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Speed Control of DC Motor using Fuzzy Logic based on LabVIEW

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Abstract- Speed control of DC Motor is vital in many applications. In this paper, an effort has been made to control the speed of the DC motor using fuzzy logic control (FLC) based on LabVIEW (Laboratory Virtual Instrument Engineering Workbench) program. LabVIEW provides a graphical programming environment suited for high-level or system-level design. The fuzzy logic controller designed to apply the required control voltage that sent to dc motor based on fuzzy rule base of motor speed error (e) and change of speed error (Ce). In this paper results of FLC, PI and PID Controller are compared. The simulation results demonstrate that the response of DC motor with FLC show a satisfactory well damped control performance.

Index Terms- DC Motor, Ziegler-Nichols Tuning, Speed Control, Fuzzy Logic and PID controller, LabVIEW

I. INTRODUCTION

The DC motors have been popular in the industry control area for a long time, because they have many good characteristics, for example: high start torque characteristic, high response performance, easier to be linear control etc. There are different control approaches which depend on the different performance of motors. The basic property of DC motor is that speed can be adjusted by varying the terminal voltage. Therefore, the DC motor control is riper than other kinds of motors. Classic Control has proven for a long time to be good enough to handle control tasks on system control; however its implementation relies on an exact mathematical model of the plant to be controlled and not simple mathematical operations. The fuzzy logic, unlike conventional logic system, is able to model inaccurate or imprecise models. The fuzzy logic approach offers a simpler, quicker and more reliable solution that is clear advantage over conventional techniques. Fuzzy logic may be viewed as form of set theory [1]. When compared to the conventional controller, the main advantage of fuzzy logic is that no mathematical modeling is required. Since the controller rules are especially based on the knowledge of the system behavior and experience of the control engineer, the FLC requires less complex mathematical modeling than classical controller does. LabVIEW is better for control applications and MATLAB is better for data manipulation. LabVIEW is the graphical development environment for creating flexible and scalable test, measurement, and control applications rapidly and at minimal cost.

II. SYSTEM DESCRIPTION

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. The equivalent circuit of the DC motor using the armature voltage control method [8] is shown in Figure 1:

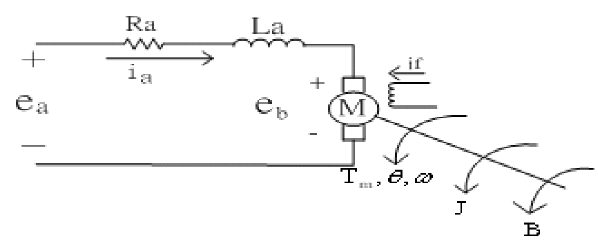

Figure 1: Equivalent circuit of the DC motor.

Where

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

Because the back EMF e_b is proportional to speed ω directly, hence

$$e_b(t) = K_b \frac{d\theta(t)}{dt} = K_b \omega(t) \quad (1)$$

Making use of the KCL voltage law we can get

$$e_a(t) = R_a i_a(t) + L_a \frac{di_a(t)}{dt} + e_b(t) \quad (2)$$

From Newton law, the motor torque can obtain

$$T_m(t) = J \frac{d^2\theta(t)}{dt^2} + B \frac{d\theta}{dt} = K_T i_a(t) \quad (3)$$

Taking Laplace transform, the above equations can be formulated as follows:

$$E_b(s) = K_b \Omega(s) \quad (4)$$

$$E_a(s) = (R_a + L_a s) I_a(s) + E_b(s) \quad (5)$$

$$T_m(s) = B\Omega(s) + Js\Omega(s) = K_T I_a(s) \quad (6)$$

The DC motor armature control system functional block diagram from equations (4) to (6) is shown in Figure 2:

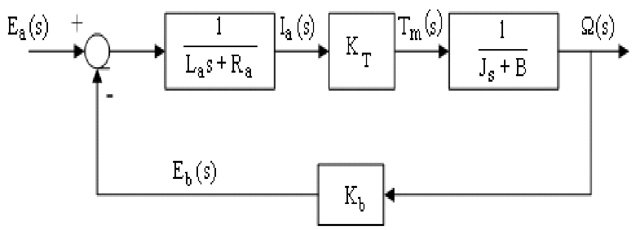

Figure 2: DC motor armature control system functional block diagram.

