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A Proposed DC Motor Sliding Mode Position Controller Design using Fuzzy Logic and PID Techniques

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Abstract: Due to the robustness of sliding mode controllers (SMCs), especially against model uncertainties and disturbances, and also its ability in controlling nonlinear and multi-input multi-output (MIMO) systems; a DC motor sliding mode position controller design using fuzzy logic (FL) and proportional-integral-derivative (PID) techniques, is proposed in this paper. Also, due to system uncertainties that can lead to chattering phenomena in control law which can excite non-modeled dynamics and may damage the process, different approaches, like intelligent techniques, are used to minimize these effects. In this paper, the FL will be considered in the design of SMC. Also, a PID will be used in the outer loop in the control law then the gains of the sliding term and PID term are tuned on-line by a fuzzy system, so the chattering is avoided and response of system is improved against external load here. Presented simulation results confirm the above proposal and demonstrate the performance improvement to the example of DC motor.

Keywords: DC Motor, Fuzzy Logic, PID and Sliding Mode

1. Introduction

All practical processes have many systems having nonlinear behavior. These properties are always unknown and time varying. The commonly used PID controllers are simple to be implemented in different applications, but they suffer from poor performance if there are uncertainties and nonlinearities. Recently much research has been devoted to the robust control systems, where the FL, neural network (NN) and sliding-mode based controllers are applied [1-3].

The sliding mode control is robust to plant uncertainties and insensitive to external disturbances. It is widely used to obtain good dynamic performance of controlled systems. However, the chattering phenomena due to the finite speed of the switching devices can affect the system behavior significantly. Additionally, the sliding control requires the knowledge of mathematical model of the system with bounded uncertainties [4].

Reduced chattering may be achieved without sacrificing robust performance by combining the attractive features of fuzzy control with SMC. FL is a potent tool for controlling ill-defined or

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parameter-variant plants. By generalizing fuzzy rules, a FL controller can cope well with severe uncertainties. Fuzzy schemes with explicit expressions for tuning can avoid the heavy computational burden [5].

DC motors are generally controlled by conventional PID controllers, since they designed easily, have low cost, inexpensive maintenance and effectiveness. It is necessary to know system's mathematical model or to make some experiments for tuning PID parameters. However, it has been known that conventional PID controllers generally do not work well for non-linear systems, and particularly complex and vague systems that have no precise mathematical models [6].

To overcome these difficulties, various types of modified conventional PID controllers such as auto-tuning and adaptive PID controllers were developed lately. Also FLC can be used for this kind of problems. When compared to the conventional controller, the main advantage of FL is that no mathematical modeling is required [7].

In this paper the combined solution we have proposed and designed a robust controller. We have used a PID outer loop in the control law then the gains of the sliding term and PID term are tuned on-line by a fuzzy system.

2. Model of a DC motor

DC motors are widely used in industrial and domestic equipment. The control of the position of a motor with high accuracy is required. The electric circuit of the armature and the free body diagram of the rotor are shown in Figure (1).

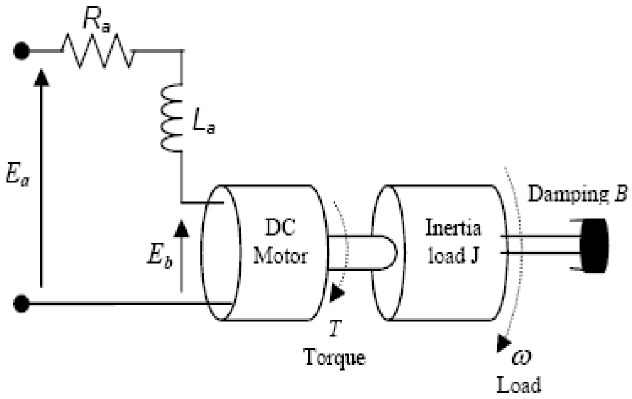

Figure (1) DC motor structure

A desired speed may be tracked when a desired shaft position is also required. In fact, a single controller may be required to control both the position and the speed. The reference signal determines the desired position and/or speed. The controller is selected so that the error between the system output and reference signal eventually tends to its minimum value, ideally zero. There are various DC motor types. Depending on type, a DC motor may be controlled by varying the input voltage whilst another motor only by changing the current input.

