APPLICATION OF ADAPTIVE SLIDING MODE POSITION CONTROLLER WITH PI TUNING TO PERMANENT MAGNET BRUSHLESS DC MOTOR DRIVE SYSTEM

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Abstract
This paper presents a brief study of proportional integral sliding mode control (PISMC) techniques for controlling the rotor position of PMDC motor drive system. In particular, since SMC is robust in the presence of the matched uncertainties and external disturbances, the desired position is perfectly tracked. In addition, the advantages and disadvantages of both proportional-integral (PI) and sliding mode control (SMC) control methods are studied. Since the major drawback of SMC is a phenomenon, known as chattering, resulting from discontinuous controllers, the PISMC method presented reduced the chattering very well. The performance of this method, PISMC is compared with the responses of the system with PID and conventional SMC controllers, and the PISMC is found to be better with higher precision and better robustness to plant imprecision and external disturbances than PID controllers.

Keywords: Proportional-integral (PI), sliding mode control (SMC), proportional integral sliding mode control (PISMC)

Introduction
The main two types of d.c. motors used for industrial processes are; the conventional DC motor where the flux is produced by the current through the field coil of the stationary pole structure, and the brushless dc motor where the permanent magnet provides the necessary air gap flux instead of the wire-wound field poles. The BLDC motor with trapezoidal shape back e.m.f drives have been extensively used in many applications, ranging from servo to traction drives because of several distinct advantages. It has the following advantages over the conventional brushed DC motors and induction motors: dynamic response, high efficiency, better speed versus torque characteristics, long operating life noiseless operation, high power density large torque to inertial ratio and higher speed ranges. In addition brushless DC motors are smaller in volume, inexpensive easy to control, reliable and season. So it is widely applied in areas which need high performance drive such as automotive, aerospace, medical instrumentation, actuation, robotics, machine tools, industrial automation equipment and many others shown by Lee and Elisani, (2003), Hong et, al, (2007) and Akkaya et al (2007).

Many machine design and control schemes have been developed for the purpose of improving the performance of BLDC motor drives. In order to implement an effective control in simulation, the model of the motor has to be known.

Various researchers (Safi et al 1995; Figueroa et al, 2003 and Hung et al, 2007) have proposed some simulation models based on state – space equations, Fourier series, d – q axis model and variable sampling for the analysis of this type of motor drives.

From control point of view, DC motors exhibit excellent control characteristics because of the decoupled, nature of the field and armature mmf's. Recently, many modern control methodologies such as non linear control (Hemati et al, 1990), optimal control (Pelezewski and Kunz, 1990), variable structure control (Lin et al, 1999) adaptive control (Cerruto et al; 1995) and particle swarm optimization strategy (Nasri et al, 2007) have been widely proposed for linear brushless permanent magnet DC motor.

An LQR method to optimally tune the PID gains was presented by Yu et al, (2004). In this method the response of the system is near optimal but it requires mathematical calculations and solving equations Lin et al, (2003) have applied GA – based PID control for brushless DC motor. Genetic algorithm is originally motivated by the mechanism of natural selection and evolutionary genetics.

Sliding mode control (SMC) is one of the popular strategies to deal with uncertain control systems (Young et al, 1999). The main feature of SMC have carried out be researchers in such areas as robotic manipulators, aircrafts DC motors, chaotic systems and soon.(e.g. Choi et al, 2001; Huang and Wei, 2002; Guan et al, 2005; Jafarovet al 2005 and Huang and Kuo, 2006). Because there was not powerful microprocessor systems is the past and there existed considerable chattering in SMC systems. In this paper the adaptive sliding mode control with PI tuning is presented for brushless DC motor control system. The goal is to achieve systems robustness against parameter variations and external disturbances. Suitable PI control gain parameters can be systematically obtained according to the developed adaptive law. To reduce high frequency chattering in the controller, the boundary layer technique is applied (slotine and li, 1991). Simulation results showed that the chattering is eliminated and satisfactory position trajectory tracking is achieved.

