Adaptive bounding design for output feedback control using neural networks

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Abstract

The paper is extending output feedback nonlinear control and backstepping approaches to a class of systems approximately diffeomorphic to output feedback systems. The uncertainties under consideration are of two types - parametric and non-parametric. The non-parametric terms are assumed to be bounded by unknown constants. The backstepping procedure is applied to adapt with respect to both parametric uncertainties and the upper bound of non-parametric uncertainties.

1 Introduction

Recently the interest in output feedback control approaches using neural networks have increased and new methods have been suggested. Neural network output feedback control schemes have been proposed for robot manipulators described by second order system [6] and for the nonlinear systems diffeomorphic to the standard form [11]. Adaptive backstepping design approaches have been studied for output feedback systems with bounded approximation errors [3, 2]. In these neural output feedback control approaches, a bound on the approximation error (sometimes referred to as network reconstruction error or modeling error) is assumed to be known [3, 1] or is used only to obtain performance bounded [6, 11]. In many practical situations such a bound on the network reconstruction error is unknown.

In this paper, an adaptive bounding design approach is proposed to handle the unknown approximation error bound for output feedback control using neural networks. The considered system includes two types of uncertainties; parametric and non-parametric. The parametric ones are modeled by universal approximators such as neural networks. The non-parametric ones include not only approximation errors but also some terms unmodeled by the output feedback form. The non-parametric terms are assumed to be bounded by unknown constants.

The parametric portion can be handled using the methods presented in [8]. However as stated there [8, pp. 17], "robust modifications are yet to be developed". That's why it is of great interest to extend and analyze these results applied to systems with non-parametric uncertainties arising from approximation errors and model order. A bounding design method to handle the non-parametric terms is presented in [9, 10] together with a parametric adaptation scheme for the case of full state feedback. In the present paper, the backstepping procedure is applied to adapt with respect to both parametric uncertainties and the upper bound of non-parametric uncertainties. The main technology used to compensate for non-parametric uncertainties is recursive adaptive bounding design [9, 10], which until recently was used only for full state feedback systems. The benefit of such design procedure is that the performance can be improved by better handling of bounded non-parametric uncertainties with unknown bounds. The results are applicable also to semi-physically modeled systems of gray-box type, in which some parts of the plant equations in output feedback form are obtained analytically and others are approximated. In such case we obtain global stability results in the special case when state-dependent bounds hold globally.

2 Problem statement and preliminaries

Consider the system with the structure

$$\begin{aligned}
\dot{x}_i &= x_{i+1} + f_i^o(y) + \tilde{f}_i(x,u), \ 1 \le i \le \rho - 1 \\
\dot{x}_i &= x_{i+1} + f_i^o(y) + \tilde{f}_i(x,u) + g_i(y)u(t), \ \rho \le i \le n-1 \\
\dot{x}_n &= f_n^o(y) + \tilde{f}_n(x,u) + g_n(y)u(t), \\
y &= x_1
\end{aligned} \tag{1}$$