In this paper a DC motor is controlled via the input voltage. The control design and theory for controlling a DC motor via current is nearly the same. For simplicity, a constant value as a reference signal is injected to the system to obtain a desired position. However, the method works successfully for any reference signal, particularly for any stepwise time-continuous function. This signal may be a periodic signal or any signal to get a desired shaft position, i.e. a desired angle between 0 and 360 degrees from a virtual horizontal line. The dynamics of a DC motor may be expressed as:

$$V_t = R_a I_a + L_a \frac{dI_a}{dt} + E_a \tag{1}$$

$$T = J\frac{d\omega}{dt} + B\omega - T_l \tag{2}$$

$$T = K_T I_a \tag{3}$$

$$E_a = K_a \omega \tag{4}$$

$$\frac{d\omega}{dt} = \phi \tag{5}$$

with the following physical parameters:

E_a: The input terminal voltage (source), [V];
E_b: The back emf, [V];
R_a: The armature resistance, [Ω];
I_a: The armature current [A];
L_a: The armature inductance, [H];
J: The moment inertial of the motor rotor and load, [kg.m^2/s^2];
T: The motor torque, [N.m];
ω: The speed of the shaft and the load (angular velocity), [rad/s];
ϕ: The shaft position, [rad];
B: The damping ratio of the mechanical system, [N.m.s];
T_k: The torque factor constant, [N.m/A];
B_k: The motor constant [V.s/rad].

Block diagram of a DC motor is shown in Figure (2).

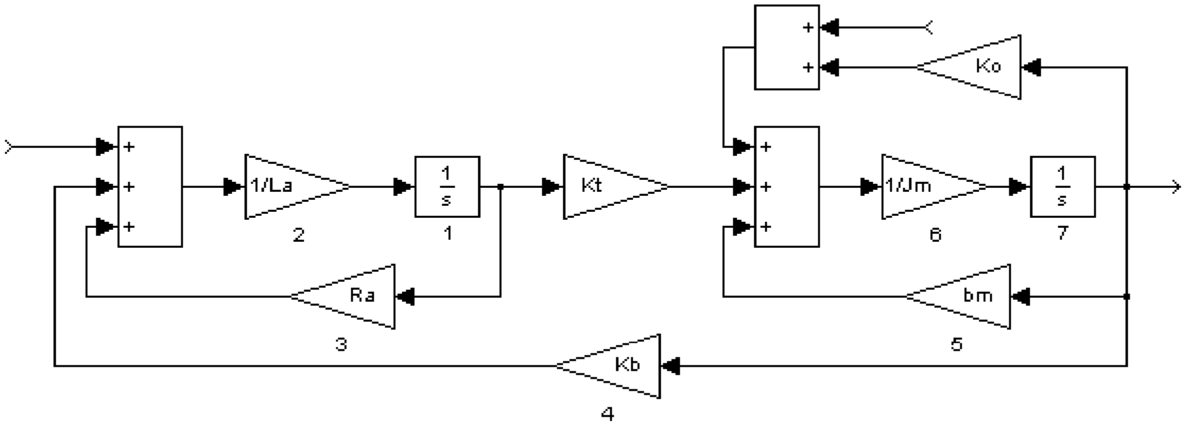

Figure (2) DC motor block diagram

3. SMC

SMC is a Variable Structure Controller (VSC). Basically, a VSC includes several different continuous functions that can map plant state to a control. Surface and the switching among different functions are determined by plant state that is represented by a switching function. Without lost of generality, consider the design of a SMC for the following second order system: (here *u*(*t*) is the input to the system)

$$u = u_s + u_{eq} \tag{6}$$

Where $u_s = -k.\mathrm{sat}(s/\phi)$ and constant factor ϕ defines the thickness of the boundary layer. $\mathrm{sat}(s/\phi)$ is a saturation function that is defined as:

$$\mathrm{sat}(s/\phi) = \begin{cases} \dfrac{s}{\phi} & \text{if} \left|\dfrac{s}{\phi}\right| \le 1 \\ \mathrm{sgn}(s/\phi) & \text{if} \left|\dfrac{s}{\phi}\right| > 1 \end{cases} \tag{7}$$

