FUZZY Based PID Controller for Speed Control of D.C. Motor Using LabVIEW

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Abstract: - This paper presents an implementation of self-tuned PID controller (FPID) for speed control of DC motor based on LabVIEW (Laboratory Virtual Instrument Engineering Workbench Environment). The algorithms of fuzzy PID controller (FPID) and conventional PID controller (CPID) are implemented using PID and Fuzzy Logic simulation toolkits of the Lab View environment. The simulation results demonstrate that the designed self-tuned PID controller realize a perfect speed tracking with lesser rise time and settling time, minimum steady state error and give better performance compared to conventional PID controller.

Key-Words: - DC Motor, Ziegler-Nichols Tuning, Speed Control, Fuzzy Logic and Fuzzy plus PID controller, LabVIEW.

1 Introduction

Virtual instrumentation is the use of optimizable software and modular measurement hardware to aids in creating a user-defined measurement system, called virtual instruments. LabVIEW is a software package for high performance numerical computation and visualization. It is ideal for any measurement or control system, and the heart of the NI (National Instruments) design platform. NI-LabVIEW provides comprehensive tool that is needed to build any measurement or control application in dramatically lesser time, LabVIEW is the ideal development environment for innovation, discovery, and accelerated results [4][8].

In this paper, speed of a DC motor is controlled using different tuning algorithms. The DC motors are popular in the industry control area for a long time because they possess good characteristics, for example: high start torque characteristics, high response performance, easier to be linearly controlled etc. The basic property of DC motor is that speed of DC motor can be adjusted by varying its terminal voltage. Therefore, the DC motor control is better than other kinds of motors. The real-time application can be easily understood and interfaced with LabVIEW with a quick response but it may not be very apparent and easily comprehensive with MATLAB and other simulation software. In the present work, PID controller is used to control the speed of the DC motor.

2 DC Motor Mathematical Model

DC motor system is a separately excited DC motor, which is often used to the velocity tuning and the position adjustment [3] [10].The equivalent circuit of the DC motor using the armature voltage control method is shown in Fig.1:
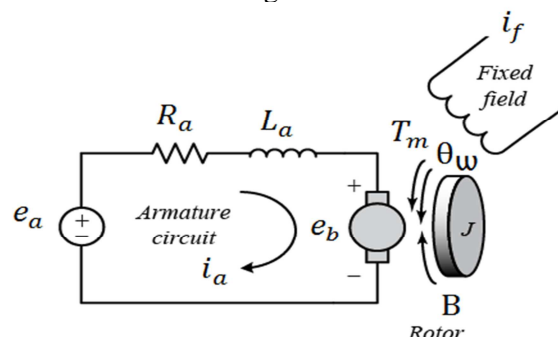

Fig.1: Equivalent circuit of the DC motor.

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	:	An angular velocity of rotor (rad/s)
J	:	Rotor inertia (kgm^2)
B	:	Friction constant (Nms/rad)
K_b	:	EMF constant (Vs/rad)
K_T	:	Torque constant (Nm/A)

The functional block diagram of a DC motor armature voltage control system is shown in Fig.2:
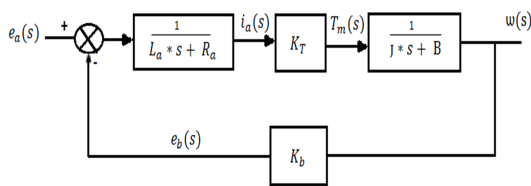

Fig. 2: DC motor armature control system block diagram.

The transfer function of DC motor speed with respect to the input voltage can be written as follows,

$$\frac{w(s)}{e_a(s)} = \frac{K_T}{(L_a*s+R_a)(J*s+B)+K_T*K_b} \quad (1)$$

A LabVIEW based DC motor model was built in order to run fuzzy and PID algorithms and also to analyze their works.

