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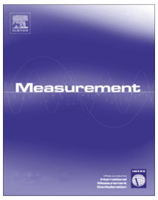

Control of a DC motor using algebraic derivative estimation with real time experiments

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ABSTRACT

This paper presents an experimental control scheme for DC motors which combines an overlapping implementation of the algebraic derivative estimation method and a disturbance estimator based on the aforementioned algebraic derivative method. The methodology only requires the measurement of the angular position of the motor and the voltage input to the motor. The main advantages of the proposed approach are: it is independent of the motor's initial conditions, the methodology is robust to Coulomb friction effects, it does not require any statistical knowledge of the noises that corrupt the data, the derivative estimation process does not require initial conditions or dependence between the system input and output, and the algorithm is computed on-line and in real time. The effectiveness of the proposed controller has been verified by means of computer simulations and it has also been experimentally implemented on a laboratory prototype with excellent results in both, stabilization and trajectory tracking tasks.

1. Introduction

High performance motor drive systems are of primary importance in any industrial application [1]. The DC motor is an essential source of movement in electromechanical systems which are not too powerful [2]. Its main advantage is that it is easy to control the speed or position with a wide adjustable range in order to follow a predetermined time trajectory under different load inputs [3]. Extensive research efforts have been carried out in the past, and various applications can be found in literature: Applications include robot manipulators [4], positioning tables [5], liquid pumps [6], overhead crane mechanisms [7] or disk motion control [8], among many others. The study of effective control methods which exploit the high-speed and high accuracy positioning/tracking performance of DC motors has been the subject of sustained interest for many years. High speed operation is usually required to achieve high productivity, and precision/accuracy becomes more and more rigorous because of the reduced size of the modern electromechanical applications [9]. In [10] Eker combined traditional root mean square errors with discrete time identification algorithms for the on-line control of a mechanical system. Olsson et al. [11] proposed the control of a DC motor using the Coulomb friction estimation and its corresponding compensation. Nouri et al. [12] studied the problem of controlling the speed of a DC motor by using recurrent neural networks, and a sliding mode control with a PID type of sliding surface is implemented in [13]. In recent years, algebraic techniques have been developed for the fast, on line, reliable estimation, or identification, of system parameters, states, failures and input perturbations. The fundamentals of the approach, for the linear system case can be found in the works of Fliess and Sira-Ramírez [14–16], and one of the procedures for parameter identification of a DC Motor model was presented in [17].

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In this paper, a new control scheme is proposed for the trajectory tracking of a DC motor in the presence of unknown nonlinear effects caused by Coulomb friction, model parametric uncertainties and possible noisy effects in the input control and the output signal. It employs a faster, non-asymptotic, algebraic approach for the determination of time derivative estimates of a signal under additive noise levels and it is endowed with a compensation term based on an algebraic derivative disturbance estimator. The algebraic derivative method relies on a truncated Taylor series approximation of an analytical time signal and its representation as a chain of integrators. The use of operational calculus permits the influence of initial values to be eliminated, and a triangular system of equations is obtained which allows the respective signal time derivatives to be solved up to a certain desired order. The result is a general representation of a linear, time-varying output equation that allows an online-estimation of the required time derivatives [18]. As this approximation is only valid during a certain finite time interval, a periodic resetting of the calculations is necessary. The use of two parallel overlapping estimators to reduce the effects of the computational resettings was presented in [19]. The estimation of the disturbance values and their corresponding compensation in the control system is very important in precision mechanisms because their nonlinear behavior may result in steady state errors, limit cycles, or poor performance [11].

