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Sliding Mode Predictive Tracking Control for DC Permanent Magnet Motor in NCSs with Random Delay and Packet Dropouts

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Abstract: This paper studies the tracking control of dc permanent magnet motor (DC-PMM) in networked control systems (NCSs) with random delay and packet dropouts in feedback channel (sensor to controller) and the feedforward channel (controller to actuator). A sliding mode predictive tracking control algorithm based on the theory of pseudo partial derivative (PPD) is designed to compensate random delay and packet dropouts in process of motor control. The stability of the proposed method and the convergence of the tracking error are analyzed and proved. Finally, an example about dc motor in NCS is given to verify the effectiveness of the proposed method. Simulation results show that the outputs of dc motor can better track the desired trajectory after compensating by the presented method, and are quite stable.

Keywords: DC-PMM, packet dropouts, PPD, random delay, sliding mode control, tracking control.

1. INTRODUCTION

Networked control systems (NCSs) are feedback control systems in which the system components such as sensors, controller, and actuators are connected through the wireless communication networks. In recent years, NCSs are widely used in various fields, e.g., cloud control system [1], teleoperation systems [2, 3] and so on. Compared with traditional control systems, NCSs have several advantages, such as resource sharing, low cost, easily extensible, simple installation and maintenance and high reliability [4]. However, with NCS brings favorable conditions, there also appeared a lot of new problems, such as constraints on communication bandwidth, delay, packet dropouts, jitter [5]. Among all the problems, the network-induced delay and packet dropouts are commonly known as the major causes of deterioration in system performance.

Many methods have been presented to handle these two issues in NCSs (see, e.g., [6–17], and references therein), in which a representative one is networked predictive control (NPC) method that actively compensates for the delay and packet dropout. To mention a few, in [8], a data-based networked predictive control (DBNPC) method is proposed to actively compensate for the two-channel packet dropouts. In [9], an observer-based networked predictive control (NPC) method is proposed to compensate for the distributed delays and packet dropouts in the feedback channels. A new networked predictive control scheme is proposed in [14], this scheme mainly consists of the control prediction generator and network delay compensator, the control prediction generator provides a set of future control predictions to make the closed-loop system achieve the desired control performance and the network delay compensator removes the effects of the network transmission delay and data dropout. In [15], a dynamic predictive feedback linearization controller is proposed so that the system dynamics and delays caused by networked communication time and data dropouts are compensated. In [16], a novel networked predictive control (NPC) scheme is proposed to overcome the effects of network delay and data dropout. By taking the full advantage of the packet-based transmission in NCSs, a state-based networked predictive control approach is proposed [17], to actively compensate the network communication delay. However, all the aforementioned NPC methods only consider either delay or packet dropouts or some methods need assume feed-forward channel or feedback channel is ideal, or some methods are designed based on the accurate model as well as adequate uncertainty description of the linear or non-linear plant.

Nowadays, PMM has received increased attention for high performance electric drive applications because of its considerable advantages, such as wide-speed operation

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range, high-power density, large torque to inertia ratio, and free from maintenance [18]. Many control schemes for DC electric motors have been reported in the literature (see, e.g., [19–23] and references therein). In traditional dc motor control, system components are located in the same place and connected by point-to-point wiring.

However, in many practical systems, such as teleoperation system, aeronautics and astronautics, etc. dc motor and controller are difficult to be located in the same place; the signals are required to be transmitted from one place to another. Hence, communication networks are used to connect those system components, that is, the so-called NCSs. The control of motor in NCSs will be impacted by network-induced delay and packet dropouts, which will lead to the deterioration of control performance. In [22], considering the networked dc motor system in the presence of time delays and packet losses, an output tracking controller which included two control parameters is designed, the delays and packet losses are treated as the parameters perturbation, then the controller design problem is transformed into an optimization problem. But the design of controller need know the accurate motor model. In [23], considering the possible network-induced random delays in both feedback and forward channels, a robust speed synchronization controller is designed for an integrated motor transmission power train system, the delay is modeled by using two Markov chains in the controller design process. To actively compensate for the controller-to-actuator delays in networked DC motor, in [24], the “send all, apply one” scheme is proposed, that is, sending a sequence of control signals, then at the actuator/plant node, applying the appropriate control signal according to the actual controller to actuator delay. However, in [23, 24], the impact of packet dropouts is ignored, which also affect the control performance.