The function between *us* and s/ϕ is shown in the Figure (3):

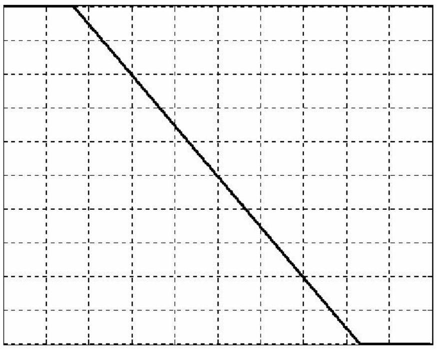

Figure (3) Switching surface in the phase plane

The control strategy adopted here will guarantee the system trajectories move toward and stay on the sliding surface *s* = 0 from any initial condition if the following condition meets:

$$s\dot{s} \le -\eta|s| \tag{8}$$

Where η is a positive constant that guarantees the system trajectories hit the sliding surface in finite time .Using a sign function often causes chattering in practice. One solution is to introduce a boundary layer around the switch surface.

This controller is actually a continuous approximation of the ideal relay control. The consequence of this control scheme is that invariance of sliding mode control is lost. The system robustness is a function of the width of the boundary layer. The principle of designing sliding mode control law for arbitrary-order plants is to make the error and derivative of error of a variable is forced to zero. In the DC motor system the position error and its derivative are the selected coordinate variables those are forced to zero. Switching surface design consists of the construction of the switching function. The transient response of the system is determined by this switching surface if the sliding mode exists. First, the position error is introduced:

$$e(k) = \theta_{ref}(k) - \theta(k) \tag{9}$$

where $\theta_{ref}(k)$ and $\theta(k)$ are the respective responses of the desired reference track and actual rotor position, at the *k* the sampling interval and *e*(*k*) is the position error. The sliding surface (s) is defined with the tracking error (e) and its integral ($\int edt$) and rate of change ($\dot{e}$).

$$s = \dot{e} + \lambda_1 e + \lambda_2 \int edt \tag{10}$$

Where $\lambda_1, \lambda_2 \rangle 0$ are a strictly positive real constant. The basic control law of SMC is given by:

$$U=-k.sgn(s) \tag{11}$$

Where k is a constant parameter, sign (·) is the sign function and S is the switching function.

4. Design of fuzzy PID SMC

In this section, a fuzzy sliding surface is introduced to develop a SMC. Which the expression $-k.sat(s/\phi)$ is replaced by an inference fuzzy system for eliminate the chattering phenomenon.

In addition, to improve the response of system against external load, the SMC design with a PID out loop.

The designed fuzzy logic controller has two inputs and an output. The inputs are sliding surface (s) and the change of the sliding surface ($\dot{s}$) in a sample time, and output is the fuzzy gain (k_{fuzz}).The fuzzy controller consists of three stages: fuzzyfication, inference engine and defuzzyfication. Then, a 3x5 rule base was defined - Table (1) - to develop the inference system. Both fuzzyfication and inference system were tuned experimentally. The membership function of inputs variable are depicted in Figures (4) and (5) and the membership function of the output variable is depicted in Figure (6).

Table (1) Fuzzy rule base

S,S'	NB	NS	ZE	PS	PB
N	B	B	M	S	M
Z	B	M	S	M	B
P	M	S	M	B	B

where NB=Negative big; NS: Negative Small; Z: Zero; PS: Positive Small; PB: Positive Big; M: Medium. For example when S is (NS) and $\dot{s}$ is (P), so k_{fuzz} is Small(S). The sliding function is defined as:

$$s = \dot{e} + \lambda_1 e + \lambda_2 \int edt \qquad (12)$$

where $\lambda_1, \lambda_2 \rangle 0$ are a strictly positive real constant. The control law is defining as:

$$u = k_v s + k\,\mathrm{sgn}(s) \qquad (13)$$

where $k_v s = k_v \dot{e} + k_v \lambda e + k_v \lambda \int_0^t edt$ and $k_v = N_v k_{fuzz}, k = N k_{fuzz}$

Tracking loop for out PID and k, k_v are gain to ensure for stability and sgn is sign function.