The transfer function of DC motor speed with respect to the input voltage can be written as follows [11],

$$G(s) = \frac{\Omega(s)}{E_a(s)} = \frac{K_T}{(L_a s + R_a)(Js + B) + K_b K_T} \quad (7)$$

$$= \frac{0.028}{(4.47296 \times 10^{-8})S^2 + 3.18204\ 10^{-5}S + 0.00078994} \quad (8)$$

A LabVIEW based servo control system was built in order to run fuzzy and PID algorithms and also to analyze their works. The control system's aims are %0.5 or less overshot, No steady state error, Minimum settling time, Minimum rising time.

III. PID Controller Description and Design

The development of PID control theories has already been from 60 years. PID control has been one of the control system design method of the longest history. However, this method is still extensively used [7] [8]. 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. These functions have been enough to the most control processes. The PID controller system block diagram is shown in Figure 3:

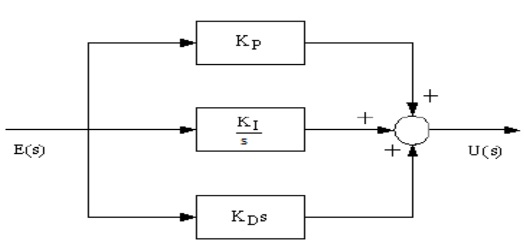

Figure 3: PID controller system block diagram.

The relationship between the input e(t) and output u(t) can be formulated in the following,

$$U(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \quad (9)$$

The transfer function is expressed as follows,

$$C(s) = K_P + \frac{K_I}{s} + K_D s = \frac{U(s)}{E(s)} \quad (10)$$

The PID DC motor speed control system block diagram is shown in Figure 4:

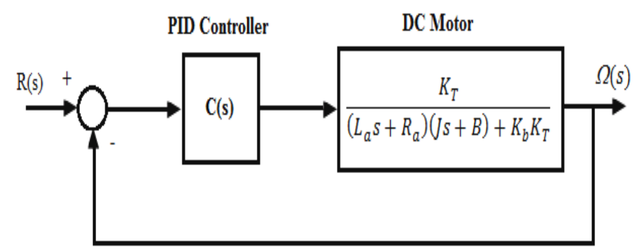

Figure 4: PID DC motor speed control system block diagram

The closed loop transfer function of DC motor speed control system expresses as follows,

$$G(s) = \frac{(K_P + \frac{K_I}{s} + K_D s)\frac{K_T}{(L_a s + R_a)(Js+B) + K_b K_T}}{1 + (K_P + \frac{K_I}{s} + K_D s)\frac{K_T}{(L_a s + R_a)(Js+B) + K_b K_T}} \quad (11)$$

$$= \frac{(K_D s^2 + K_P s + K_I)K_T}{L_a J s^3 + (R_a J + BL_a + K_D)s^2 + (R_a B + K_b K_T + K_P)s + K_b K_T} \quad (12)$$

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 ultimate gain (K_u) and period of oscillations is ultimate time period (P_u). It allows us to use the ultimate gain value, Ku, and the ultimate period of oscillation (P_u) to calculate K_P, K_I and K_D. These two parameters, K_u and P_u are used to find the loop-tuning constants of the controller (P, PI, or PID) using the formula tabulated in Table I:

Controller	K_p	τ_i	τ_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 I: for Ziegler Nichols parameters

Then according to Z-N tuning rule, by using ultimate gain and ultimate period P, PI, PID gains K_P, K_I and K_D obtained using relation $K_I = K_P/\tau_I$ and $K_D = K_P * \tau_D$ [14] for DC motor is shown in Table II:

Controller	K_P	K_I	K_D
P	0.5542	0	0
PI	0.4987	85.5540	0
PID	0.6650	190.011	0.0005819

Table II: Simulated results for Ziegler Nichols.

