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Modelling and Simulation for Industrial DC Motor Using Intelligent Control

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This paper presents an overview of Proportional Integral control (PI) and Artificial Intelligent control (AI) algorithms. AI and PI controller are analyzed using Matlab [Simulink] software. The DC motor is an attractive piece of equipment in many industrial applications requiring variable speed and load characteristics due to its ease of controllability. The main objective of this paper illustrates how the speed of the DC motor can be controlled using different controllers. The simulation results demonstrate that the responses of DC motor with an AI control which is Fuzzy Logic Control shows satisfactory well damped control performance. The results shows that Industrial DC Motor model develop using its physical parameters and controlled with an AI controller give better response, it means it can be used as a controller to the real time DC Motor.

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Keywords: DC Machine; PI Controller; Fuzzy logic control.

Nomenclature

J	moment of inertia of the rotor ($Kg.m^2/s^2$)
b	damping ratio of the mechanical system (Nms)
R	electric resistance (ohm)
L	electric inductance (mH)
V	input source voltage (V)
T	Torque (N)
i	armature current (A)
K_t	armature constant
K_e	motor constant
$\hat{\theta}(t)$	Speed output (rad/sec)

1. Introduction

DC motors are the important machine in the most control systems such as electrical systems in homes, vehicles, trains, and process control. It is well known that the mathematical model is very crucial for a control system design. For a DC motor, there are many models to represent the machine behavior with a good accuracy. However, the parameters of the model are also important because the mathematical model cannot provide a correct behavior without correct parameters in

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the model. In this paper study the characteristics of PI controllers and fuzzy logic controllers and their application to an industrial DC motor at steps included Structure, characteristic and the mathematical model and simulation of stability response for speed control of DC motor. Contains the design & simulation studies used to demonstrate the basic theoretical feasibility of the system used by PI & Fuzzy-PI Control to achieve better response by less noise and less overshoot.

2. Mathematical Model of DC Motor

A common actuator in control systems is the DC motor. It directly provides rotary motion and, coupled with wheels or drums and cables, can provide translational motion. The electric circuit of the armature and the free body diagram of the rotor are shown in the following figure:

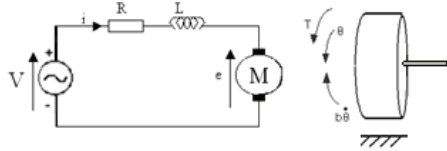


Fig. 1. DC motor equivalent circuit.

The torque is proportional to current as a following.

$$T = K_t i \quad 1$$

The back emf e , is related to the rotational velocity by the following equation:

$$e = K_e \dot{\theta}(t) \quad 2$$

In SI units (which we will use), K_t (armature constant) is equal to K_e (motor constant).

From the figure above we can write the following equations based on Newton's law combined with Kirchhoff's law can be written as follows :

$$J \cdot \ddot{\theta}(t) + b \cdot \dot{\theta}(t) = K_e \cdot i(t) \quad 3$$

$$L \cdot \frac{di(t)}{dt} + R \cdot i(t) = V(t) - K \cdot \dot{\theta}(t) \quad 4$$

Using Laplace Transforms, the above modeling equations can be expressed in terms of operator(s)

$$(Js + b) \cdot \theta(s) = K \cdot I(s) \quad 5$$

$$(Ls + R) \cdot I(s) = V(s) - K \cdot \dot{\theta}(s) \quad 6$$

From equation (5):

$$I(s) = \frac{(Js+b) \cdot \theta(s)}{K} \quad 7$$

Substitute equation (7) into equation (6) to get :

$$\frac{(Ls+R)(Js+b) \cdot \theta(s)}{K} = V(s) - K \cdot \dot{\theta}(s) \quad 8$$

From equation (8):

$$\frac{\theta(s)}{V(s)} = \frac{K}{(Ls+R)(Js+b)+K^2} \quad 9$$

The DC motor parameters are given in table 1:

