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Modified Chattering Free Sliding Mode Control of DC Motor

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Abstract: *This paper is concerned with the design of a Modified Sliding Mode Controller for the position control of DC Motor. The DC motor can be modeled as a linear time invariant single input single output (SISO) system. In this paper synthesis and analysis of position control of a DC motor using chattering free sliding mode controller and conventional PID controllers are carried out and their performance is evaluated. The performance of modified sliding mode controller is superior to conventional PID controllers even in the presence of disturbances.*

Keyword: *chattering free Sliding mode controller; DC Motor; PID Controller*

I. Introduction

The proportional-integral-derivative (PID) controller is extensively used in many industrial control applications [1] due to is simplicity and effectiveness in implementation. The three controller parameters, proportional gain Kp, Integral gain Ki, and derivative gain Kd, are usually fixed. The disadvantage of PID controller is poor capability of dealing with system uncertainty, i.e., parameter variations and external disturbance. In recent years, there has been extensive research interest in robust control systems, where the fuzzy logic, neural network and sliding-mode based controllers [1] [2].

Sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems [3]. The main feature of SMC is the robustness against parameter variations and external disturbances and is widely used to obtain good dynamic performance of control systems. Various applications of SMC have been conducted, such as robotic manipulators, aircrafts, DC motors, chaotic systems etc. [4] [5] [6].

The finite speed of switching devices involved in SMC cause the phenomenon of chattering and it affects the performance of the system adversely. Chattering is a phenomenon of high frequency switching of the control action which causes high frequency oscillations in the output, heating up of electrical circuits and premature wear in actuators. A modified sliding mode control technique can reduce the chattering without sacrificing the robustness of the system.

DC motor are generally controlled by conventional Proportional – Integral – Derivative (PID) controllers. For effective implementation of PID controller it is necessary to know system's mathematical model for tuning PID parameters. However, it has been known that conventional PID controllers generally do not work well for non-linear systems, particularly complex and vague systems that have no precise mathematical models. To overcome these difficulties, various types of modified conventional PID controllers such as auto-tuning and adaptive PID controllers were developed lately [7].

This paper is focused on the performance comparison of the of the modified sliding mode controller with PID controller for the position control of a DC motor

II. Mathematical Modeling Of A Dc Motor

DC motors are widely used in various industrial and electronic equipment where the position control with high accuracy is required. The electric circuit of the armature and the free body diagram of the rotor are shown in fig. 1. The desired speed is tracked according to the shaft position of the motor. A single controller is required to control the position as well as the speed of the motor. The controller is selected so that the error between the system output and reference signal eventually tends to its minimum value, ideally zero. The reference signal determines the desired position and/or speed. Depending on type, a DC motor may be controlled by varying the input voltage or field current.

Here the variation of input voltage is used as the control parameter for the position control. A constant dc voltage is selected as a reference signal to obtain the desired position of the motor. 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 is given in eqn (1)-eqn (5)

$$V_t = R_a I_a + L_a \frac{dI_a}{dt} + E_b \quad (1)$$

$$T = J\frac{d\omega}{dt} B\omega - T_L \quad (2)$$

$$T = K_t I_a \quad (3)$$

$$E_b = K_b \omega \quad (4)$$

$$\omega = \frac{d\theta}{dt} \quad (5)$$

Where

V	Input terminal voltage (v)	E_b	Back emf (v)
Ra	The armature resistance (ohm)	La	the armature inductance (H)
J	The moment of inertia of the rotor and load (Kg-m^2/s^2)	Kt	the torque constant (N-m/A)
B	The damping ratio of mechanical system (N/m/s)	Kb	the motor constant (v-s/rad)
θ	The angular displacement (rad)		