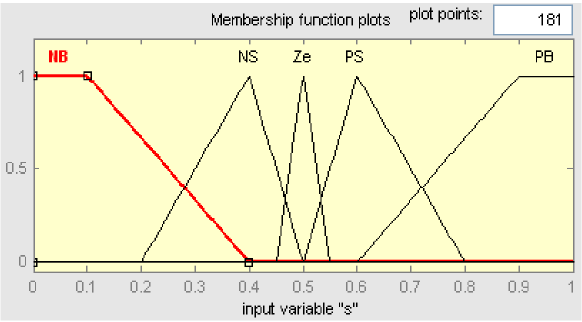

Figure (4) Membership functions for (s) normalized inputs

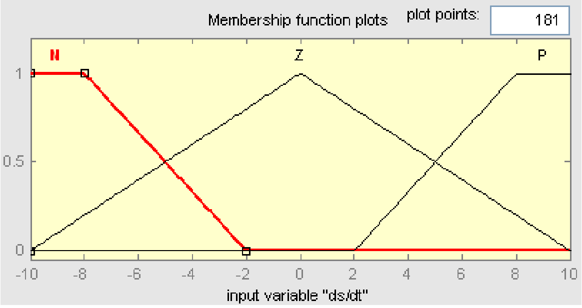

Figure (5) Membership functions for (ds/dt) normalized inputs

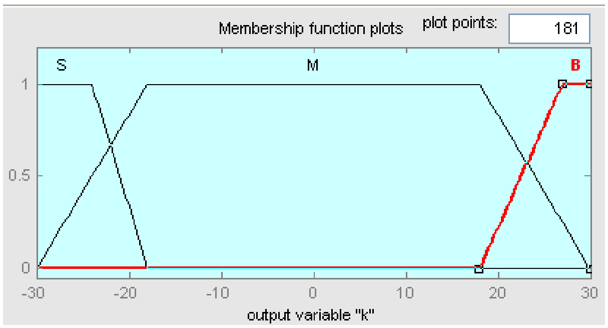

Figure (6) Membership functions for (K_{fuzz}) normalized outputs

5. Simulation results

In this section, the overall model of DC motor with SMC and fuzzy logic and PID is implemented in MATLAB/SIMULINK. The SIMULINK model of the FSMC is shown in Figure (7) and the FPIDSMC is shown in Figure (8).