Table 1: DC Motor parameters.

parameters	values
<i>R</i>	5.2 Ω
<i>L</i>	1.1 mH
<i>J</i>	0.01 kg.m
<i>b</i>	0.02 N.m.sec/rad. s ⁻¹
<i>K</i>	0.75 N.m. A ⁻¹

3. PID Controller

PID controllers have a long history in control engineering and they have been proven to be robust, simple and stable for many real world applications. Roughly, P action is related to the present error, I action is based on the past history of error, and D action is related to the future behaviour of the error. From estimation point of view, P, D actions, and I correspond to filtering, smoothing and prediction problems respectively. This type of neuro-controller is meaningful from a viewpoint of application because PID controllers are so widely used today. The equation of a PID controller is given by :

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \tag{10}$$

Where K_p is proportional, K_i is integral, and K_d is derivative gain of the controller. for this study the derivative control canceled to use only PI Controller, so the control became:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt \tag{11}$$

A proportional controller (K_p) will have the effect of reducing the rise time and will reduce but never eliminate the steady-state error. An integral control (K_i) will have the effect of eliminating the steady-state error.

4. FUZZY CONTROLLER

Fuzzy logic consists of three parts: Fuzzification, inference and defuzzification. Fuzzification is an interface that produces a fuzzy subset from the measurement; that is, it is a mapping from the set of measurements. The inference is an interface that produces a new fuzzy subset from the result of the fuzzification using for example a set of rules. The results of the inference are a fuzzy subset associated with the output. The defuzzification is an interface that produces a crisp output from the results of the interface [1].

One of the Fuzzy logic controller structures consists of two inputs and one output MISO. The first input to the Fuzzy Logic Controller is basically from the error signal $e(t)$ between actual output of the system and the desired input while the second input is from the changing of the system error $\Delta e(t)$. The Mamdani fuzzy modelling was first proposed as the first attempt to control an industrial plant by a set of linguistic control rules obtained from experienced human operator (Mamdani). Figure 2 is an illustration of a two input-single output Mamdani type fuzzy model. A typical rule in Mamdani-type fuzzy model with two-input single-output has the form (If x is A and y is B then z is C)

In Mamdani’s fuzzy model crisp values are used as inputs and defuzzification is used to convert a fuzzy set to a crisp value.

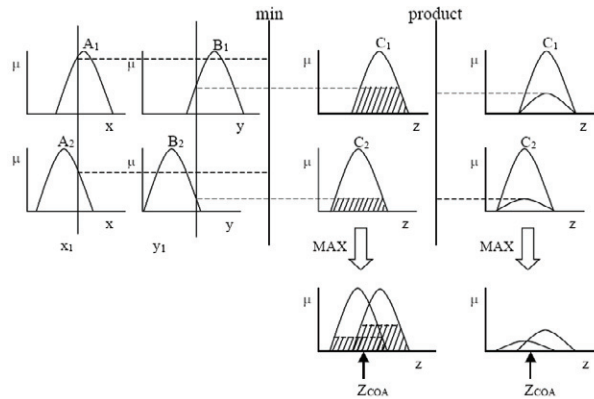


Fig. 2. Two-input Single-output Mamadani fuzzy model.

Fuzzy proportional integral is an inelegant modern control. If there is a sustained error in steady state, integral action is necessary. The integral action will increase the control signal if there is a small positive error, no matter how small the error is; the integral action will decrease it if the error is negative.

A controller with integral action will always return to zero in steady state. the gains are related as follows:

$$GCE * GCU = K_p \tag{12}$$

$$\frac{GE}{GCE} = \frac{1}{T_i} \tag{13}$$

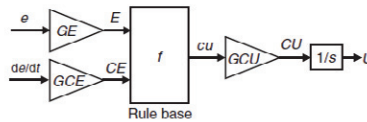


Fig. 3. Fuzzy PI Controller.

Notice that the proportional gain now depends on GCE. The gain on the integral action is determined by the ratio between the two input gains GE and GCE.

