Advanced Robotics, 2014
Vol. 28, No. 14, 983–996, http://dx.doi.org/10.1080/01691864.2014.899163

FULL PAPER

Noncertainty equivalent adaptive control of robot manipulators without velocity measurements

Mohamadreza Homayounzade* and Mehdi Keshmiri

Department of Mechanical Engineering, Isfahan University of Technology (IUT), Isfahan, Iran

(*Received 6 September 2013; revised 2 January 2014; accepted 17 January 2014*)

This paper presents a noncertainty equivalent adaptive motion control scheme for robot manipulators in the absence of link velocity measurements. A new output feedback adaptation algorithm, based on the attractive manifold design approach, is developed. A proportional-integral adaptation is selected for the adaptive parameter estimator to strengthen the passivity of the system. In order to relieve velocity measurements, an observer is designed to estimate the velocities. The controller guarantees semiglobal asymptotic motion tracking and velocity estimation, as well as L_∞ and L_2 bounded parameter estimation error. The effectiveness of the proposed controller is verified by simulations for a two-link robot manipulator and a four-bar linkage. The results are further compared with the earlier certainty-equivalent adaptive partial and full state feedback controller to highlight potential closed-loop performance improvements.

Keywords: adaptive control; noncertainty equivalence principle; robot control; stability analysis; velocity estimation

1. Introduction

The study of adaptive control problem has a long history dating back at least to the work by [1]. The solution to adaptive control of robotic systems based on complete state measurement has been elaborated for many years and so far a great number of globally stable algorithms have been developed.[2–6] Despite the numerous studies in the field, the existing results still suffer from some significant shortcomings. First, they require the measurement of joint velocities. Second, roughly speaking, every existing nonlinear adaptive control applied to robotic systems is based on the certainty equivalence principle.

It is well known that measurement of joint velocities is impractical in industrial robotic systems. The first-order derivative of the position signal is considered as the most accessible and the easiest method to estimate the joint velocities. However, this may engender an unacceptable amount of noise in velocity estimation. To handle this escalation in velocity measurement, a significant number of works have focused on reconstructing the missing signal from the physical measurements, meanwhile ensuring the system's closed-loop stability. For instance, in [7–10], model-based observers are utilized and in [11,12] filtering techniques and/or variable structure type algorithms [13] are used to estimate the joint velocities.

While there has been a notifying amount of research dedicated to the design of adaptive full state feedback control and model-based observer–controller scheme for robotic systems, there are fairly few algorithms which combine both adaptive schemes and velocity observation. Adaptive velocity observer-based tracking controllers for robotic systems have been considered by [14,15]. In [14], the passivity-based adaptive control algorithm is combined with sliding observer scheme; however, this method necessitates the online inverse dynamics computation. Repetitive and adaptive control of robot manipulators with velocity estimation is presented in [15]. In case of the repetitive control, the robot is required to track prescribed periodic trajectories through repeated learning trials.

In [16–20] in lieu of observer techniques, filtering techniques are employed to estimate joint velocities from the joint position measurements. Afterwards, the adaptive output feedback controller is developed.

To the best of our knowledge, all the available literature on adaptive output feedback control of robotic systems belong to the class of certainty-equivalent adaptive (CEA) control systems which create stable integral adaptation laws. In this class of controllers, the estimated parameters are directly utilized for the synthesis of the controller. Therefore, any improvement in the adaptive controllers regarding the parameter estimation performance can be considered as a novel work in the field.

Recently, a novel immersion and invariance (I&I) approach to the adaptive control of nonlinear systems has been proposed that yields noncertainty equivalent adaptive (NCEA) control systems.[21,22] The NCEA controller causes the system trajectories to converge to a manifold on which the controller improves the performance of a deterministic system. The NCEA parameter estimator consists of a judiciously chosen nonlinear function of the state variables in addition to the integral

*Corresponding author. Email: m.homayounzade@me.iut.ac.ir