A New Approach to Global Adaptive Tracking for Nonlinear Systems in Generalized Output-Feedback Canonical Form

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Abstract—In this paper, a new global adaptive output feedback dynamic compensator is proposed for tracking of a class of systems that are globally diffeomorphic into systems in generalized output feedback canonical form. Output-dependent nonlinearities are allowed to enter in both cases as additive and multiplicative. The system is allowed to contain unknown parameters multiplying output-dependent nonlinearities. The proposed method relies on a novel parameter estimator and state observer design methodology and the standard backstepping construction. It is shown in the paper the proposed design has three distinctive features not present in the known designs. The applicability and the effectiveness of our method are illustrated by means of respectively, a numerical example and two magnetic levitation systems which are, controlled by the coil current and the voltage applied to coil circuit.

I. INTRODUCTION

In recent decades, adaptive control of nonlinear systems has received a great deal of attention. Under the assumption that all the states are available for feedback, adaptive feedback linearization techniques were proposed in [1]. The adaptive backstepping technique was developed in [2] and its feature called over-parameterization was removed by the tuning functions method in [3]. The natural extension, namely adaptive output feedback, is to consider the case where measurement of partial states is available. In this direction, the majority of results including many publications and several monographs [4, 5] focus on systems in output feedback canonical form in which the only nonlinearities are additive and output-dependent. Recently, [6-8] proposed the global adaptive output feedback controllers for a class of more general system structures named generalized output-feedback canonical form. The common feature on the aforementioned adaptive control is that the design of parameter estimator or (and) state observer follows the classical certainty-equivalent principle.

More recently, a novel adaptive mechanism, which does not follow the certainty-equivalent principle, was firstly proposed in [9] within the framework of Immersion and Invariance (I&I) stabilization and I&I adaptive control. Further, within the framework of this new systems and control philosophy, work [10] presented a novel adaptive backstepping algorithm for the system in parametric feedback form which has the advantage of an improved performance and the tunability in comparison with the tuning functions design in [4]. However, it is only suitable in situation where the “virtual” control coefficients are ones hence limiting its range of applications. In [11] the novel method in [10], which is for systems in so-called parametric feedback form to a general form whose “virtual” control parameters are functions of system feedback states, was extended and applied to excitation control in power systems. Still these new results assume that all the feedback states are measured.

The output feedback case under the above-mentioned novel adaptive mechanism has received little attention in the literature with regard to adaptive control problem, except in the recent papers [12, 13]. Work [12] addressed and solved the problem of stabilization by means of output feedback for a class of nonlinear systems that do not contain uncertainties. And [13] presented a global output feedback stabilizer for a class of uncertain nonlinear systems described by equations

\[
\dot{\eta} = F(x_i)\eta + G(x_i) + \Delta_0(\eta, x_i)
\]

\[
\dot{x}_i = x_{i+1} + \phi_i(x_i)\eta + \Delta_i(\eta, x_i), \quad i = 1, \ldots, n
\]

with \((\eta, x_1, \ldots, x_n) \in \mathbb{R}^m \times \mathbb{R} \times \cdots \times \mathbb{R}\), input \(x_{n+1} = u\) and output \(y = x_1\), where \(\Delta_i(\cdot)\) are unknown perturbation functions. It should be noted, however, this class of systems do not allow for parametric uncertainties.

We propose a new global adaptive tracking output feedback controller for a class of systems that are globally diffeomorphic into the form (1), which was firstly dealt with in [6] within the framework of classical adaptive control. The proposed design can be considered as a natural extension of our algorithm in [11] to output feedback case.

\[
\dot{x}_1 = \phi_{(1,1)}(x_1) + \phi_{(1,2)}(x_1)x_2 + \theta^T \Omega_1(x_1),
\]

\[
\dot{x}_2 = \phi_{(2,1)}(x_1) + \phi_{(2,2)}(x_1)x_2 + \phi_{(2,3)}(x_1)x_3 + \theta^T \Omega_2(x_1),
\]

\[
\vdots
\]

\[
\dot{x}_n = \phi_{(n,0)}(x_1) + \sum_{j=2}^{n} \phi_{(n,j)}(x_1)x_j + \mu(x_i)u + \tilde{\theta} \Omega_n(x_1), \quad (1)
\]
\[ y = x_1, \]

where \( x = [x_1, x_2, \ldots, x_n]^T \in \mathbb{R}^n \) is the state, \( u \in \mathbb{R} \) is the input, and \( y \in \mathbb{R} \) is the output. The \( \theta \in \mathbb{R}^{n_\theta} \) is a vector of constant unknown parameters. The \( \phi_{i,j}(x_i) \neq 0 \) and \( \Omega_i \) are known smooth nonlinear functions of \( x_i \).