Permanent brushless Dc motor drive system modeling

Permanent brushless DC motors use mechanical commutators and brushes to achieve the commutation. However, BLDC motors adopt Hall Effect sensors in place of mechanical commutators and brushes (Hambley, 1997). The stators of BLDC motors are the coils and the rotors are the permanent magnets. The stators develop the magnetic fields to make the rotor rotate. Hall Effect sensors detect the rotor position as the commutation signals. In this paper, a three phase and two – pole BLDC motor is studied. The speed of the BLDC motor is controlled by means of a three – phase and half – bridge pulse – width modulation (PWM) inverter.

The dynamic characteristics of BLDC motors are similar to that of permanent magnet DC motors. The characteristic equations of BLDC motors can be represented as (Ong. 1998):

$$V_{in}(t) = \frac{Ldi(t)}{dt} + R.i(t) + e_b(t) \quad (1)$$

$$e_b(t) = K_b\omega(t) \quad (2)$$

$$T(t) = K_m i(t) \quad (3)$$

$$T(t) = J\frac{dw}{dt}(t) + B.\omega(t) \quad (4)$$

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

Where

$V_{in}(t)$ is the applied voltage

$e_b(t)$ is the back e.m.f.

T is the torque

$\omega(t)$ is the motor speed

L is the stator inductance

R is the stator resistance.

$i(t)$ is the current of the circuit.

J is the moment of inertia.

B is the viscous coefficient

K_m is the motor torque constant

K_b is the back e.m.f. constant

From the characteristics equations (1) to (4) the transfer function of the speed model is obtained as

$$\frac{\omega(s)}{V_{in}} = \frac{K_m}{LJS^2+(LB+RJ)S+K_mK_b} \qquad (6)$$

$$\omega(s)S^2 + \left(\frac{LB+RJ}{LJ}\right)S\,\omega(s) + \left(\frac{K_mK_b}{LJ}\right)\omega(s) = K_mK_{in} \qquad (7)$$

The block diagram for the BLDC motor with respect to eqns (1) to (4) is as shown in fig

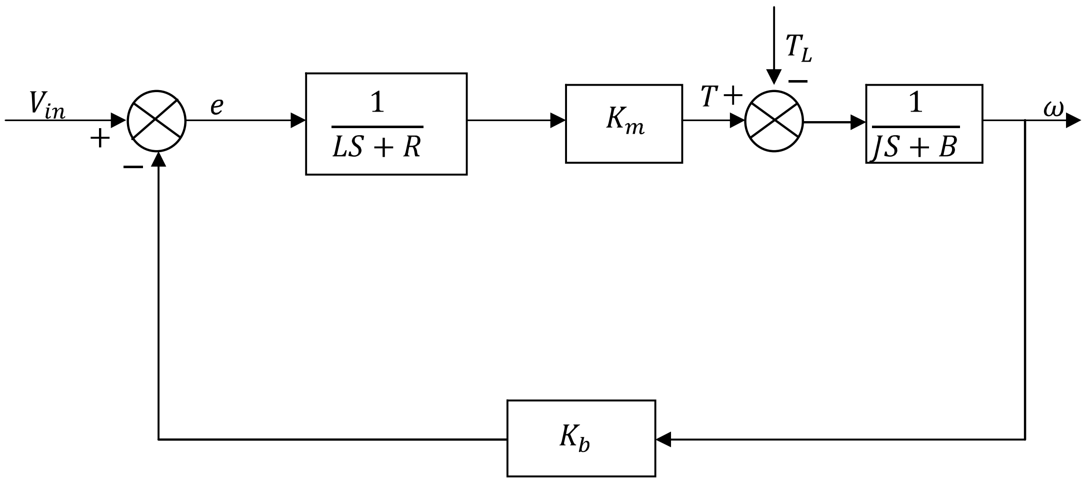

Fig 1: Block Diagram of BLDC motor

The above shows a second order system let e be the error between the desired trajectory y_d and the output y, i.e.