PID controller transfer function for DC motor using Ziegler Nichols tuning method is shown in Equation 13.

$$U(s) / E(s) = \frac{0.0005819S^2 + 0.66504S + 190.0114}{S} \quad (13)$$

IV. FUZZY CONTROLLER DESCRIPTION & DESIGN

The fuzzy logic foundation is based on the simulation of people's opinions and perceptions to control any system. One of the methods to simplify complex systems is to tolerate to imprecision, vagueness and uncertainty up to some extent [15]. Fuzzy provides a remarkably simple way to draw definite conclusions from vague ambiguous or imprecise information. It is suitable for applications such as the speed control of dc motor which has non-linearities.

A fuzzy control system is a control system in which a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively). Fuzzy Logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy Logic's approach to control problems mimics how a person makes decisions, only much faster. Fuzziness is connected with the degree to which events occur rather than likelihood of their occurrence.

FLC have some advantages compared to other classical controller such as simplicity of control, low cost and the possibility to design without knowing the exact mathematical model of the process. Fuzzy logic incorporates an alternative way of thinking which allows modeling complex systems using higher level of abstraction originating from the knowledge and experience.

Components Characteristic of a Fuzzy Controller:

- Preprocessing
- Fuzzification
- Rule Base
- Defuzzification
- Post processing

Preprocessing: The inputs are most often hard or crisp measurement from some measuring equipment rather than linguistic. A preprocessor block in Figure: 5 shows the conditions of measurements before enter the controller.

Fuzzification: The first block inside the controller is fuzzification which converts each piece of input data to degrees of membership by a lookup in one or several membership functions.

Rule Base: The collection of rules is called a rule base. The rules are in "*If Then* "format and formally the *If side* is called the *conditions* and the *Then side* is called the *conclusion.* The computer is able to execute the rules and compute a control signal depending on the measured inputs *error* (e) and *change in error* (Ce).

Defuzzification: Defuzzification is when all the actions that have been activated are combined and converted in to a single non-fuzzy output signal which is the control signal of the system. The output levels are depending on the rules that the systems have and the positions depending on the non-linearity's existing to the systems. To achieve the results, develop a control curve of the system representing the I/O relation of the system, and based on the information define the output degree of membership function with the aim to minimize the effect of non-linearity.

Post processing: The post processing block often contains an output gain that can be tuned and also become as an integrator.

An expert operator develops flexible control mechanism using words like "suitable, not very suitable, high, little high and much. Figure 5: Shows process blocks for a fuzzy controller.

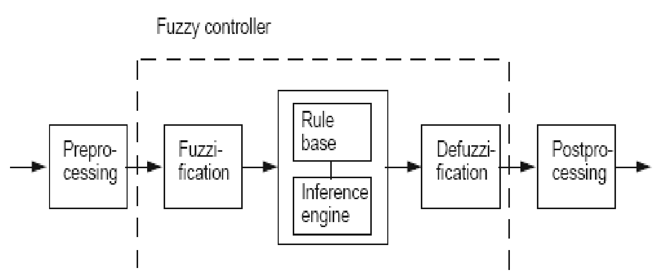

Figure 5: Process Blocks for a Fuzzy Controller.

Although the classic controllers depend on the accuracy of the system model and parameters, FLC uses different strategies for motor speed control. Basically, FLC process is based on experiences and linguistic definitions instead of system model. It is not required to know exact system model to design FLC. In addition to this, if there is not enough knowledge about control process, FLC may not give satisfactory results [18].

Defining Input and Output:

The goal of designed FLC in this study is to minimize speed error. In addition, the change of error plays an important role to define controller input. Consequently FLC uses error (e) and change of error (Ce) for linguistic variables which are generated from the control rules. Equation (14) and Equation (15), determines required system equations.

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$$e(t) = r(t) – u(t) \quad (14)$$

$$\dot{e}(t) = e(t) – e(t-1). \quad (15)$$

r(t) is desired speed and u(t) is actual speed.

Defining membership functions and rules:

System speed comes to reference value by means of the defined rules. For example, first rule is, 'if e(t) is NA then u(t) is DM'. According to this rule, if error value is negative large then output will be negative large. To calculate FLC output value, the inputs and outputs must be converted from 'crisp' value into linguistic form. Fuzzy membership functions are used to perform this conversion. In this paper, all membership functions are defined between -5 and 5 intervals.

