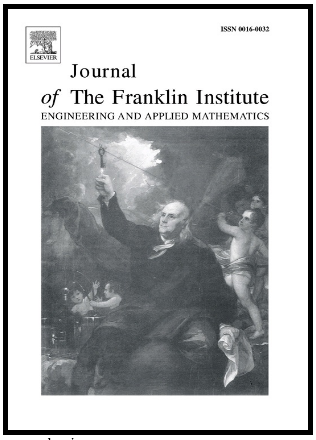

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Robust Adaptive Asymptotic Tracking Control of A Class of Nonlinear Systems with Unknown Input Dead-Zone

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***Abstract*—This paper considers the tracking control for a class of uncertain single-input and single-output (SISO) nonlinear strict-feedback systems with unknown input dead-zone nonlinearity, parametric uncertainties and unknown bounded disturbances. By constructing a smooth dead-zone inverse and applying the backstepping recursive design technique, a robust adaptive backstepping controller is proposed, in which adaptive control law is synthesized to handle parametric uncertainties and a novel robust control law to attenuate disturbances. The robust control law is developed by integrating a sufficiently smooth positive integral function at each step of the backstepping design procedure. In addition, a smooth projection mapping is used and assumptions are made that the prior knowledge of the extents of parametric uncertainties and the variation ranges of the bounds of disturbances is known to facilitate the backstepping recursive design. However, the exact bounds of disturbances are not required. The major feature of the proposed controller is that it can theoretically guarantee asymptotic output tracking performance, in spite of the presence of unknown input dead-zone nonlinearity, various parametric uncertainties and unknown bounded disturbances via Lyapunov stability analysis. Comparative simulation results are obtained to illustrate the effectiveness of the proposed control strategy.**

***Index Terms*—dead-zone inverse; robust control; adaptive control; backstepping; smooth projection mapping; disturbance suppression**

I. INTRODUCTION

Control of nonlinear systems is of great significance since the majority of practical systems exhibit nonlinear dynamic behaviors, such as the dynamic behaviors of electrical motors [1-2], robot manipulators [3], hydraulic systems [4-5], and so on. However, these systems are typically subjected to various parametric uncertainties and disturbances, which could severely deteriorate the achievable control performance, leading to undesirable control accuracy, limit cycles and even instability [6]. In order to handle parametric uncertainties and disturbances in nonlinear systems and improve the tracking performance, extensive research has been devoted to the design of high performance nonlinear controller. During the past several decades, adaptive control design for nonlinear systems to achieve globally asymptotic stability of the closed loop system has been proposed and undergone rapid developments, with plenty of publications presented, such as [8-10]. Specially, under the assumption that the nonlinear systems are subjected to parametric uncertainties only, systematic approaches of adaptive control were proposed in [9], which can achieve asymptotic output tracking performance. And the inherent overparameterization problem was overcome by introducing the idea of tuning function in [10]. In fact, no matter how accurate the practical system model and parameter identification are, modeling errors and external disturbances always exist in physical systems. Hence, some robust adaptive tracking controllers were developed for nonlinear systems with consideration of parametric uncertainties and disturbances simultaneously in [11-13]. In addition, an adaptive robust control (ARC) strategy was proposed by Yao *et al*. in [14] for uncertain nonlinear systems in the presence of various modeling uncertainties. As an effective control strategy, adaptive robust control has been widely employed in many applications [15-18]. However, most of the existing results in the literature can only achieve bounded-error trajectory tracking performance rather than the strongly expected asymptotic tracking with zero steady-state error in the presence of parametric uncertainties and disturbances. To cope with this issue, adaptive sliding mode control was presented for uncertain nonlinear systems with perturbations in [19], which assures that the tracking error converges to zero asymptotically. It is worth to note that the discontinuous function contained in the controller [19] may cause severe chattering, which limits the employment of the controller in engineering practice. In [21, 22], adaptive control design was integrated with a novel robust integral of the sign of the error (RISE) control proposed in [20] to obtain asymptotic tracking performance, meanwhile ensuring the continuity of the final control input. However, all these RISE based adaptive controllers can

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