3 Tuning Methods
Speed of DC motor can be controlled using different tuning methods and are as follows:-
I.   PID Controller (Ziegler- Nichols Method)
II.   Fuzzy Controller
III. PID Plus Fuzzy Controller

3.1 PID Controller (Ziegler- Nichols Method)
The development of PID control theories has already started in early sixties. PID control has been one of the control system design methods of the longest history. PID controller is mainly to adjust an appropriate proportional gain (K_P), integral gain (K_I), and differential gain (K_D) to achieve the optimal control performance [4][6]. The relationship between the input e(t) and output u(t) can be formulated in the following,

$$U(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \quad (2)$$

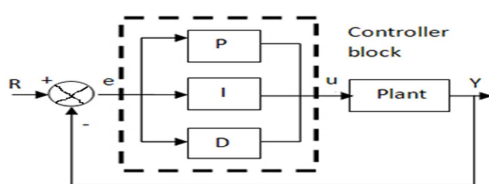A general PID controller system block diagram is shown in Fig.3:

Fig. 3: PID controller system block diagram.

The transfer function is expressed as follows,

$$C(s) = K_P + \frac{K_I}{s} + K_D s = \frac{U(s)}{E(s)} \quad (3)$$

PID controllers are tuned in terms of K_P, K_I and K_D. Ziegler- Nichols is a type of continuous cycling method for controller tuning. The term continuous cycling refers to a continuous oscillation with constant amplitude and is based on the trial-and-error procedure of changing the proportional gain (K_P). K_P Is increased from small value till the point at which the system goes to unstable. Thus the gain at which system starts oscillating is noted as the ultimate gain (K_u) and period of oscillations is the ultimate time period (P_u).

These two parameters, K_u and P_u are used to find the loop-tuning constants of the PID controller using the formula tabulated in Table.1 [3] [8]

Controller	K_P	K_I	K_D
P	$0.5K_u$	∞	0
PI	$0.45K_u$	$\frac{P_u}{1.2}$	0
PID	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

Table.1 for Ziegler Nichols parameters

The advantage of this method is that it is a proven online method and includes dynamics of whole process, which gives a more accurate picture of how the system is behaving.

3.2 Fuzzy Controller Design
Fuzzy Logic (FL) incorporates a simple, rule-based **IF X AND Y THEN Z** approach to a solving control problem rather than attempting to model a system mathematically. Fuzzy logic provides an alternative way to represent linguistic and subjective attributes of the real world in computing. FL requires some numerical parameters in order to operate such as what is considered significant error and significant rate-of-change-of-error, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them.[7] [10]

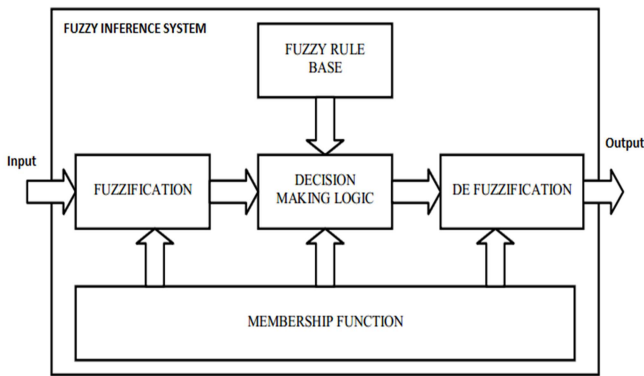Fuzzy controller process block is shown in Fig.4:

Fig.4: Process Blocks for a Fuzzy Controller.

Basically, FLC process is based on experiences and linguistic definitions instead of system model. The input to the Fuzzy Controller are error e(t) and Change of error de(t).

$$e(t) = R(t) - U(t) \qquad (4)$$

$$de(t) = e(t) - e(t-1) \qquad (5)$$

Using fuzzy control rules speed of DC motor can be controlled. Block diagram for speed control of DC motor using fuzzy controller is shown in Fig.5:
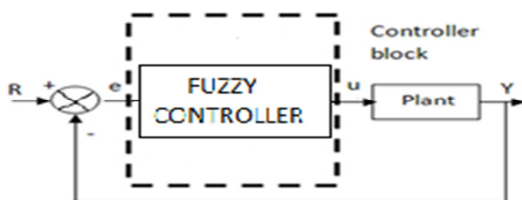

Fig.5: Speed control of DC motor using fuzzy controller.