$$e = y_d - y \qquad (8)$$

Controller design

In order to have a second – order error dynamics we define a signal x_r as (Kuo et al, 2008);

$$\dot{x}_r = \ddot{y}_d + K_1\dot{e} + K_0 e \qquad (9)$$

Where K_1 and K_0 are chosen by designers such that the roots of $S^2 + K_1S + K_0 = 0$ are in the open left – half complex plane. From the general second order, transfer function characteristics equation which is given as, $S^2 + 2\xi\omega_n S + \omega_n^2 = 0$,

$K_1 = 2\xi\omega_n = \frac{LB+RJ}{LJ}$, and

$K_O = \omega_n^2 = \frac{K_m K_b}{LJ}$

Where ξ is t he damping ratio and ω_n is the natural frequency.

The design procedure of the robust sliding mode control is divided into two steps; the first step is to define a sliding surface function such that in the sliding mode the system behaves equivalently as a linear system. The second step is to determine a control law such that the system will reach and stay on the sliding surface, $S = 0$.

First, the sliding function will be defined as;

$$S = x_2 - x_r \qquad (10)$$

If sliding mode occurs, i.e., $S = 0$., then

$$x_2 = x_r \qquad (11)$$

By substituting eqn. (11) into (9), we have

$$\ddot{e} + K_1\dot{e} + K_0 e = 0 \qquad (12)$$

Eqn. (12) implies that the tracking error will approach zero $(e \to 0)$ as time approaches infinity. Next, let the control input, *U*, be

$$U = U_{PID} + U_S \qquad (13)$$

Where

$$U_{PID} = \frac{1}{b} \left[k_p e + K_i \int edt + k_D\dot{e}\right] \qquad (14)$$

$$U_s = -\frac{1}{b} \quad [|f| + g + \alpha + |\dot{x}_r| + K_2]sqn(s) \qquad (15)$$

In eqn. (15) the gain K_2 is a positive scalar and $sqn(.)$ is the sign function, given by

$$Sqn(s) = \begin{Bmatrix} +1 & S > 0 \\ -1 & S < 0 \end{Bmatrix} \qquad (16)$$

The gains, k_p, K_i and k_D for the PID controller can be obtained by adaptive laws as follows;

$$\dot{K}_p = -n_1 Se \qquad (17)$$

$$\dot{K}_I = -n_2 S \int edt \qquad (18)$$

$$k_D = -n_3 Se \qquad 19)$$

Where $n_i > 0$ is the learning rate, $i = 1,2,3$.

Stability analysis

The Lyapunov theorem has been chosen for the proving of the stability of the proposed control system, that the error response asymptotically converges to the sliding surface if the control law U is made to satisfy the condition $S^T\dot{S} \le 0$.

Let the Lyapunov function candidate be;

$$V = {}^1\!/_2\, S^T S \qquad (20)$$

$${}^1\!/_2\left(S^2 + \frac{1}{n_1}K_p^2 + \frac{1}{n_2}K_I^2 + \frac{1}{n_3}K_D^2\right) \qquad (21)$$

Taking the derivative of eqn. (21) gives

$$\dot{V} = S\dot{S} + \frac{1}{n_1}K_p\dot{K}_p + \frac{1}{n_2}K_I\dot{K}_I + \frac{1}{n_1}K_D\dot{K}_D \qquad (22)$$

Substituting the adaptive laws in eqns. (17) to (19) and control laws of eqns. (13) to (15) into eqn. (22) we obtain:

$$\dot{V} = |S|[(|\Delta f| - g) + (|d| - \alpha) - K_2] \qquad (23)$$

Thus eqn. (23) < 0

Guarantee the reaching and sustaining of the sliding mode.
In general, the inherent high frequency chattering of the control input may limit the practical application of the proposed method. $Sgn(s)$ in eqn 15 can be replaced by the saturation function, $at\left({}^{s}/_{\phi}\right)$, i.e.

