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ADAPTIVE FUZZY TRACKING CONTROL FOR STRICT-FEEDBACK NONLINEAR SYSTEMS WITH UNKNOWN TIME DELAYS

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Abstract. *A novel adaptive fuzzy tracking controller is proposed for a class of strict-feedback nonlinear time-delay systems with unknown virtual control coefficients. The unknown time delays are compensated for by introducing appropriate Lyapunov-Krasovskii functionals. Fuzzy logic systems in Mamdani type are used to approximate unknown nonlinear functions. The decoupled backstepping approach is applied to construct an adaptive fuzzy tracking controller which guarantees semi-global uniform ultimate boundedness of all the signals in the closed-loop system and the tracking error to converge to a small neighborhood around the origin. The proposed design scheme contains less adaptive parameters than the existing results and efficiently overcomes the controller singularity problem. Finally, a simulation example is given to demonstrate the effectiveness of the proposed design procedure.*
Keywords: Nonlinear time-delay systems, Adaptive control, Fuzzy control, Backstepping

1. **Introduction.** In many real plants, nonlinearities can neither be linearly parameterized nor satisfy matching conditions. For such nonlinear systems, the early neural and fuzzy control approaches [1]-[3] can not be used to achieve control purpose. To control such nonlinear systems, adaptive neural and fuzzy control schemes have been developed for strict-feedback nonlinear systems by combining the backstepping technique, e.g., [4]-[6]. The main idea of these schemes is that neural networks and fuzzy logic systems are used to approximate unknown nonlinear functions, and then the backstepping approach is employed to design adaptive controllers. However, a drawback of the aforementioned control methods is that a lot of parameters are needed to be tuned online, so that the learning time tends to be unacceptably large for the higher-order systems. Recently, several adaptive fuzzy schemes have been developed for strict-feedback nonlinear systems [7, 8], which contain less adaptive parameters than the existing adaptive controllers.

Another challenging problem in control of nonlinear systems lies in stabilization of nonlinear time-delay systems. It is well known that the existence of time delays may destroy the stability of control systems or degrade the control performance. Therefore, the stability analysis and controller synthesis of nonlinear systems with time delays are important both in theory and in practice [9, 10]. More recently, the practical adaptive neural control scheme was proposed in [11] for nonlinear time-delay systems with the strict-feedback structure by using the backstepping approach. Further improvement was