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Adaptive output feedback tracking control of robot manipulators using position measurements only

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Abstract

In this paper, a new adaptive neuro controller for trajectory tracking is developed for robot manipulators without velocity measurements, taking into account the actuator constraints. The controller is based on structural knowledge of the dynamics of the robot and measurements of joint positions only. The system uncertainty, which may include payload variation, unknown nonlinearities and torque disturbances is estimated by a Chebyshev neural network (CNN). The adaptive controller represents an amalgamation of a filtering technique to generate pseudo filtered tracking error signals (for the elimination of velocity measurements) and the theory of function approximation using CNN. The proposed controller ensures the local asymptotic stability and the convergence of the position error to zero. The proposed controller is robust not only to structured uncertainty such as payload variation but also to unstructured one such as disturbances. Moreover the computational complexity of the proposed controller is reduced as compared to the multilayered neural network controller. The validity of the control scheme is shown by simulation results of a two-link robot manipulator. Simulation results are also provided to compare the proposed controller with a controller where velocity is estimated by finite difference methods using position measurements only.

Keywords: Adaptive tracking control; Neural network; Position measurements; Robot dynamics; Actuator constraints

1. Introduction

The design of robust adaptive controllers suitable for real-time control of multiple-input–multiple-output (MIMO) nonlinear systems is one of the most challenging tasks for many control engineers, especially when complete knowledge of the system is not available. A robot manipulator is an uncertain nonlinear dynamic MIMO system which suffers from structured and unstructured uncertainties such as payload variation, friction, external disturbances, etc. In the last few decades, artificial intelligent control using fuzzy logic systems (FLS) and neural networks (NN) has undergone a rapid development to design feedback controller for complex systems.

Fuzzy logic provides human reasoning capabilities to capture uncertainties, which cannot be described by precise mathematical models. Neural networks offer exciting advantages such as adaptive learning, parallelism, fault tolerance and generalization. They have proven to be very powerful techniques in the discipline of systems control, especially when the controlled system is hard to be modeled mathematically, or when the controlled system has large uncertainties and strong nonlinearities. FLS have been extensively adopted in adaptive control of robot manipulators (Berstecher, Palm, & Unbehauen, 2001; Golea, Golea, & Benmahammed, 2002; Tsai, Wang, & Lin, 2000; Yi & Chung, 1997; Yoo & Ham, 2000). All these methods require both the position and velocity measurements, which can be problematic in practice.

Recently a lot of work has been carried out in the field of control of robot manipulators using neural networks (NN) based controllers (Barambones & Etxebarria, 2002; Behera,

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Chaudhury, & Gopal, 1996; Ertugrul & Kaynak, 2000; Lewis, Jagannathan, & Yesildirek, 1996; Wai, 2003) which require measurements of both position and velocity. Barambones and Etxebarria (2002) proposed a neural scheme with adaptive switching gain. Here two different NN architectures are proposed to estimate the elements of the unknown nonlinear function and the elements of inertia matrix. Behera et al. (1996) proposed a neuro adaptive hybrid controller for robot manipulator tracking control where three multilayer neural networks are used to learn the inertia matrix, Coriolis vector and the gravitational torque vector respectively. It however, suffers from computational complexity. Ertugrul and Kaynak (2000) utilized two NNs to realize the objective of trajectory tracking based on sliding mode control methodology. The equivalent control and the switching control terms are the outputs of the two NNs. Lewis et al. (1996) develop a multilayer NN controller for robot manipulator that gives satisfactory performance using e-modification term in the weight tuning laws of NN and a robustifying control signal but is computationally complex. In Wai (2003), Wai presented a sliding mode neural network control system for position control of robotic manipulators. Here a NN controller is developed to estimate the equivalent control. The robot problem has also been addressed using combined methods. In Er and Gao (2003) and Liu et al. (2005) fuzzy neural networks are used to improve system performance achieving accurate tracking or set point control with fast and smooth response.

Algorithms have also been developed based on conventional adaptive control techniques for controlling manipulators with only joint measurements as done by Burg, Dawson, and Queiroz (1996), Canudas de Wit and Fixot (1991) and Zhang et al. (2000) where there is no constraint on the actuators. Although the literature covers a wide range of controllers which allow the effective implementation of robot manipulators, it is interesting to consider controllers supported by a rigorous stability analysis, explicitly taking actuator constraints into account. The problem of regulation/set point control under actuator constraints was studied by Colbaugh, Barany, and Glass (1997), Kelly, Santibanez, and Berghuis (1997) and Laib (2000) based on conventional adaptive control techniques. To the best of our knowledge no work has been reported on a CNN controller taking into account actuator constraints. The contribution of the present paper is the introduction of a simple adaptive controller, which utilizes a CNN for estimating the uncertainties for the tracking control of robot manipulators under actuator constraints. Moreover in the proposed controller, only position measurements are required. Velocity measurement increases cost and imposes constraints on the achievable bandwidth. However, velocity measurements are often replaced by numerical derivatives of the measured position. This may lead to chattering of control inputs due to the combined effect of noisy measurements and unmodelled phenomena (Canudas de Wit & Fixot, 1991; Zhang, Dawson, Queiroz de, & Dixon, 2000). To avoid this undesirable behavior a dynamic filter is used in the proposed work. This filter will be used to generate pseudo filtered tracking error signal which will eliminate the need for velocity measurement. There is no need of the knowledge of the inertia matrix and the Coriolis vector. A good estimate of the gravity forces and the inertia matrix is hardly available since the gravity vector and inertia matrix parameters depend on payload, which is usually unknown. A mismatch in the estimation of these terms leads to a shift in the equilibrium point and consequently to a position steady state error. The gravity vector along with payload variation, torque disturbance and other nonlinearities is considered to be system uncertainty which is approximated using CNN. Here the design of the controller is performed through a Lyapunov analysis, thus accounting for the effect of the filter measurements in the closed loop system.

Recently it is proved that Chebyshev Neural network (CNN) has powerful representation capabilities whose input is generated by using a subset of Chebyshev polynomials Patra and Kot, 2002. Being a single layer neural network, its computational complexity is less intensive as compared to multilayered perceptron (MLP) and can be used for on-line learning. CNN has been briefly described in subsequent Section 2. The detailed description of CNN and its approximation properties is given in Lee and Jeng (1998), Namatame and Ueda (1992) and Patra and Kot (2002). Considerable research has been conducted in system identification (Patra & Kot, 2002; Purwar, Kar, & Jha, in press) and identification-based control (Jeng & Lee, 1997) using CNN. In Purwar et al. (in press) on-line system identification using CNN is taken up. The system identification of discrete time systems using off line training is also dealt within Patra and Kot (2002). They have shown that CNN-based identification requires less computation as compared to MLP. However, CNN has not been used for the purpose of direct closed loop control. In this paper, an attempt is made to exploit the CNN for direct closed loop control application to robot manipulators in continuous time domain that can yield guaranteed performance. An on-line tuning law of the neural network weights is presented. In this paper we utilize a CNN to estimate the uncertainties of the robot manipulator. To reduce the error between the real uncertainty function and the estimator, we design simple and robust adaptive laws based on Lyapunov stability theory. The performance of the proposed controller has been compared with the multilayered neural net (NN) robot controller in Lewis et al. (1996) where there are no actuator constraints and which requires both position and velocity measurements. Simulation results are also provided to compare the proposed controller with a controller where velocity is estimated by finite difference methods using position measurements only. The simulation results show the effectiveness of the proposed controller in keeping the actuators within their torque capabilities as well as achieving small positioning errors even in the presence of input disturbances and payload variations for different desired trajectories and initial conditions.