$$sat(s/\emptyset) = \begin{Bmatrix} 1 & {}^{s}/_{\emptyset} \geq 1 \\ {}^{s}/_{\emptyset} & -1 < {}^{s}/_{\emptyset} < 1 \\ -1 & {}^{s}/_{\emptyset} \leq -1 \end{Bmatrix} \quad (24)$$

Where ϕ is the width of boundary layer. With this replacement, the sliding surface function S with an arbitrary initial value will reach and stay within the boundary layer$|s| \leq \phi$.

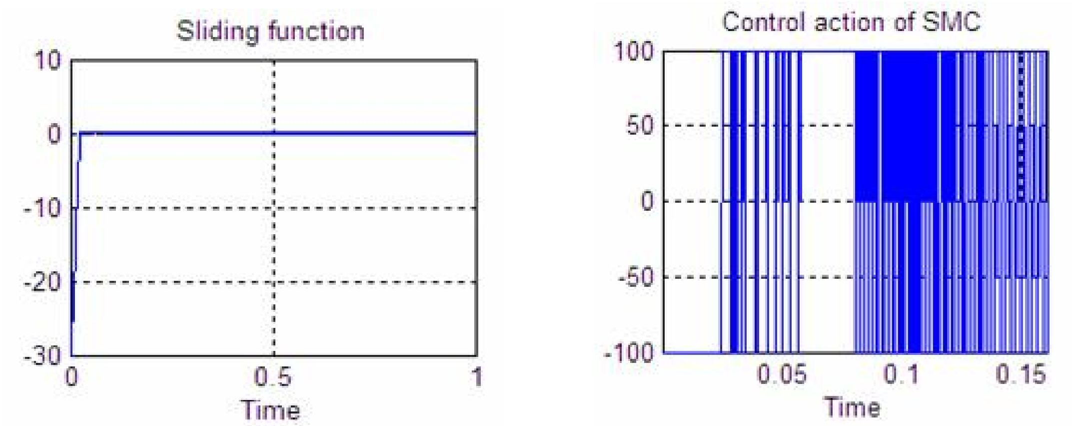

Figure 2: The responses of the DC motor system (18) using the SMC (20) without disturbance.

