Design of Self Tuning PID Controller Using Fuzzy Logic for DC Motor Speed

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Abstract: The development of high performance motor drives is very important in industrial as well as other purpose applications such as electric trains and robotics. Generally, a high-performance motor drive system must have good dynamic speed command tracking and load regulating response to perform task.

In this paper present an implementation of self-tuned Fuzzy-PID controller for speed control of DC motor based MATLAB/SIMULINK. The algorithms of Fuzzy-PID controller and conventional PID controller are implemented using PID and Fuzzy logic simulation toolkit of the Matlab.

The simulation results demonstrate that the designed self-tuned Fuzzy-PID controller realize a perfect speed tracking with lesser over shoot and settling time, minimum steady state error and give better performance compared to conventional PID controller and Fuzzy controller.

Key Words: DC Motor, Speed Control, Ziegler Nichols method, PID Controller, Fuzzy Logic Controller and Fuzzy-PID Controller, MATLAB/SIMULINK.

1. Introduction

A basic control system has an input, a process, and an output. The basic objective of control system is of regulating the value of some physical variable or causing that variable to change in a prescribed manner in time.

For a large variety of Industrial applications dc motors are being used such as elevators, electric trains, automobiles, robots. Micro-machines are electric machines with parts the size of red blood cells, and find many applications in medicine.

Several conventional and numeric controller types, the controllers can be: Proportional integral (PI), proportional integral derivative (PID), Fuzzy Logic Controller (FLC) or the combination between them: Fuzzy-Neural Networks, Fuzzy-Genetic Algorithm, Fuzzy-Ants Colony, Fuzzy-PID.

Control system design and analysis objectives include: producing the response to a transient disturbance follows a specified pattern (over-damped or under damped), minimizing the steady-state errors, and achieving the stability. [1]

2. DC Motor Mathematical Model

In armature control of separately excited DC motors, the voltage applied to the armature of the motor is adjusted without changing the voltage applied to the field. The development of the
mathematical model is to relate the voltage applied to the armature to the velocity of the motor [14] [7]. the equivalent circuit of the DC motor is shown in fig.1:

![Equivalent Circuit Diagram](image)

Fig.1: equivalent circuit of the DC motor.

Whereas:
- \( V_a \): Voltage source (v)
- \( R_a \): Armature resistance (Ω)
- \( L_a \): Armature inductance (H)
- \( I_a \): Armature current (A)
- \( V_c \): Induced voltage (v)
- \( W_a \): Angular velocity of rotor (rad/s)
- \( J \): Rotor inertia (kgm²)
- \( B \): Friction constant (Nms/rad)
- \( K_b \): Back electromotive force constant (v/rad)
- \( K_v \): Torque constant (Nm/A)

The overall transfer function between the output angular velocity and input applied voltage given within the last block in fig.2

![Block Diagram](image)

Fig.2: block diagram of the DC motor model

The transfer function of DC motor speed with respect to the voltage source can be written as:

\[
\frac{w_a(s)}{V_a(s)} = \frac{K_t}{La(s^2) + (Ra + L_a)s + RaB + KtKv} \tag{1}
\]

MATLAB based DC motor model was built in order to run fuzzy and PID algorithms and also to analyze.

3. Tuning Methods

Speed of DC motor can be controlled using different tuning methods such as:

I. PID Controller.
II. Fuzzy Logic Controller.
III. Fuzzy-PID Controller.

3.1 PID Controller (Ziegler-Nichols)

The structure of PID includes proportional term, integral term and derivative term. The PID controller is mainly to adjust appropriate proportional gain \((k_P)\), integral gain \((k_I)\), and differential gain \((k_D)\) to achieve the optimal control performance. PID structure as shown in Fig.3, \( r(t) \) is reference, \( e(t) \) is error, \( u(t) \) is controller output and \( y(t) \) system output.

![PID Controller Structure](image)

Fig.3: PID Controller Structure

Relation between the input \( e(t) \) and output \( u(t) \) can be formulated in the following:

\[
e(t) = r(t) - y(t) \tag{2}
\]

\[
U(t) = k_P e(t) + k_I \int_0^t e(t) dt + k_D \frac{de(t)}{dt} \tag{3}
\]

The transfer function is expressed (Laplace domain):

\[
C(S) = \frac{U(S)}{E(S)} = k_P + \frac{k_I}{S} + k_DS \tag{4}
\]

PID controllers are tuned in terms of \( K_p \), \( K_I \) and \( K_D \). Ziegler-Nichols is a type of controller tuning. It is performed by setting the \( I \) (integral) and \( D \) (derivative) gains to zero. The "P" (proportional) gain, \( k_P \) is then increased (from zero) until it reaches the ultimate gain \( k_u \), at which the output of the control loop has stable and consistent...
oscillations $k_u$ and the oscillation period $T_u$ are used to set the $P$, $I$, and $D$ gains depending on the type of controller used:[3]

Table.1: Ziegler–Nichols Method

<table>
<thead>
<tr>
<th>Control Type</th>
<th>$K_p$</th>
<th>$K_i$</th>
<th>$K_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td>$0.50K_u$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$PI$</td>
<td>$0.45K_u$</td>
<td>$0.54K_u/T_u$</td>
<td>-</td>
</tr>
<tr>
<td>$PID$</td>
<td>$0.60K_u$</td>
<td>$1.2K_u/T_u$</td>
<td>$3K_uT_u/40$</td>
</tr>
</tbody>
</table>

3.2 Fuzzy Logic Controller

Fuzzy logic is express by means of the human language. Based on fuzzy logic, a fuzzy controller converts a linguistic control strategy into automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database (IF X AND Y THEN Z). Fuzzy logic controller (FLC) process is shown in Fig.4.

