note that K_U is the smallest value of K_P that will cause sustained oscillations.

Measure the ultimate time period T_U of the sustained oscillations. With these i.e. K_P and T_U we can now solve tor the remaining parameters with the given table:[4] The stability can be increased if necessary by decreasing the K_P.

Controller	K_P	T_I	T_D
P	$0.5K_u$		
PI	$0.45K_u$	$T_u/1.2$	
PID	$0.6K_u$	$T_u/2$	$T_u/8$

Figure .3. Table of rules

Also $K_I = \frac{K_P}{T_I}$ and $K_D = K_P \times T_D$ [2]

D. The Fuzzy Logic Controller

The fuzzy logic controller uses the principles of fuzzy logic to control processes. The conventional Boolean logic of true or false has been extended to include the concept of partial truth for the values which lie between being "completely true" and "completely False". For such values, a concept of degree of membership has been introduced wherein they are slotted into their membership functions depending on the range in which they fall. The concept of fuzzy logic is interesting since it eliminates complicated hardware installation of plant modelling. Instead, it relies on a set of If-then rules with an attempt to replicate human thought processes in technical environments.[5]

It consists of three major stages; Fuzzification, Fuzzy Inference, and the Defuzzification.

Fuzzification is the process whereby the crisp inputs are changed to fuzzy membership sets. Here the speed error signal e(t) and the change in speed error Ce(t) are the input signals, while u(t) is the output of the FLC.

Fuzzy Inference is the stage where the controller takes the decision based on the rule base. This rule base is drawn by the expert experience or knowledge database. The fuzzy logic operates in an IF-THEN manner, that is, IF input is say NB (negative big), THEN output will be say PS (positive small).

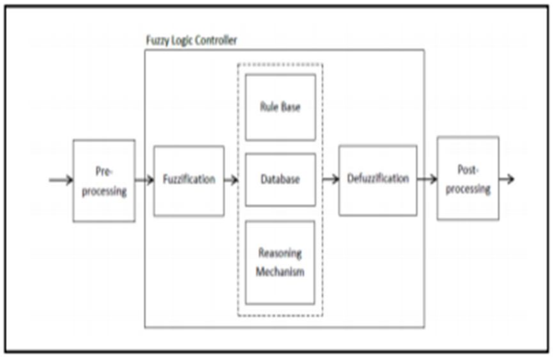
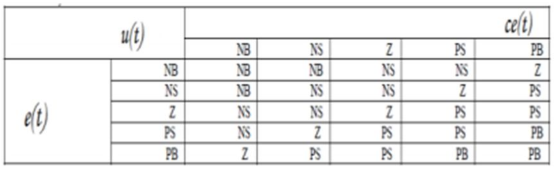


Fig.4a. Block diagram of an FLC.



u(t)		ce(t)				
		NB	NS	Z	PS	PB
e(t)	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

Fig.4b. Fuzzy inference table

The membership functions should overlap each other in order ensure continuity, so as to cater for every input condition. The type of fuzzy inference system used in this paper is the Mandani inference system.

Defuzzification is the process of changing the fuzzy output to crisp output. The most commonly use method of defuzzification is the centroid defuzzification as shown by the expression below.

$$x* = \frac{\int \mu i\,(x)x\,dx}{\int \mu i(x)dx}$$

where x* is the defuzzified output

µi(x) is the aggregated membership function
x is the output variable

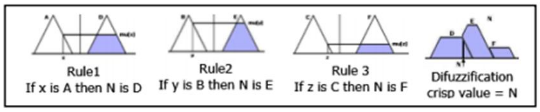


Fig.5. diagram for max min centroid defuzzification

III. RESULTS AND ANALYSIS

Here are the membership functions for *e(t), Ce(t)* and *u(t)*:

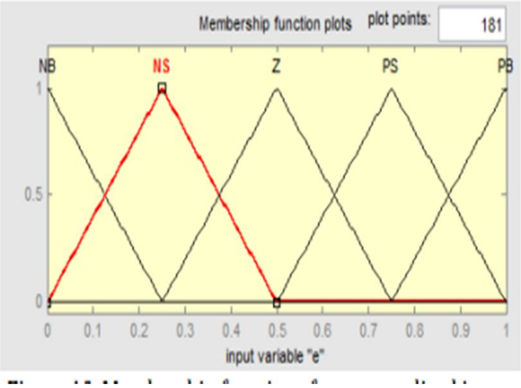


Fig.6. Fuzzy membership function plot for e(t)