Sliding mode control is a nonlinear and robust control strategy for the systems with communication constraints, which can guarantee perfect tracking performance despite the controlled system suffers from delay and packet dropouts. In [27], a nonlinear speed-control algorithm for the permanent-magnet synchronous motor PMSM servo systems using sliding-mode control and disturbance compensation techniques is developed. In [28], Boban *et al.* presented a design of digitally controlled positional systems with Euler velocity estimation within the framework of the discrete-time sliding mode control.

Motivated by the aforementioned works, in this paper, for the DC-PMM in NCSs with random delay and packet dropouts in both channels, a novel compensation algorithm is presented by combining the sliding mode control and the theory of pseudo partial derivative. Firstly, the mathematical model of dc motor is transformed into the equivalent partial form dynamic data model. Then, the sliding mode control based on PPD is employed to design the control law. Furthermore, a sliding mode predictive tracking control algorithm is proposed to compensate random delay and packet dropouts in process of motor control. Finally, a dc motor in NCS is executed to demonstrate the effectiveness of the proposed method.

The rest of this paper is organized as follows: Section 2 gives mathematical model of DC-PMM. A sliding mode predictive tracking control algorithm based on the theory of pseudo partial derivative (PPD) for DC-PMM in NCSs is designed in Section 3. In Section 4, simulation studies are performed to demonstrate the effectiveness of the proposed scheme. Conclusion is given in Section 5.

2. SLIDING MODE CONTROL FOR DC-PMM

2.1. Model of DC-PMM

The mathematical model of dc motor as following [20]:

$$L_a\frac{di_a}{dt} = \upsilon - R_a i_a - k_e\omega, \tag{1}$$

$$J\frac{d\omega}{dt} = -b'\omega + k_m i_a, \tag{2}$$

where ω is the angular velocity, k_e is the counter electromotive force constant, υ is the input voltage in the motor armature terminals, L_a is the armature inductance, i_a is the armature current, k_m is the motor torque constant, J is the moment of inertia of the rotor and motor load, R_a is the armature resistance, and b' is the viscous friction coefficient of the motor.

Furthermore, let

$$F = \omega. \tag{3}$$

Thus, the differential parametrization of the system variables is given by

$$i_a = \frac{1}{k_m}(J\dot{F} + b'F), \tag{4}$$

$$\omega = F, \tag{5}$$

$$\frac{JL_a}{k_m}\ddot{F} + \frac{1}{k_m}(b'L_a + JR_a)\dot{F} + (\frac{b'R_a}{k_m} + k_e)F = \upsilon. \tag{6}$$

The (6) can be rewritten as following:

$$a_0\ddot{F} + a_1\dot{F} + a_2F = \upsilon, \tag{7}$$

where $a_0 = \frac{JL_a}{k_m}$, $a_1 = \frac{1}{k_m}(b'L_a + JR_a)$, $a_2 = (\frac{b'R_a}{k_m} + k_e)$.

Hence, the discrete-time form of this model is as the following:

$$a_0\ddot{F}(k) + a_1\dot{F}(k) + a_2F(k) = \upsilon(k). \tag{8}$$

Let$y(k) = \dot{F}(k)$,$u(k) = \upsilon(k)$, obtain

$$\dot{y}(k) = \frac{u(k)}{a_0} - \frac{a_1}{a_0}y(k) - \frac{a_2}{a_0}G(k), \tag{9}$$

where $G(k) = \int y(t)dt$.