Available online at www.sciencedirect.com
SCIENCE DIRECT®

Fuzzy Sets and Systems 152 (2005) 651–664

FUZZY sets and systems
www.elsevier.com/locate/fss

Adaptive control of robot manipulators using fuzzy logic systems under actuator constraints

S. Purwar[a, b, *], I.N. Kar[a], A.N. Jha[a]

[a] *Department of Electrical Engineering and Computer Science, Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India*
[b] *M.N. National Institute of Technology, Allahabad, India*

Received 22 March 2004; received in revised form 14 October 2004; accepted 23 November 2004
Available online 15 December 2004

Abstract

In this paper, a stable fuzzy adaptive 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 link positions only. The gravity torque including system uncertainty like payload variation, etc., is estimated by a fuzzy logic system (FLS). The adaptive controller represents an amalgamation of a filtering technique to eliminate velocity measurements and the theory of function approximation using FLS to estimate the gravity torque. 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 parameter variation, but also to unstructured one such as disturbances. The validity of the control scheme is shown by simulations on a two-link robot manipulator.

Keywords: Adaptive tracking control; Fuzzy logic system; 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,

* Corresponding author. Department of Electrical Engineering and Computer Science, Indian Institute of Technology, Hauz Khas, New Delhi 110 016, India. Tel.: +91 11 26591073; fax: +91 11 26581264.
E-mail addresses: spurwar@rediffmail.com (S. Purwar), ink@ee.iitd.ernet.in (I.N. Kar).

0165-0114/$ - see front matter
doi:10.1016/j.fss.2004.11.012

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 and neural networks has undergone rapid development and can be considered as an effective tool for nonlinear controller design.

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.

Recently, a lot of work has been carried out in the field of control of robot manipulators using neural networks (NN)-based controllers [1,2,12] which require measurements of both position and velocity. FLS have also been extensively adopted in adaptive control of robot manipulators [3,6,8,9,13,15,17,19,20,22,23]. In [3], Berstecher develops a linguistic heuristic-based adaptation algorithm for a fuzzy sliding mode controller. The algorithm relies on the linguistic knowledge in the form of fuzzy IF–THEN rules. Golea et al. [9] present a fuzzy model reference adaptive controller for nonlinear systems where a Tagaki–Sugeno fuzzy model-based controller is used. Tsai et al. [20] propose a robust multilayer fuzzy controller for the model following control of robot manipulators with torque disturbance and measurement noise. Yi and Chung [22] define a set of fuzzy rules based on the knowledge of error and derivative of error for designing the controller. Yoo and Ham [23] exploit the function approximation capabilities of FLS to compensate for the parametric uncertainties of the robot manipulator. Chuan-Kai Lin [6] proposes reinforcement learning systems combined with fuzzy control for robot arms. Here the reinforcement learning signal is used to update the weights of a fuzzy logic system which is used to approximate an unknown nonlinear function. This approximated function is then used for computing the control law. In [13] Li presents a hybrid control scheme for tracking control of a manipulator which consists of a fuzzy logic proportional controller and a conventional integral and derivative controller. Moreover, this controller was compared to a conventional PID controller and the performance of the fuzzy P+ID controller was found superior to conventional PID controller. In [17] Sylvia Kohn-Rich and Henryk Flashner present tracking control problem of mechanical systems based on Lyapunov stability theory and robust control of nonlinear systems. The control law has a two-component structure—a conventional PD control and a fuzzy component of robust control which is aimed at minimizing the chattering effect. Tong Shaocheng et al. [19] develops a robust fuzzy adaptive controller for a class of unknown nonlinear systems. In the control procedure, FLS are implemented to estimate the unknown functions and robust compensators are designed in H^∞ sense for attenuating the unmatched uncertainties. In [24], Rainer palm develops a mamdani fuzzy controller following the pattern of suboptimal control. The proposed controller in the paper is compared and found to have higher tracking quality than a conventional PD controller. In [8], Fuchun Sun et al. propose a nuero fuzzy adaptive control methodology for trajectory tracking of robotic manipulators. Here the fuzzy dynamic model of the manipulator is established using the Tagaki–Sugeno fuzzy framework. Based on the derived fuzzy dynamics of the manipulator, the neuro fuzzy adaptive controller is developed to improve the system performance by adaptively modifying the fuzzy model parameters. All these methods require both the position and velocity measurements, which can be problematic in practice.

Algorithms have also been developed based on conventional adaptive control techniques for controlling manipulators with only joint measurements as done by Canudas and Fixot [5], Burg et al. [4], Zhang