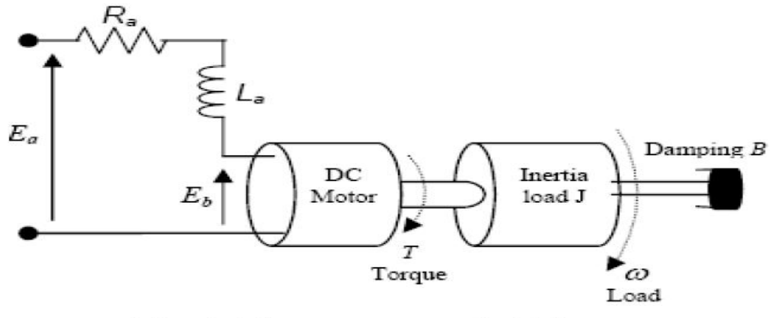

Fig.1. Structure of a DC Motor

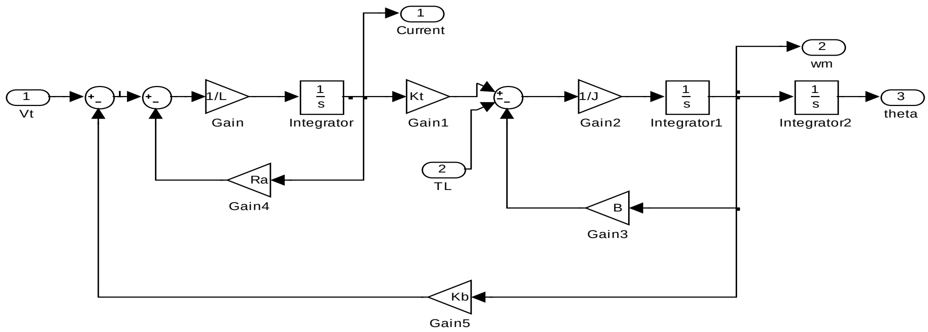

Fig.2. Simulink Block diagram of a DC Motor

III. Sliding Mode Control

Sliding mode control has long proved its interests. They are relative simplicity of design, control of independent motion (as long as sliding conditions are maintained) and invariance to process dynamics characteristics and external perturbations.

A Sliding Mode Controller 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. The basic control law of SMC is given by:

$$u = -k\,sign(s) \qquad (6)$$

Where k is a constant parameter, sign (·) is the sign function and s is the switching function. Chattering is a phenomenon present in the sliding mode control which affects the performance of the system significantly. In order to reduce the effect of chattering, the control law in the sliding mode controller is modified as $u = -k\,sat(s/\phi)$ and constant factor ϕ defines the thickness of the boundary layer. $sat(s/\phi)$ is a saturation function that is defined as:

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

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:

$$s\dot{s} \le -\eta|s| \qquad (8)$$

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:

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

Where θ_{ref} (k) and θ (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 of e. The sliding surface is given by eqn (10)

$$s = \dot{e} + \lambda_1 e + \lambda_2 \int edt \qquad (10)$$

Where $\lambda_1, \lambda_2 > 0$ are a strictly positive real constant. Also the value of ϕ is taken as unity.

IV. PID CONTROLLER

The time domain representation of PID controller is given in eqn (11)

$$u(t) = K_p\left[e(t) + T_d \frac{de(t)}{dt} + \frac{1}{T_i}\int e(t)dt\right] \qquad (11)$$

Where e (t) is the error (difference between reference input and output), u(t) is the control variable, Kp is the proportional gain Td is the derivative time constant and Ti is the integral time constant. The above equation can also be written as eqn (12)

$$u(t) = K_p e(t) + K_d \frac{de(t)}{dt} + K_i \int e(t)dt \qquad (12)$$

Where Kd= Kp Td and Ki= Kp/ Ti. Each of these coefficients makes change in the characteristics of the response of the system. In order to get the desired performance characteristics of the system these parameters are to be accurately tuned. The tuning Process of the PID controller can be complex due to its iterative nature. First it is necessary to tune the proportional mode, then the integral and then the derivative mode to stabilize the overshoot. The tuning process is to be continued iteratively.

