Robust High Gain Adaptive Output Feedback Tracking Control for Nonlinear Systems

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Abstract:

For a class of nonlinear systems which satisfy a certain condition so called output feedback exponential passivity (OFEP), it is well known that one can easily design a high-gain output feedback control system. The designed high-gain controller has simple structure and high robustness. However, from the viewpoint of practical application, it is important to consider a robust control scheme for controlled systems for which some of the assumptions of output feedback stabilization are not valid. In this paper, we deal with a design problem of the robust high-gain adaptive output feedback control for the above-mentioned class of nonlinear systems with uncertain nonlinearities and/or disturbances.

1. Introduction

It is well known that the high gain output feedback control is a good control tool of robust stabilization for uncertain control systems that satisfy certain assumptions. The conditions for high gain output feedback stabilization are well recognized as almost strictly positive realness (ASPR) for linear systems [1] and output feedback exponential passivity (OFEP) [2] for nonlinear systems. The main conditions on ASPR and OFEP are that the system to be controlled be globally exponential minimum phase and have strong relative degree of one. In addition to the above conditions, for nonlinear systems, the Lipschitz conditions for nonlinear functions are imposed. Under these conditions, one can easily design a stable adaptive output feedback controller which has a very simple adaptive controller structure. Unlike other methods we do not need any a priori information (e.g.: the order of the system and the size of the uncertainty) for the output feedback adaptive method. In other words, the control strategy has a simple control structure and high robustness to system uncertainties. In spite of its very restrictive assumptions, the high gain output feedback strategies still attract a great deal of attention due to their simplicity and high robustness. However from the viewpoint of practical applications, it is important either to consider a relaxation of restrictions imposed on the controlled systems or to design a robust control scheme for controlled systems for which some of the assumptions of output feedback stabilization are not valid.

With this point in mind, many robust adaptive schemes based on the high gain output feedback strategy and alleviation methods for the restrictions on the controlled system have been proposed for linear systems [3], [4], [5]. Unfortunately, however, there are only few proposals that dealt with the high gain output feedback based robust adaptive control for the above-mentioned class of nonlinear systems with bounded disturbance or noise[6], [8]. There are also few papers that dealt with alleviation methods for the restrictions on the nonlinear controlled system for the high gain output feedback [7],[8].

In this paper, we just focus on the robust stabilization and tracking problems and then consider a robust adaptive output feedback tracking control scheme for the above-mentioned class of nonlinear systems with output dependent nonlinear uncertainties and/or disturbances. Considering the uncertain nonlinearities as a kind of output dependent disturbance, the proposed method is able to deal with robust stabilization problems via a high gain adaptive output feedback for nonlinear systems, for which some Lipschitz conditions on nonlinear functions are not satisfied with respect to output signal. It is noted that, concerning the alleviation for the restriction of the relative degree, some interesting schemes [7],[8] including the shunt or parallel feedforward compensation have been proposed and it might be possible to combine these methods with the proposed control scheme for systems with relative degree of more than one.

2. Preliminaries

Consider affine nonlinear systems

$$\begin{aligned} \dot{\boldsymbol{x}}(t) &= \boldsymbol{f}(\boldsymbol{x}) + \boldsymbol{g}(\boldsymbol{x})u(t) \\ y(t) &= h(\boldsymbol{x}) \end{aligned} \tag{2.1}$$

where $\boldsymbol{x}(t) \in R^n$ is a state vector, $u(t) \in R$ is an input, $y(t) \in R$ is output, and $\boldsymbol{f}(\boldsymbol{x}), \boldsymbol{g}(\boldsymbol{x}) : R^n \to R^n$ and $h(\boldsymbol{x})R^n \to R$ are sufficiently smooth (e.g. of class C^∞) functions such that $\boldsymbol{f}(0) = 0$, $h(0) = 0$, i.e. it is assumed that $\dot{\boldsymbol{x}}(t) = \boldsymbol{f}(\boldsymbol{x})$ has an equilibrium at the origin.

It is well known [9], [10] that if the system (2.1) has strong relative degree of 1, then there exists a smooth nonsingular change of coordinates: $z = \Phi(\boldsymbol{x})$ such that the system (2.1) can be transformed to the normal form:

$$\begin{aligned} \dot{y}(t) &= a(y, \boldsymbol{\eta}) + b(y, \boldsymbol{\eta})u(t) \\ \dot{\boldsymbol{\eta}}(t) &= \boldsymbol{q}(y, \boldsymbol{\eta}) \end{aligned} \tag{2.2}$$

Throughout this paper, we consider the case where the controlled system (2.1) has relative degree of 1 so that it is described by the form of (2.2)

3. Robust Adaptive Output Feedback Tracking

3.1. Problem statement

Consider the following SISO nonlinear system with uncertain nonlinearities or disturbances:

$$\begin{aligned} \dot{y}(t) &= a(y, \boldsymbol{\eta}) + b(y, \boldsymbol{\eta})u(t) + f_1(t, y, \boldsymbol{\eta}) \\ \dot{\boldsymbol{\eta}}(t) &= \boldsymbol{q}(y, \boldsymbol{\eta}) + \boldsymbol{f}_2(t, y, \boldsymbol{\eta}) \end{aligned} \tag{3.1}$$

where $f_1(t, y, \eta), \boldsymbol{f}_2(t, y, \eta)$ are uncertain nonlinearities or disturbances.

We impose the following assumptions on the controlled system (3.1):