5. Analysis and Result

Figure 4 shows the full plant design. PI control system designed in MATLAB Simulink where controller coefficients were adjusted using the Signal Constraint block. The optimization process of controller parameters where $K_p=11$ and $K_i=42$ so after calculation and apply the parameters of fuzzy control to Matlab Simulink $GCE = 0.56, GCU = 18$ and $GE = 24$. Inputs of Fuzzy-PI control are “error” and “change of error” where the output is “control”. Input variables of Fuzzy-PI consist of three fuzzy sets for every input N (negative), Z (zero), P (positive) and output variables consist of five fuzzy sets as shown in Figure 5 shows fuzzy surface.

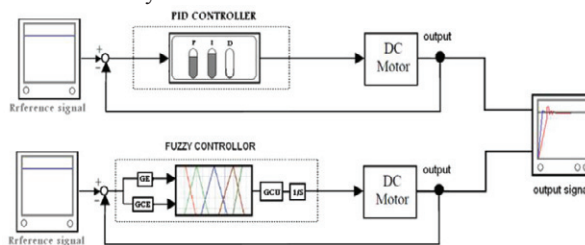


Fig. 4. PI and FPI control

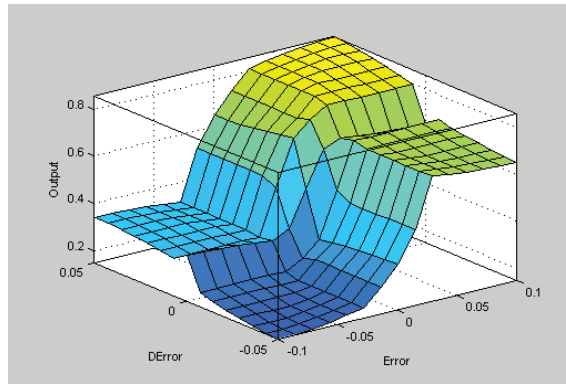


Fig. 5. shows fuzzy surface.

In figure 6, the step response curve of DC motor speed regulating system simulation controlled by two controllers PI control, and fuzzy-PI which shows that fuzzy-PI has fast dynamic response and very small overshoot.

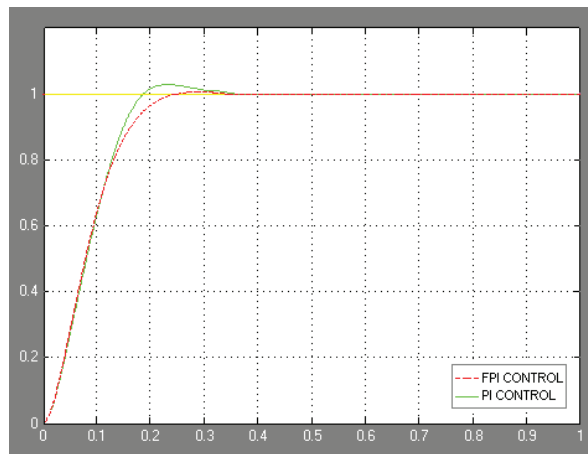


Fig. 6. Compare between PI and Fuzzy-PI control.

6. Conclusion

In this paper we have studied about different method for speed control of DC motor. The modeling and steady state operation of DC motor are studied. We have also studied basic definition and effect of fuzzy logic and fuzzy set. This paper introduces a design method of two inputs and one outputs fuzzy-PI controller and make use of MATLAB fuzzy toolbox to design fuzzy controller. The fuzzy controller adjusted the proportional, integral (K_p, K_i) gains of the PI controller according to speed error and change in speed error. From the simulation results it is concluded that, compared with the conventional PI controller, where fuzzy-PI controller has a better performance in both transient, overshoot and steady state response. Fuzzy-PI has better dynamic response curve, shorter response time, very small overshoot, no steady state error. The response of fuzzy is high quality compared to the classical PI controller.

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