Fuzzy rule data base used are ‘if e(t) is NA then u(t) is DM'. 'if e(t) is NB then u(t) is DB'. 'if e(t) is CERO then u(t) is STR'. 'if e(t) is CERO and Ce(t) is ENA then u(t) is AM'. 'if e(t) is CERO and Ce(t) is EPA then u(t) is DM'. ‘if e(t) is PA then u(t) is AM'. 'if e(t) is PB then u(t) is AP'.

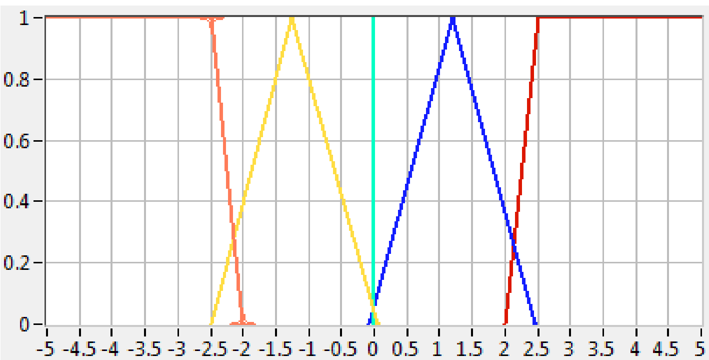

Figure: 6 Membership functions of position error e (t).

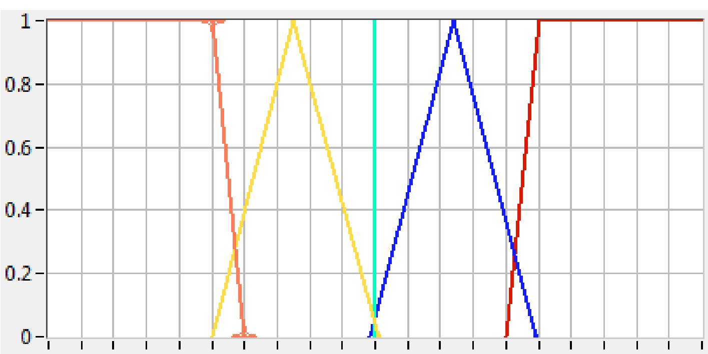

Figure: 7 Membership functions of control signal u (t).

V. EXPERIMENTAL RESULTS

The operation of a FLC is based on heuristic knowledge and linguistic description to perform a task. The performance of the FLC is then improved by adjusting the rules and membership function. The designed FLC consists of three components.

- Fuzzification of input values
- Fuzzy inference
- Defuzzification of fuzzy output

Simulation results for P PI PID and fuzzy controller are shown in Figure: 9 to Figure: 12.

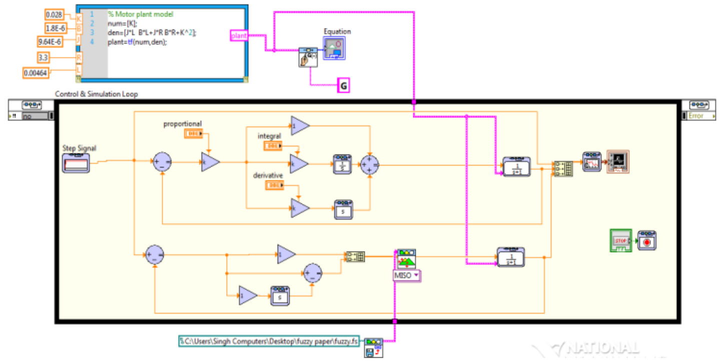
Figure: 8 Sub VI for DC motor using Fuzzy and PID controller.

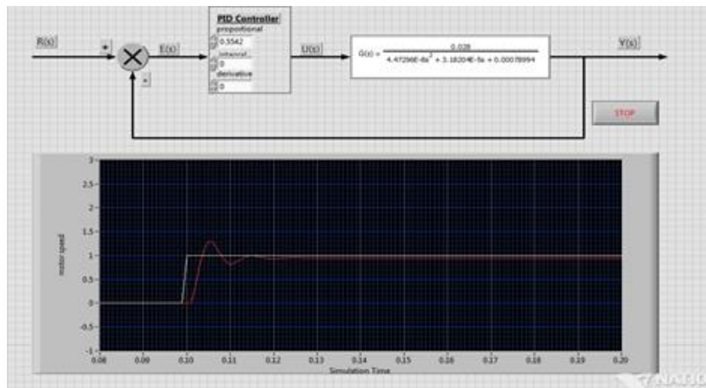
Figure: 9 Step Response for proportional controller.