Fuzzy membership function using triangular and trapezoidal functions for speed of error is shown in Fig 6; for speed of change of error is shown in Fig 7; and for output signal is shown in Fig 8.
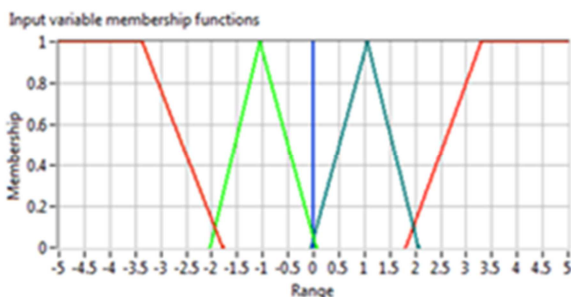
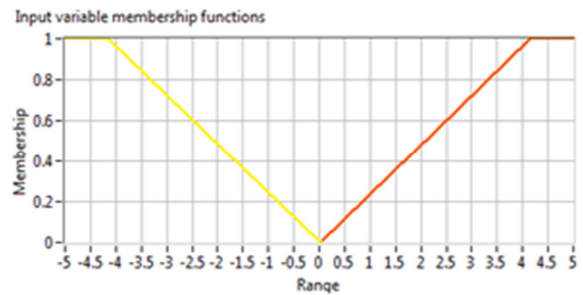Fig.6: Membership Function for error signal.

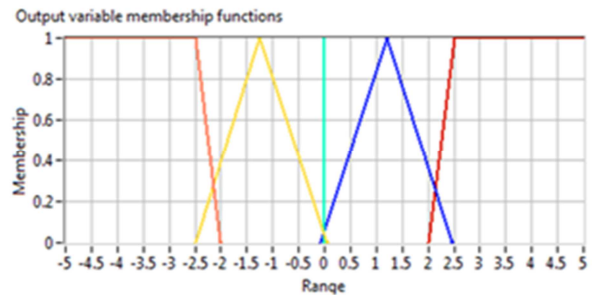Fig.7: Membership Function for change of error signal.

Fig.8: Membership Function for output signal.

Based on speed of error, change of error, output signal and some defined set of rules we have input – output relationship for fuzzy controller as shown in Fig 9. Here U(t) is output signal, e(t) is speed of error and Ce(t) is change of speed of error.
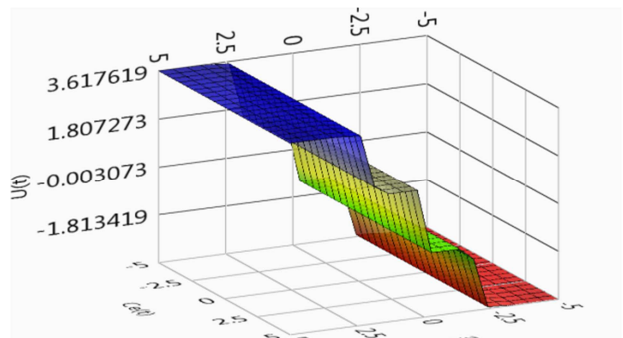

Fig.9: Input and output relationship for fuzzy controller.

3.2 PID Plus Fuzzy Controller Design

Fuzzy plus PID (FPID) provides good performance as compared to standalone Fuzzy. Simple rule base are used for Fuzzy controller while FPID uses different rule base for proportional, integral and derivative gains to make response faster [12].

The input to the Self-tuning Fuzzy PID Controller are error e(t) and Change of error de(t) as given in Eqn.4 and in Eqn.5. Using fuzzy control rules on-line, PID parameters K_P, K_I and K_D is adjusted, which constitute a self-tuning fuzzy PID controller is shown in Fig 10.

The gains parameters K_P, K_I and K_D are finalized and optimized automatically instead of manual calculation of the gains.
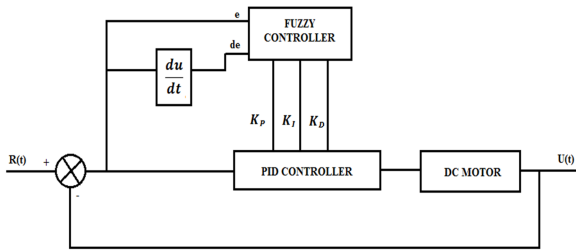

Fig.10: The structure of self-tuning fuzzy PID controller.