Ziegler-Nichols tuning method of PID controllers

The tuning of PID controller involves the selection of the best values of the gains of K_p, K_i and K_d of the control law. A number of methods are available for the tuning of PID controllers.

The tuning of a PID controller generally aims to match some predetermined ideal response profile for the closed loop system. Many algorithms are available to guarantee the best performance of the PID controller. The Ziegler-Nichols tuning method of PID controllers is presented here.

The Ziegler-Nichols tuning method is described in the following steps

- Set the controller to Proportional mode only
- Set the gain K_p to a small value
- Apply a step input to the system and observe the response
- Increase the K_p in steps and observe the step response in each step
- Keep increasing K_p until the response show constant amplitude oscillations
- Note the value of K_p and the time period of the sustained oscillations. This gain is the ultimate gain Ku and the time period is P_u
- Apply the criteria of the Table for the determination of the parameters of the PID controller

The PID controller parameters are selected for the Quarter Decay Response (QDR) according to the table.I

Table I. Zeigler-Nichols parameters for QDR

Control Action	K_p	K_i	K_d
P	$K_u/2$		
PI	$K_u/2.2$	$1.2\ K_p/P_u$	
PID	$K_u/1.7$	$2\ K_p/P_u$	$K_p\ P_u/8$

For the DC motor system the ultimate gain Ku and the time period is P_u are obtained as K_u=3.8, Pu=0.28sec. From these the PID controller parameters are obtained as K_p= 2.23 , K_i= 27.14 , K_d=1.33

V. Simulation Results & Discussions

In this section, the overall model of DC motor with PID controller and sliding mode controller is implemented in MATLAB/Simulink.

The simulink model of the PID controller is shown in fig. 3 and that of the modified chatter free SMC is shown in fig. 4. The fig.5 shows the response of the system with conventional sliding mode controller for a step input in presence of cyclic disturbance. Here the overshoot is considerably reduced as compared to PID controller. But the output is oscillating at high frequency due to chattering. The fig.6 shows the response of the system with modified chatter free SMC for a step input at no-load. The performance comparison is given in table II. From table it is clear that the performance of the sliding mode controller is far better than that of the PID controller