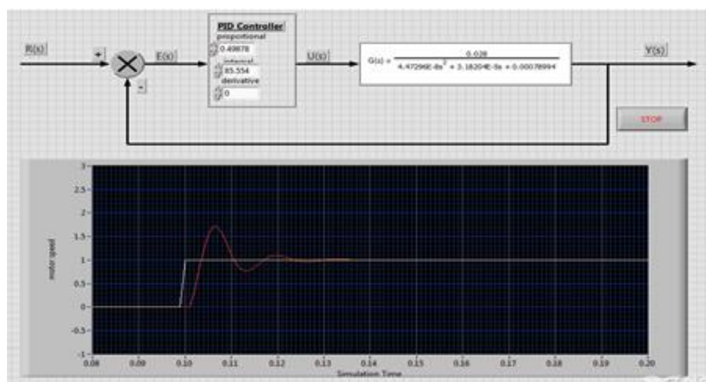
Figure: 10 Step Response for proportional plus integral controller

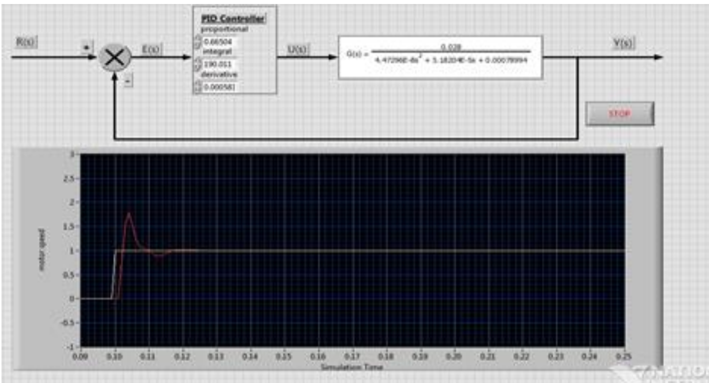

Figure: 11 Step Response for PID controller.

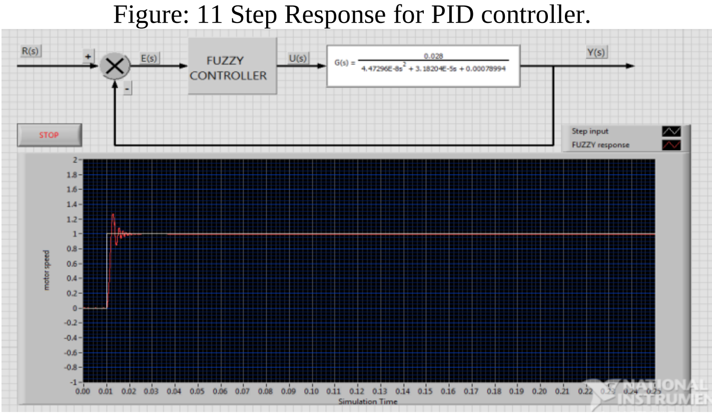

Figure: 12 Step Response for Fuzzy controller.

Comparison of PID controller and Fuzzy controller step response specifications are tabulated in Table III.

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

Table III: Comparison of PID controller and Fuzzy controller.

From the simulation results tabulated in Table III: it is concluded that by step response specifications using Fuzzy controller damping ratio, rise time, settling time, peak value and peak time is better than PID controller. Fuzzy controller results in less oscillation at the control system response. Less oscillations means better controllability and less sensitivity to change in system condition.

VI. CONCLUSION

The results of experiment demonstrate that the proposed fuzzy logic controller is sensitive to variation of the reference speed. The results of the controller are as follows.

1. The speed control of dc motor by proposed controller (FLC) gains optimal performance.
2. The proposed controller achieved to overcome the disadvantage of conventional controller's sensitiveness to inertia variation and sensitiveness to variation of the speed with drive system of dc motor.

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