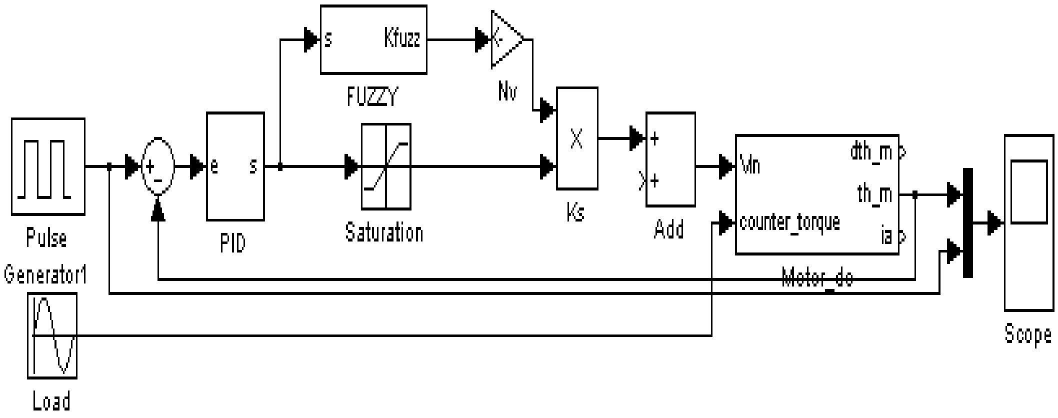

Figure (7) SIMULINK block diagram of FSMC

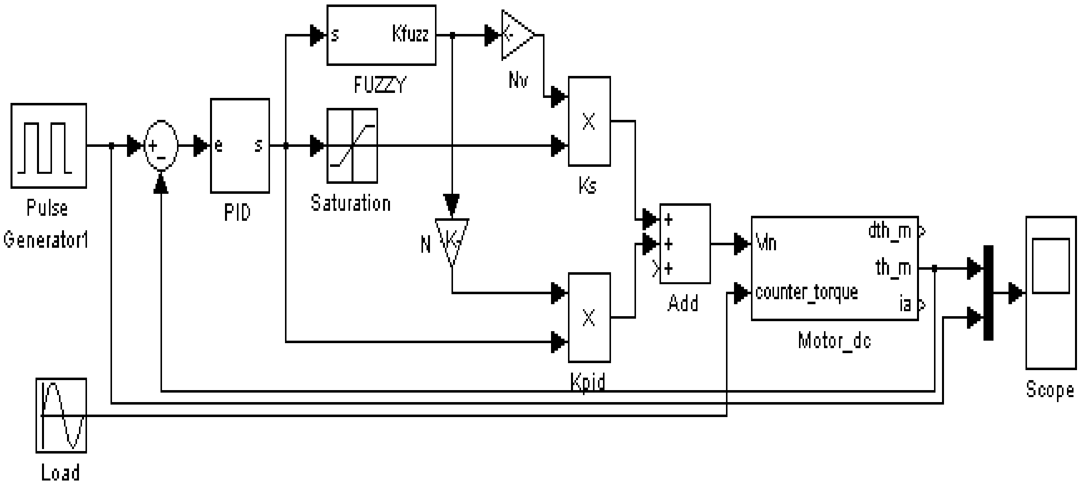

Figure (8) SIMULINK block diagram of FPIDSMC

In order to test the effectiveness and robustness of the FSMC and FPIDSMC controllers against uncertainties and external disturbances and external load, we change the parameters of DC motor and use sine wave block with amplitude and frequency = 2. The curves with green color represent the controllers without Uncertainties, disturbances and external load. The curves with red color represent response of system against uncertainties in the system.

The DC motor was also operated at full load for 0.5 second, and then the load torque was increased to 130% of its full load value for a period of 0.5 second. The simulation results are shown in Figures (9) to (12). Figures (9) and (10) represent the system response to the FSMC controller. Figures (11) and (12) represent the system response to the FSMC controller.

From the above Figures, we find that the speed overshoot with adaptive controller is smaller than that with fuzzy controller. Also the recovery time with neural controller is shorter than that with fuzzy controller.

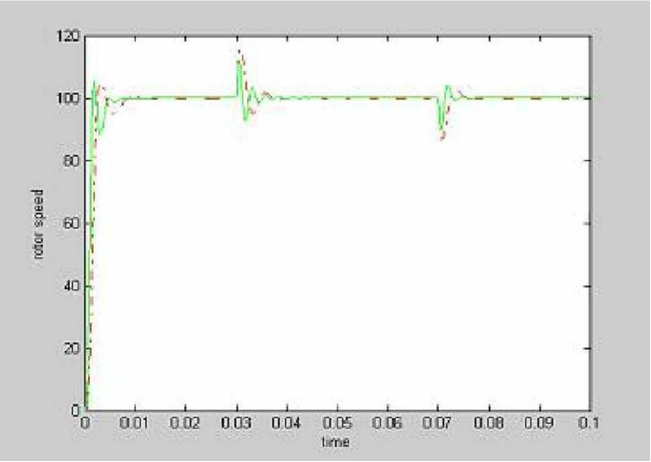

Figure (9) **Rotor speed response when the DC motor equipped with FSMC controller**