Fuzzy membership function using triangular functions for speed of error is shown in Fig 11; for speed of change of error is shown in Fig 12; output signal for proportional gain is shown in Fig 13; output signal for integral gain is shown in Fig 14; and output signal for derivative gain is shown in Fig 15.
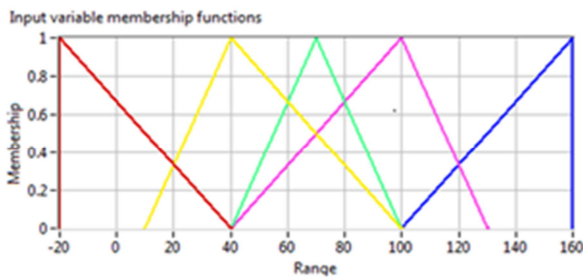
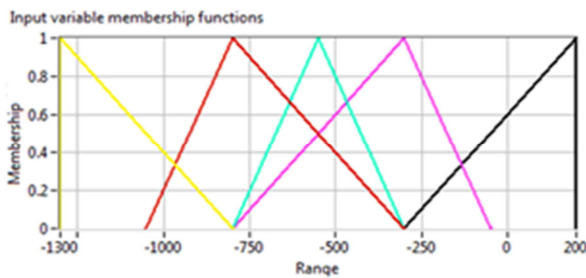

Fig.11: Membership Function for error signal (FPPID).

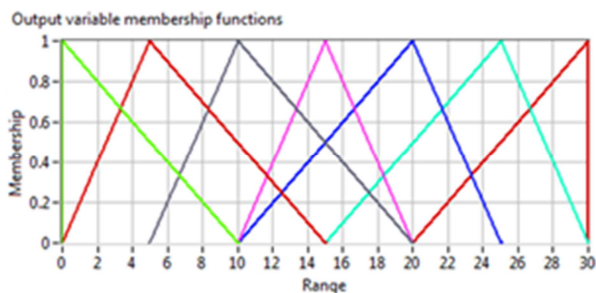Fig.12 Membership Function for change of error signal (FPPID).
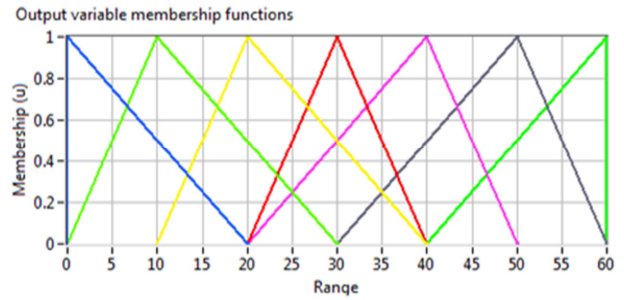

Fig.13 Membership Function for output signal (K_p)

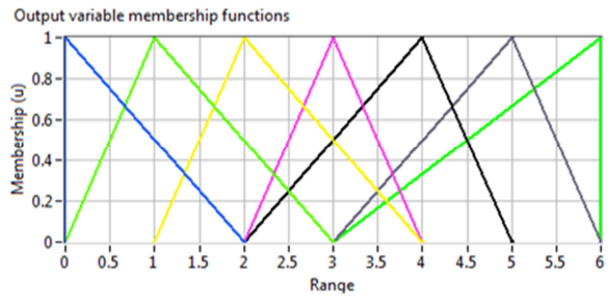
Fig.14: Membership Function for output signal (K_i)

Fig.15: Membership Function for output signal (K_d)

Input output relationship for proportional, integral and derivative controller based on error signal, change of error signal and respective output signals for fuzzy plus PID controller are shown in Fig.16, Fig.17, and Fig.18 respectively.