The paper is structured as follows: Section 2 illustrates the dynamic model of the DC servomotor and the problem formulation. Section 3 briefly introduces the theory behind the algebraic derivative method and the notion of an overlapping estimator as a means to improve the quality of the derivative estimators under noisy conditions. Section 4 is devoted to deriving the feedforward controller, based on algebraic derivative and parameter estimation, which is used in the position control of a DC motor. The velocity and the parameter estimation is carried out by means of an overlapping algebraic derivative estimator. This section shows that the proposed controller produces an asymptotically exponentially convergent tracking error behavior towards the origin of coordinates in the error space. In Section 5, comparisons between a PD controller with Coulomb compensation and the robust feedforward controller are illustrated to evaluate the performance and remarkable improvements in the system response. Section 6 describes a laboratory experimental setup and presents the results obtained with the proposed control algorithm. Finally, Section 7 is devoted to the conclusions of this article and proposals for future work.

2. The DC motor model and problem formulation

2.1. DC motor dynamics

This section is devoted to the background results of the linear model of the DC motor. It is assumed that the linear model is affected by an unknown perturbation input caused by Coulomb friction effects (see [11]). The DC motor is assumed to be fed via a servo-amplifier with a current, inner loop, control. The main dynamic equation of the system is obtained from Newton's Second Law:

$$ku = J\ddot{\bar{\theta}}_m + v\dot{\bar{\theta}}_m + \bar{\Gamma}_c\left(\dot{\bar{\theta}}_m\right), \tag{1}$$

where u is the motor input voltage that acts as the control variable for the system. This is the input to a servo-amplifier which controls the input current to the motor by means of an internal PI current controller (see Fig. 1(a)). The electrical dynamics can be ignored because it is much faster than the mechanical dynamics of the motor, signifying that the servo-amplifier can be considered as a constant relation, k_e, between the voltage and the current to the motor: $i_m = k_e u$ (see Fig. 1(b)), where i_m is the armature circuit current, k_e includes the gain of the amplifier, $\tilde{k}$, and R is the input resistance of the amplifier circuit. The magnitude J is the inertia of the motor and gear [kg m^2], v is the viscous friction coefficient and $\bar{\Gamma}_c$ is the unknown Coulomb friction torque which affects the motor dynamics. This nonlinear friction term is considered as a perturbation and obeys the following equation:

$$\bar{\Gamma}_c = \bar{\Gamma}_{Coul} \cdot sign\left(\dot{\bar{\theta}}_m\right), \tag{2}$$

where $\bar{\Gamma}_{Coul}$ is the static friction value which the motor torque must exceed to start the axis motions. The parameter k is the electromechanical constant of the motor servo-amplifier system and $\ddot{\bar{\theta}}_m$ and $\dot{\bar{\theta}}_m$ are the angular acceleration of the motor and the angular velocity of the motor, respectively. The constant factor n is the reduction ratio of the motor gear; thus $\theta_m = \bar{\theta}_m/n$, where θ_m is the position of the motor gear and $\bar{\theta}_m$ is the position of the motor shaft. Moreover, $\Gamma_c = \bar{\Gamma}_c n$, where Γ_c is the Coulomb friction torque in the motor gear.

The total torque delivered to the motor Γ_T is directly proportional to the armature circuit in the form $\Gamma_T = k_m i_m$, where k_m is the electromechanical constant of the motor. The electromechanical constant of the motor servo-amplifier system is therefore $k = k_m k_e$. Manipulating expression (1) one obtains:

$$u = \frac{J}{k}\ddot{\bar{\theta}}_m + \frac{v}{k}\dot{\bar{\theta}}_m + \frac{\bar{\Gamma}_c}{k}. \tag{3}$$

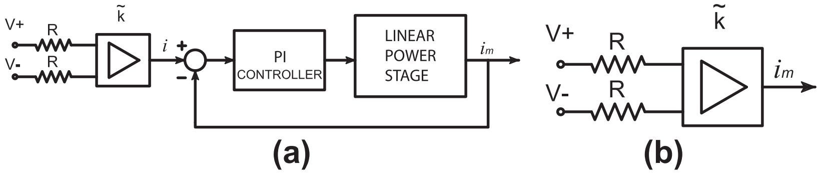

Fig. 1. (a) Complete amplifier scheme; (b) equivalent amplifier scheme.