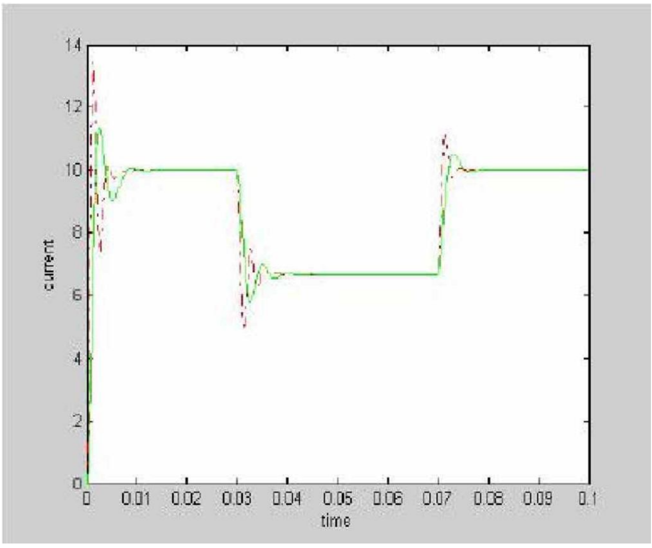

Figure (10) **DC motor current when equipped with FSMC controller**

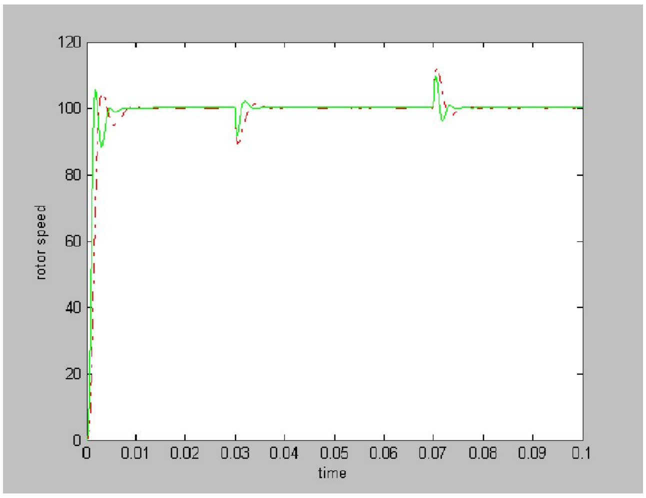

Figure (11) **Rotor speed response when the DC motor equipped with FPIDSMC controller**

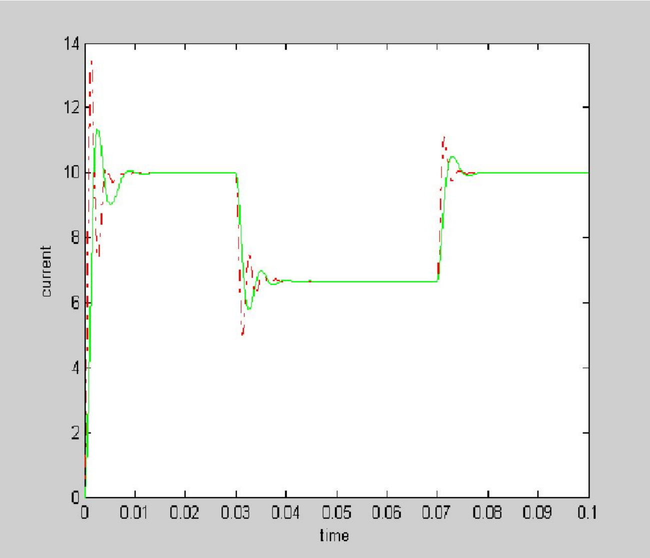

Figure (12): DC motor current when equipped with FPIDSMC controller

6. Conclusions

In this paper, the SMC using fuzzy and PID is proposed for a DC motor position control. According to the simulation results, the FPIDSMC and FSMC controller can provide the properties of insensitivity and robustness to uncertainties and external disturbances, and response of the DC motor for FPIDSMC and FSMC controllers against uncertainties and external disturbance is the same. But the comparison between the position control of the DC motor by a FPIDSMC and a FSMC shows clearly that the FPIDSMC gives better performances than FSMC against external load. So proposed controller is a robust controller, and the chattering is avoided and response of system is improved against external load.

7. References

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