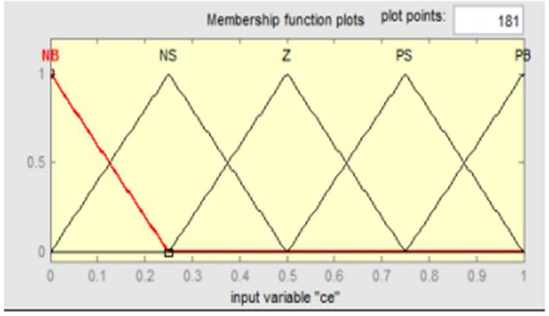


Fig.7. Fuzzy membership function plot for Ce(t)

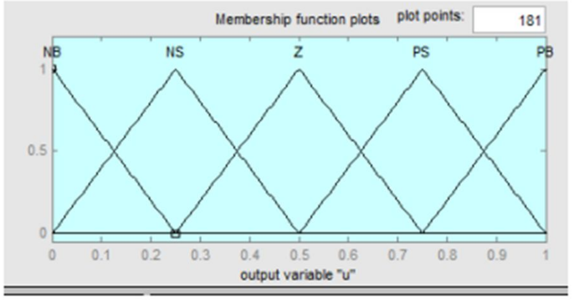


Fig.8. Fuzzy membership function plot for u(t)

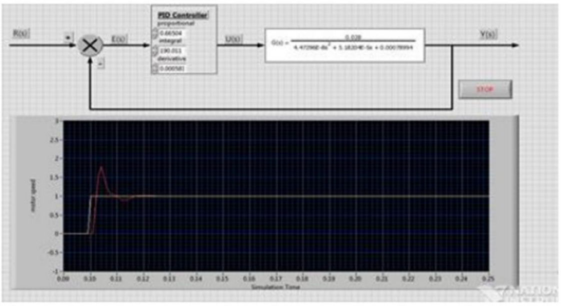


Fig.9. Step response for PID controller

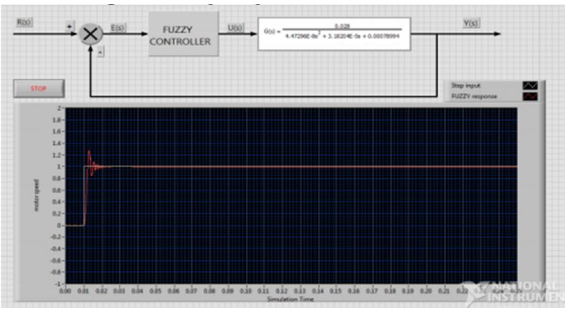
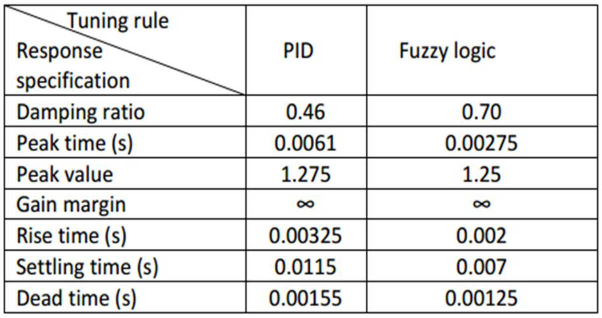


Fig.10. Step response for FLC controller



Tuning rule Response specification	PID	Fuzzy logic
Damping ratio	0.46	0.70
Peak time (s)	0.0061	0.00275
Peak value	1.275	1.25
Gain margin	∞	∞
Rise time (s)	0.00325	0.002
Settling time (s)	0.0115	0.007
Dead time (s)	0.00155	0.00125

Fig.11. Table of results for PID and FLC controllers

The table in fig.11 compares the results of the PID against that of the FLC. It compares parameters like the damping ratio, peak time, peak value etc. From the values we can infer that the fuzzy logic controller has a better damping ratio and a smaller peak time. Also the peak value, the rise time and the settling time are better than that of the PID. It is worthy to note that the FLC results in lesser oscillations at the control system response compared to the PID controller. This means a better stability of the system.