The design consists of two steps. First, design the novel parameter estimator and state observer in a unified way. Second, derive the dynamics of error state by applying the standard backstepping construction, and design some parameter estimator and state observer in a unified way.

Remark 1. As pointed out in [6], the class of systems considered in our paper include systems in which unknown parameters multiply terms involving the derivative of the output (namely \( x_2 \)), i.e. systems in which the term \( \phi_{i,1}(x_2) \) in (1) is replaced by \( y^T \phi_{i,2}(x_2) \) where \( y \in \mathbb{R}^{n_y} \) is an unknown parameter vector and \( \phi_{i,2}(x_2) \in \mathbb{R}^{n_y} \) is a vector of known functions of \( x_2 \). Systems with such terms can always be transformed to the form of (1) via a parameter dependent change of coordinates.

III. GLOBAL OUTPUT FEEDBACK TRACKING

In this section, a solution to the global output feedback tracking for generalized output feedback canonical form (1) in which the unmeasured states do occur in affine fashion. The following assumptions are needed in the sequel.

A1[6, 7]: A sufficient but not necessary condition for observability of (1) is
\[ \phi_{i,i+1}(x_i) > 0, \text{ for } i = 1, 2, \ldots, n-1 \text{ and } x_i \in \mathbb{R}. \]

A2: there exists a \( C^1 \) mapping
\[ \beta(\cdot) = [\beta_1(x_1), \beta_2(x_1), \ldots, \beta_n(x_1)]^T \]
such that the system
\[ \dot{z} = A(x_i)z, \]
\[ \begin{bmatrix}
0 & 0 & \cdots & 0 \\
\Omega_i(x_i) & 0 & \cdots & 0 \\
\phi_{1,2}(x_1) & \phi_{1,3}(x_1) & \cdots & 0 \\
\phi_{2,2}(x_1) & \phi_{2,3}(x_1) & \cdots & 0 \\
\phi_{3,2}(x_1) & \phi_{3,3}(x_1) & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
\phi_{n,2}(x_1) & \phi_{n,3}(x_1) & \cdots & 0 \\
\phi_{n,1}(x_1) & \phi_{n,2}(x_1) & \cdots & \phi_{n,n}(x_1) \\
\end{bmatrix} \\
\frac{\partial \beta}{\partial x_i} \begin{bmatrix}
0 & 0 & \cdots & 0 \\
\Omega_i(x_i) & 0 & \cdots & 0 \\
\phi_{1,2}(x_1) & \phi_{1,3}(x_1) & \cdots & 0 \\
\phi_{2,2}(x_1) & \phi_{2,3}(x_1) & \cdots & 0 \\
\phi_{3,2}(x_1) & \phi_{3,3}(x_1) & \cdots & 0 \\
\vdots & \vdots & \ddots & \vdots \\
\phi_{n,2}(x_1) & \phi_{n,3}(x_1) & \cdots & 0 \\
\phi_{n,1}(x_1) & \phi_{n,2}(x_1) & \cdots & \phi_{n,n}(x_1) \\
\end{bmatrix} 
\]
is uniformly globally stable. And moreover, for any \( x_1 \)
\[ \begin{bmatrix}
[\Omega_i(x_1)|\phi_{1,2}(x_1) \ 0 \ \cdots \ 0] \\
\end{bmatrix} \in L_2 \]
It is only assumed that \( y = x_1 \) is available for feedback.

The control objective is to find a dynamic output feedback control law of the form
\[ u = v(\hat{\eta} + \beta(y), y) \]
\[ \dot{\hat{\eta}} = h(y, \hat{\eta}) \]
such that the signals of the closed-loop system (1), (4) is globally bounded and \( \lim_{t \to \infty} y(t) = y_{\text{ref}}(t) \) where \( y_{\text{ref}}(t) \) is a bounded, n-times continuously differentiable signal.
\[
\dot{x}_2 = \phi_{(2,2)}(x_1)z_2 + \phi_{(2,3)}(x_1)z_2 + z_1^T \Omega_2(x_1) + \cdots + \phi_{(n,2)}(x_1)z_n + z_1^T \Omega_n(x_1) - \frac{\partial \beta_n}{\partial x_1} \phi_{(1,2)}(x_1)z_2 + z_1^T \Omega_1(x_1) .
\]

\[B. \text{ Control Law Design}\]

This section will propose a control law in a constructive way that ensures the closed-looped system is \(L_2\) stable [14] with respect to the “perturbation” (3).