K_P, K_I and K_D are output signals, e(t) is speed of error and Ce(t) is change of speed of error.
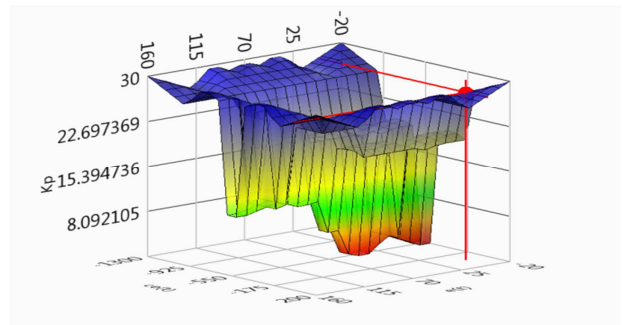

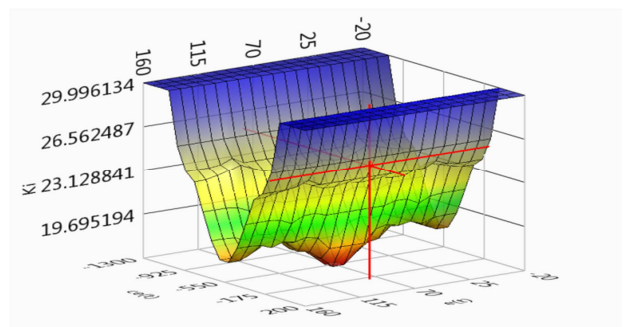Fig.16: I/O relationship for Proportional controller (K_p).

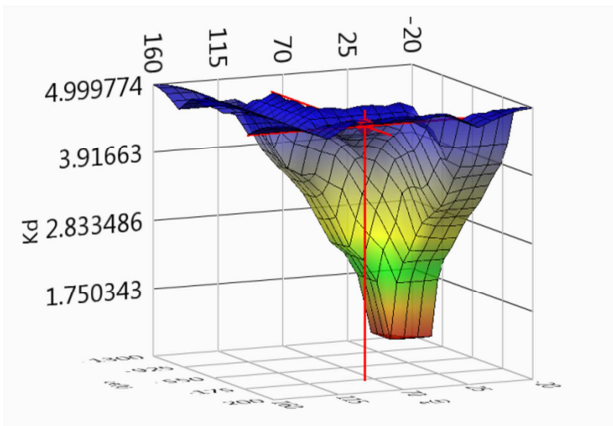Fig.17: I/O relationship for Integral controller (K_i).

Fig.18: I/O relationship for derivative controller (K_d).

4 Simulation Results

We have used LabVIEW software for simulation work in controlling the speed of DC motor because it is suitable for creating flexible and scalable design, control and test applications rapidly at minimal cost. Execution time and survey ability is better in LabVIEW so we use LabVIEW for DC motor speed control.

4.1 DC motor model is to be created with the help of LabVIEW Math script.

Armature resistance (R_a)   = 3.3 Ω
Torque constant (K_T)   = 0.028Nm/A
Armature inductance (L_a)   = 0.00464H
Friction constant (B)   = 1.8E-6Nms/rad
Rotor inertia (J)   = 9.64E-6 kgm^2
EMF constant (K_b)   = 0.028 Vs/rad

$$G(s) = \frac{0.028}{(4.47296E-8)*s^2+(3.18204E-5)*s+0.00078994} \quad (6)$$
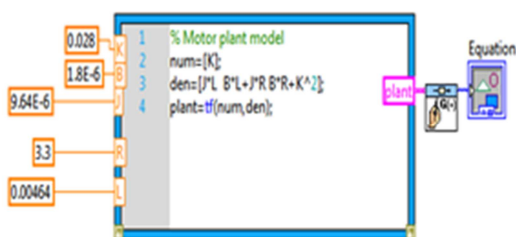

Fig.19: Math script model of DC Motor.