IV. CONCLUSION

Controlling the speed and position of the dc motor has been our target in this paper. We tested between the PID controller and the fuzzy logic controller and we found out that;

The Fuzzy controller results in less oscillation at the control system response. Less oscillations means better controllability and less sensitivity to change in system condition.[2]

We gain optimal performance when using the FLC controller in speed control.

The FLC overcomes the disadvantage of the PID controller being unable to give optimal output at varying conditions.

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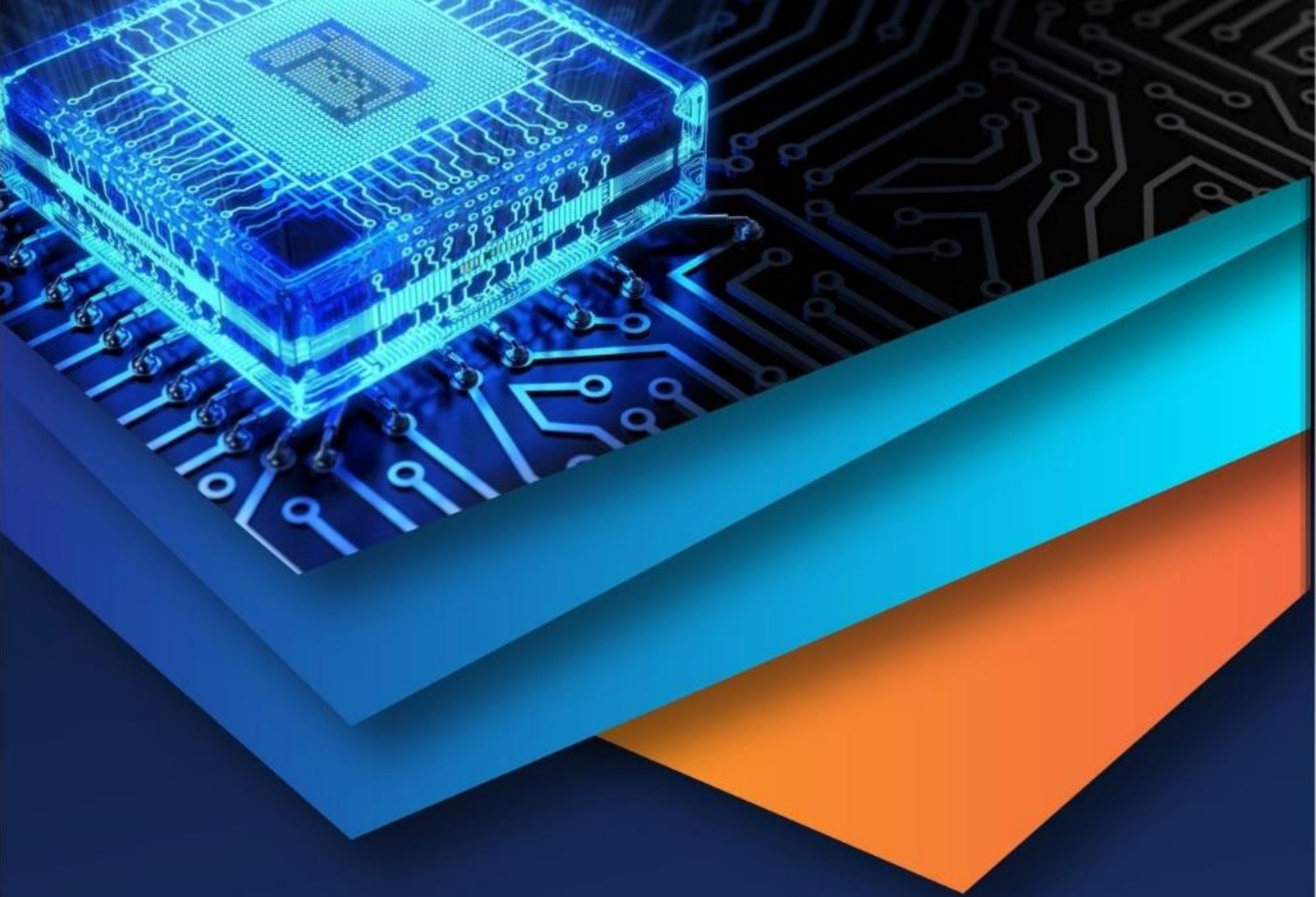

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