Now a controller can be designed by the following procedure.

Step 1. Define \(\ddot{x}_1 = x_1 - y_{\text{ref}}(t)\), its dynamics are derived by

\[
\dot{x}_1 = \phi_{(1,1)}(x_1) + \phi_{(1,2)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + [\ddot{\theta} + \beta_1(x_1) - z_1]^T \Omega_1(x_1) + \frac{\partial \beta_1}{\partial x_1} \phi_{(1,1)}(x_1) + \frac{\partial \beta_2}{\partial x_1} \phi_{(1,2)}(x_1) + \mu(x_1)u + [\ddot{\theta} + \beta_1(x_1) - z_1]^T \Omega_1(x_1) .
\]

Step 2. Differentiating (11) gives

\[
\ddot{x}_1 = \phi_{(1,3)}(x_1) + \phi_{(1,4)}(x_1) + \phi_{(2,2)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(2,3)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(2,4)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \cdots + \phi_{(n,3)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,4)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,5)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,6)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \cdots + \phi_{(n,m)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,m+1)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,m+2)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,m+3)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \phi_{(n,m+4)}(x_1)[\dot{x}_2 + \beta_2(x_1)] + \cdots + \phi_{(n,m+n)}(x_1)[\dot{x}_2 + \beta_2(x_1)] .
\]

Therefore, we have the following error dynamics which are described by (2) in a compact form.

\[
\begin{align*}
\dot{z}_1 &= \frac{\partial \beta_1}{\partial x_1} \phi_{(1,1)}(x_1)z_2 + z_1^T \Omega_1(x_1) + \\
\dot{z}_2 &= \phi_{(2,2)}(x_1)z_2 + \phi_{(2,3)}(x_1)z_2 + z_1^T \Omega_2(x_1) + \\
\dot{z}_3 &= \phi_{(n,3)}(x_1)z_2 + \cdots + \phi_{(n,m)}(x_1)z_2 + z_1^T \Omega_n(x_1) + \\
\end{align*}
\]

Take \(\tilde{x}_3\) as a “virtual” control and then define

\[
\tilde{x}_3 = \tilde{z}_3 - \ddot{x}_3(x_1, \ddot{x}_2, \ddot{\theta}, y_{\text{ref}}) .
\]

Thereafter one can select
\[ \xi_3 = \frac{1}{\phi_{(2,3)}(x_1)} \left\{ \dot{\lambda}_2(\dot{\theta}, x_1, \dot{x}_2) - \phi_{(2,3)}(x_1) \right\} - \phi_{(2,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] - \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_2(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ - \phi_{(1,1)}(x_1) + \phi_{(1,1)}(x_1) \right\} - \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,2)}(x_1) [\dot{x}_2 + \beta_2(x_1)] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
\[ + \phi_{(1,1)}(x_1) \right\} + \frac{\partial \epsilon_{\xi}}{\partial \xi} \left[ \dot{\lambda}_2(x_1) \right] + \left[ \dot{\theta} + \beta_1(x_1) \right]^T \Omega_1(x_1) \]
zero at infinity. Therefore, the whole vector \( \ddot{x} \) converges to zero. Thus the proof is completed.

IV. EXAMPLE AND APPLICATIONS

In this section, we examine the effectiveness and applicability of the proposed method by means of a numerical example and adaptive nonlinear control of two magnetic levitation systems which are, respectively, controlled by the coil current and the voltage applied to coil circuit.

A. A Fourth-Order Example

We applied the proposed method to the following system

\[
\begin{align*}
\dot{x}_1 &= (1 + x_1^2) x_2 + (1 + x_1^2) \theta, \\
\dot{x}_2 &= x_1^5 - (x_1^2 + 1) x_2 + (1 + x_1^2) x_3, \\
\dot{x}_3 &= x_1^3 x_3 + (1 + x_1 + x_1^2) x_4^4, \\
\dot{x}_4 &= x_1^4 x_2 + e^n x_4 + x_3^4 x_4 + u,
\end{align*}
\]

(23)

with the output \( y = x_1 \).