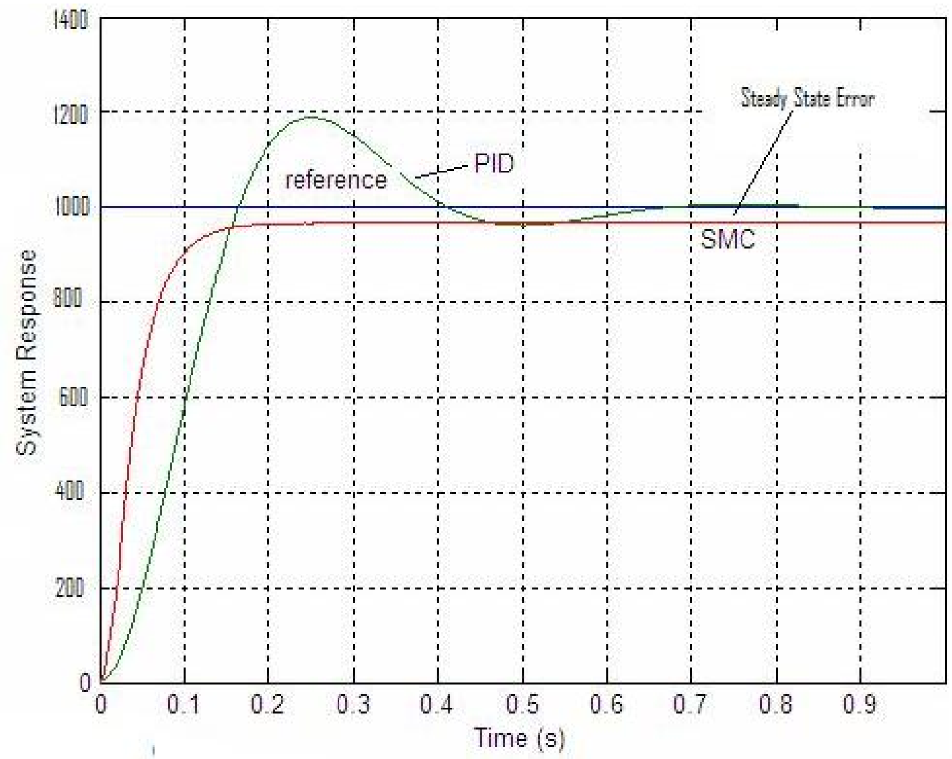

Figure 3: The output response for the DC motor without disturbance using PID controller and SMC.

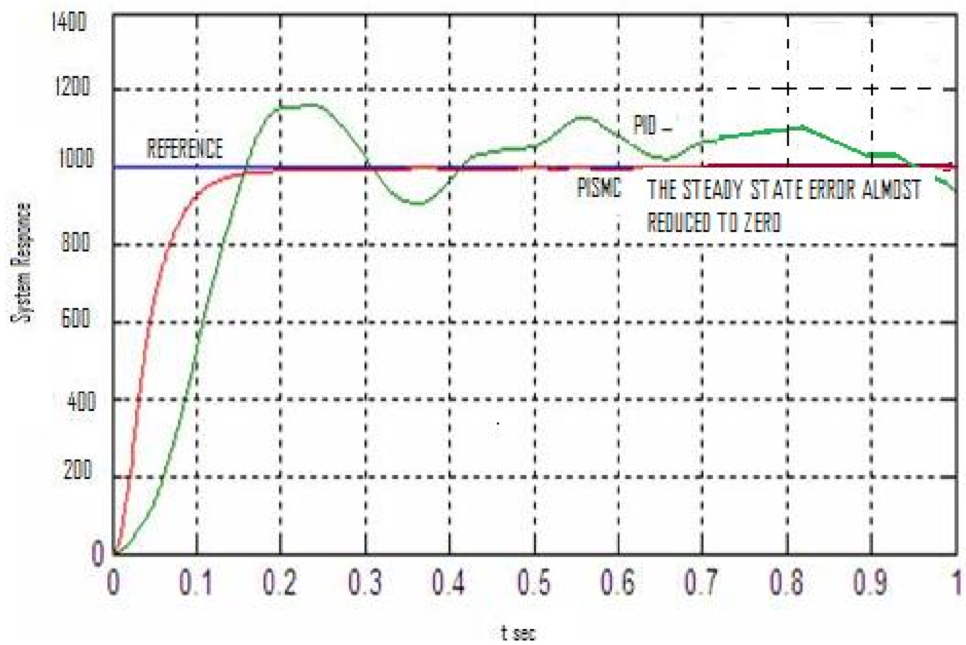

Figure 4: The responses of the DC motor system with disturbance using PID and PI - Sliding mode controllers.

Conclusions

PISMC controller was considered in this paper for controlling the speed/position of a BLDC motor. A comparison method has been included during the study to show the relative advantages and limitations of this method. From the study PID controllers are found to be suitable if there is no disturbance in the system. However, the settling time is longer than when SMC is applied to the system. Using a PISMC the desired speed is obtained, whilst when the SMC is used, the desired speed is tracked only if one considers an SMC with very high gain. Moreover, the disturbances do not affect the system in the sliding mode. The simulation results show that the controller of the proposed PISMC method has a good adaptability and strong robustness when the system is disturbed, which is better than traditional SMC (in which steady state error is not zero) and PID controllers.

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