First, set the error $e(t)$ and the change of error $ce(t)$ of the angular velocity to be the variable inputs of the fuzzy logic controller. The control voltage $u(t)$ is the variable output of the fuzzy logic controller.

$$E(t) = r(t) - u(t) \ldots (5)$$

$$Ce(t) = e(t) - e(t-1) \ldots (6)$$

Block diagram for speed control of DC motor using fuzzy logic controller is shown in Fig.5.

Fuzzy membership function using triangular functions for error input in Fig.6 for change of error inputs in Fig.7, and for output in Fig.8.

Based on speed of error, change of error, output and defined set of rules we have input and output relationship for fuzzy controller as shown in Fig.9.
3.3 Fuzzy-PID Controller

The structure of the fuzzy auto tuning PID controller designed for control speed of dc motor is shown in Fig.10. Its inputs are error (e) and the change of error (ce), the fuzzy auto tuner block adjusts the parameter of the incremental PID controller, and the incremental PID controller calculates the control output.

The fuzzy auto-tuning of PID controller is to find the fuzzy logic relationship between three parameters of PID with error (e) and change of error (ce), calculate (e) and (ce) in cycle in the operation of control system and adjust (kp), (ki) and (kd) on-line according to the fuzzy logic control principle.

Set the membership function of fuzzy variables as triangle membership function (trimf), the degree of membership function of speed control error (e) is shown in Fig.11, the degree of membership of change speed error (ce) is shown in Fig.12, the degree of membership of change kp is shown in Fig.13, the degree of membership of change ki is shown in Fig.14, the degree of membership of change kd is shown in Fig.15.
Fig. 15: Degree of Membership of Change $k_d$

According to the membership degree calculation of all fuzzy variable sets, and the fuzzy tuning rule sets and algorithms of all control parameters, the mamdani-type inference system Fuzzy-PID is developed using the fuzzy control simulation toolbox” fuzzy “ofMATLAB.

4. Results

After simulating the process control of speed control system models by using MATLAB/SIMULINK, the performance of the controllers was analyzed by comparing the output signal represented by the graph.

Fig.16 shows performance of the PID controller. Using Ziegler-Nichols method to tune PID controller parameters. Fig.17 shows Error of the closed loop system using PID controller.

Fig. 16: Step Response of the System with PID Controller.

Fig.17: Error of the Closed Loop System Using PID Controller

Fig.18 show performance of the Fuzzy controller. Fig.19 shows Error of the closed loop system using Fuzzy controller.

Fig. 18: Step Response of the System with Fuzzy Controller.

Fig. 19: Error of the Closed Loop System Using Fuzzy Controller.

Fig.20 show step response of system using fuzzy-PID controller. Fig.21 shows Error of the closed loop system using fuzzy-PID controller.

Fig. 20: Step Response of the System with Fuzzy-PID Controller.

Fig. 21: Error of the Closed Loop System Using Fuzzy-PID Controller.
Comparison between PID, Fuzzy and Fuzzy-PID controller step response specification as shown in Fig.22 and Table.2.

Table.2: Comparison between the Output Responses for Controller

<table>
<thead>
<tr>
<th>Title</th>
<th>PID controller</th>
<th>Fuzzy controller</th>
<th>Fuzzy-PID controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak</td>
<td>1.48</td>
<td>1.045</td>
<td>1</td>
</tr>
</tbody>
</table>

5. Conclusion

From the simulation results it is concluded that, compared with the conventional PID controller, Fuzzy controller and self-tuning PID controller, Fuzzy-PID controller has a better performance in both transient and steady state response. The self-tuning Fuzzy-PID has better dynamic response curve, short response time, smaller overshoot, less peak amplitude, minimum settling time, small steady state error (SSE), high steady precision compared to the conventional PID controller and Fuzzy controller.

References:

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Appendix: DC Motor Model Parameters

Armature resistance \( R_a = 0.5 \, \Omega \)

Torque constant \( K_T = 0.5 \, \text{Nm/A} \)

Armature inductance \( L_a = 0.02 \, \text{H} \)

Friction constant \( B = 0.008 \, \text{Nms/rad} \)

Rotor inertia \( J = 0.1 \, \text{kgm}^2 \)

Back emf constant \( K_b = 1.25 \, \text{Vs/rad} \)