Front Panel and Block Diagram view for speed control of DC motor using different tuning methods is shown in Fig.20 and Fig.21 respectively.
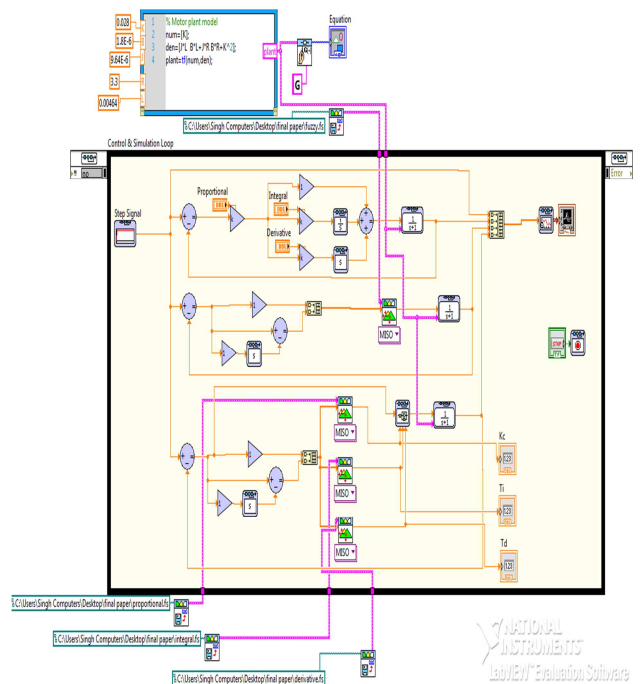

Fig.20: Front panel window for PID, Fuzzy and Fuzzy plus PID controller.

4.2 Step response is to be calculated using PID controller, Fuzzy controller and FPID controller for speed control of DC motor.
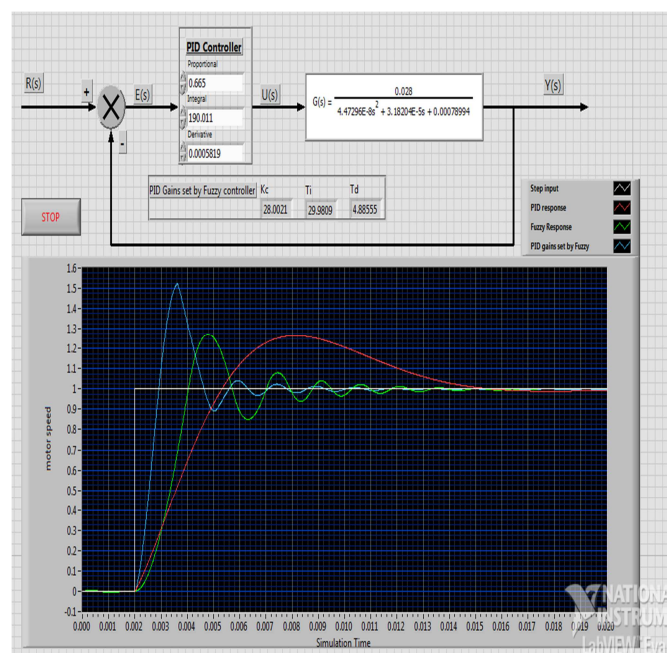

Fig.21: Block diagram window for PID, Fuzzy and Fuzzy plus PID controller.

4.3 Comparison between PID, Fuzzy and Fuzzy plus PID controller step response specifications.

Comparison between PID, Fuzzy and FPID		Tuning Rule		
		PID	Fuzzy logic	Fuzzy Plus PID
Response Specification	Damping ratio	0.67	0.76	0.79
	Peak time (s)	0.008	0.0048	0.0036
	Gain margin	∞	∞	∞
	Rise time (s)	0.0053	0.004	0.0029
	Settling time(s)	0.0144	0.0114	0.0082
	Dead time (s)	0.0036	0.0033	0.0025

Table.2: Step response specifications for PID, Fuzzy and Fuzzy plus PID controllers respectively.

5 Conclusion

From the simulation results tabulated in Table.2 it is concluded that using Fuzzy plus PID controller damping ratio, rise time, settling time and peak time is better than PID and Fuzzy controller. It can easily be deduced that FPID (Fuzzy plus PID) can maintain the speed at desired values irrespective of change of load. It can also be concluded that a superior performance is guaranteed than other conventional controllers which in fact extends from robustness of the system to the parameter variation.

Moreover simulation with LabVIEW software saves project development time as the motor position and generation of proper motor control signal can be easily adjusted. LabVIEW debugging tool is self-adaptive and easy to implement which saves considerable amount of time than other simulation software's like MATLAB.

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