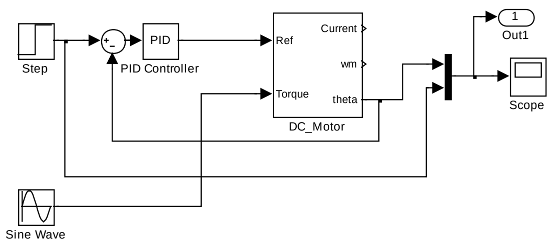

Fig.3. Simulink Block diagram of PID control

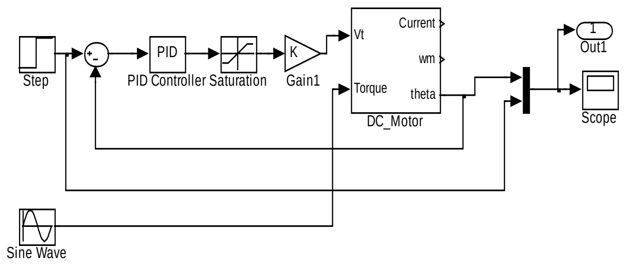

Fig.4. Simulink Block diagram of SMC

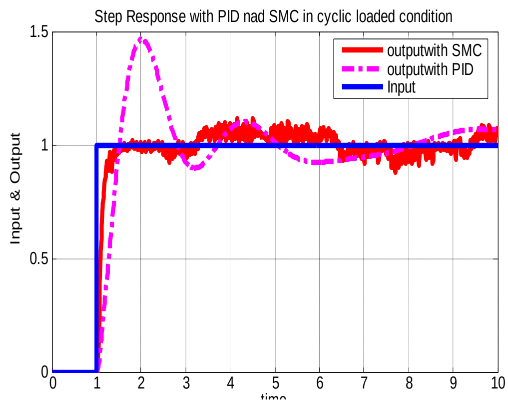

Fig.5. Step response with PID and conventional SMC in cyclic loaded condition

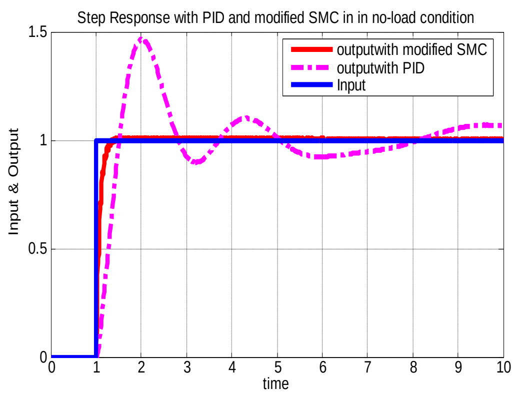

Fig.6. Step response with PID and modified SMC at no-load

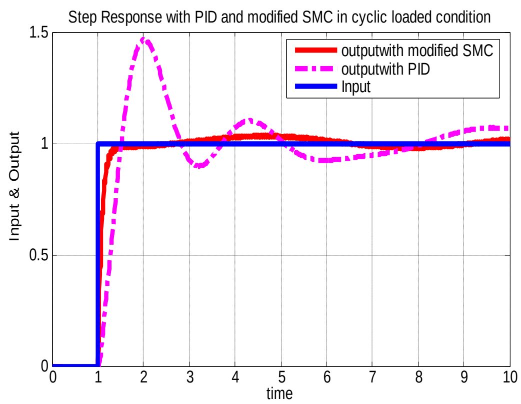

Fig.7. Step response with PID and modified SMC in cyclic loaded condition

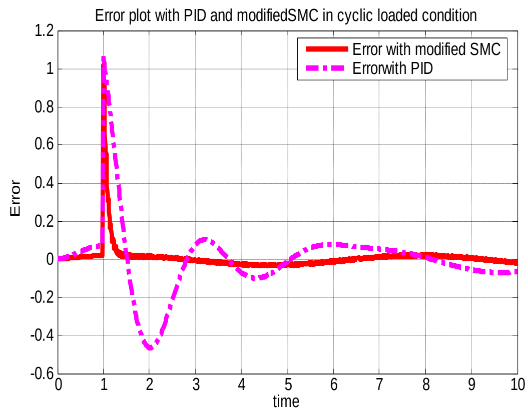

Fig.8. Error with PID and modified SMC in cyclic loaded condition

Fig.7 shows the step response of the system under disturbance by cyclic load. Under this condition also the sliding mode controller still shows better performance than the PID controller. Fig 8 shows the plot of error in this condition. So it is clear that the sliding mode controller is superior to PID controller even in the presence of disturbances like cyclic load or disturbance.

Table II. Performance comparison

	PID	Modified SMC
Rise time	0.6sce	0.4sec
Peak overshoot	40%	0%
Settling time	4 sec	0.4 sec

VI. CONCLUSION

This paper emphasizes on the effectiveness of position control of a DC motor with a Modified chattering free Sliding mode Controller and its merit over conventional PID controllers.

The PID controller and modified Sliding mode controller for the control of an armature controlled DC Motor is designed and is simulated using MATLAB and SIMULINK. From the obtained results it is clear that the performance of modified sliding mode controller is superior to that of PID controller.

The PID controller is very simple to design and very easy to implement and also give moderate performance under undisturbed conditions. But their performance deteriorates under disturbed condition like cyclic load. The sliding mode controller gives a better performance than that of PID controllers. The main problem associated with sliding mode controller is chattering. Reduced chattering may be achieved without sacrificing robust performance by modifying the control law of the sliding mode controller. The performance of the system with modified chattering free sliding mode controller is far better even in the presence of disturbances like cyclic load.

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