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Adaptive second order terminal sliding mode controller for robotic manipulators

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Abstract

In this paper an adaptive second order terminal sliding mode (SOTSM) controller is proposed for controlling robotic manipulators. Instead of the normal control input, its time derivative is used in the proposed controller. The discontinuous sign function is contained in the derivative control and the actual control obtained after integration is continuous and hence chatterless. An adaptive tuning method is utilized to deal with the system uncertainties whose upper bounds are not required to be known in advance. The performance of the proposed control strategy is evaluated through the control of a two-link rigid robotic manipulator. Simulation results demonstrate the effectiveness of the proposed control method.

1. Introduction

The robotic manipulator is a typical example where nonlinearities and uncertainties involving unmodelled dynamics and frictional effects, elasticity and the cross-coupling effects make the system highly complex. As robotic manipulators become increasingly important in industrial automation, sophisticated tasks such as painting and welding requiring perfect precision are assigned to robots for which accurate trajectory tracking is of prime concern. Hence motion control of robotic manipulators has emerged as an important area of research. In order to achieve accurate trajectory tracking by robotic manipulators over a wide range of motion with large payload variation, advanced control schemes insensitive to parametric uncertainties are absolutely necessary. Various approaches like decentralized control [1,2], feedback linearization [3,4], model predictive control [5], adaptive control [6,7] and sliding mode control [8–10] have evolved for application in motion control, especially in robotics.

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Among all these methods, sliding mode control (SMC) [11,12] has found wide acceptance and continues to draw particular attention from the research community because of its simplicity and inherent robustness. Sliding mode control has established itself as an effective control technique which has proven to be robust against system uncertainties and external disturbances [13–15]. The sliding mode technique is designed to drive the system state variables to equilibrium by using a discontinuous feedback control law. This mode has useful invariance properties in the face of uncertainties in the plant model and thus is a good candidate for tracking control of uncertain nonlinear systems. SMCs have shown good control performance for nonlinear, multi-input multi-output (MIMO) and discrete time systems. Sliding mode controllers are now-a-days widely used in a variety of application areas like robotics [10–12,16–18], process control, aerospace and power electronics [19,20]. In the conventional sliding mode control, the convergence of the states is usually asymptotic because of the linear type of switching surfaces. However, this convergence can only be achieved in infinite time, although the parameters of linear sliding mode (LSM) can be adjusted to make the convergence faster. In high precision control schemes like motion control in robotics, faster convergence is a high priority which can be achieved only at the expense of a large control input. Thismay result in the saturation of the actuators which is highly undesirable in practical applications. The terminal sliding mode (TSM) control [21,22] was able to achieve fast convergence of the states without spending a large control effort by using a nonlinear sliding surface. A nonsingular terminal sliding mode (NTSM) control was proposed [17] to overcome the singularity problem in the TSM by selection of a suitable fractional power in the discontinuous control law. Yu et al. [23] proposed a continuous finite time control scheme for rigid robotic manipulators using a new form of TSM controller. However, the TSM control suffers from two significant drawbacks. One major disadvantage of the TSM controller is the chattering phenomenon which comprises high frequency oscillations arising because of the discontinuous control signal. In practical implementations, chattering is totally undesirable because it may excite unmodelled high frequency plant dynamics resulting in unforeseen instabilities. Another difficulty faced by the TSM controller is its design prerequisite of prior knowledge about the upper bound of the system uncertainty.

In this paper, a chattering free adaptive second order terminal sliding mode (SOTSM) controller is proposed for trajectory tracking of a robotic manipulator. In the proposed controller, a nonsingular terminal sliding manifold is used to design the control law. The time derivative of the control signal is used as the control input. The derivative control signal is discontinuous because of the presence of the sign function. However, its integral, which is the actual control, is continuous and hence chattering is eliminated. An adaptive tuning law is used to estimate the unknown uncertainties. This adaptive tuning method does not require prior knowledge about the upper bound of the system uncertainty as was the case with the terminal sliding mode controllers developed so far [24–26].

The outline of this paper is as follows. Section 2 explains the design procedure of the proposed adaptive SOTSM controller. The adaptive SOTSM controller designed for trajectory tracking of robotic manipulators is described in Section 3. Simulation studies performed on a two-link robotic manipulator are presented in Section 4. Conclusions are drawn in Section 5.

2. Adaptive second order terminal sliding mode (SOTSM) controller

Let us consider a class of MIMO nonlinear system with the presence of uncertainties and external disturbance described as

$$\dot{x} = f(x) + \Delta f(x) + d(t) + bu \tag{1}$$

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