It is worth noting that the system does not satisfy the cascading upper diagonal dominance (CUDD) conditions (see [6-8] for details) so that the result of [6, 7] can not be applied to this system. The result in [16] is not applicable yet, so that the result of [6, 7] can not be applied to this system.

Cascading upper diagonal dominance (CUDD) conditions

\( \phi_{1(1,2)}(x_1), \phi_{2(2,3)}(x_1) \), and \( \phi_{3(3,4)}(x_1) \) are not constants. Furthermore, due to the existence of \( \theta \) in (23), the classical adaptive approach in [8] is not effective to this system.

Clearly, Assumption 1 for (23) naturally holds. By selecting

\[
\begin{align*}
\beta_1(x_1) &= x_1 + \frac{1}{5} x_1^5 + \frac{1}{7} x_1^7, \\
\beta_2(x_1) &= k x_1, \quad k > 0, \\
\beta_3(x_1) &= \frac{1}{2} x_1 + \frac{1}{4} x_1^4 + \frac{1}{6} x_1^6 + \frac{1}{9} x_1^9 + \frac{1}{2} x_1^2, \\
\beta_4(x_1) &= \frac{1}{2} x_1 + \frac{1}{4} x_1^4 + \frac{1}{6} x_1^6 + \frac{1}{6} x_1^6 + \frac{1}{14} x_1^7 + \frac{1}{2} x_1^2,
\end{align*}
\]

and choosing the constants \( k \) appropriately, simple computation easily shows that the assumption 2 holds. Hence, a global output feedback controller for (23) can be design as in Section 3.

B. Current-Controlled Magnetic Levitation System

We consider a magnetic levitation system where the coil current is controlled by a current feedback power amplifier. The systems dynamics can be described in the following equations [17].

\[
\begin{align*}
\dot{x}_1 &= x_2, \\
\dot{x}_2 &= g + \theta, \\
\dot{\theta} &= \frac{Q}{2 M (X_\infty + x_1)^2},
\end{align*}
\]

(24)

where the meaning of all variables is referred to [17].

Generally speaking, gravity acceleration can not be measured accurately [3], so it can be considered as an unknown parameter in practical. Hence (24) can be written as

\[
\begin{align*}
\dot{x}_1 &= x_2, \\
\dot{x}_2 &= \theta, \\
\dot{\theta} &= \frac{Q}{2 M (X_\infty + x_1)^2},
\end{align*}
\]

(25)

Our task here is to design an output feedback controller in the case where only the position \( x_1 \) is measurable, for position tracking problem of the magnetic levitation system.

It is obviously that Assumption 1 holds for (24). By selecting

\[
\begin{align*}
\beta_1(x_1) &= k_1 x_1, \quad k_1 \geq 1, \\
\beta_2(x_1) &= k_2 x_1, \quad k_2 > 0,
\end{align*}
\]

we can easily verify Assumption 2. A current-controlled position tracking controller for (24) can be designed by following the procedure in Section 3.

C. Voltage-Controlled Magnetic Levitation System

Consider the system consisting of an iron ball in a vertical magnetic field created by a single electromagnet. We assume that the electromagnet has inductance \( L \), magnetic field created by a single electromagnet. We assume that the electromagnet has inductance \( L \), resistance \( R \) and is supplied by a voltage source \( u(t) \). The problem is to regulate the ball to a nominal position by controlling the voltage.

The model of the system is given by the equations [18]

\[
\begin{align*}
\dot{x}_1 &= x_2, \\
\dot{x}_2 &= \frac{\varphi(x_1)}{m} x_3^2 - g, \\
\dot{x}_3 &= -\frac{R}{L} x_3 + \frac{1}{L} u,
\end{align*}
\]

(26)

where the meaning of all variables is referred to [17].

The equation (26) does not fall within the form of (1), because the second equation in (26) is not affine in \( x_3 \). The introduction the variable \( E = \frac{1}{2} \dot{x}_3^2 \) and redefinition of input as \( S = x_3 u \) yields

\[
\begin{align*}
\dot{x}_1 &= x_2, \\
\dot{x}_2 &= \frac{2 \varphi(x_1)}{m} E - \theta, \\
\dot{E} &= -\frac{2 R}{L} E + \frac{1}{L} S.
\end{align*}
\]

(27)

To verify assumption A 2, one can select

\[
\beta(x_1) = \begin{bmatrix} k_1 x_1 \\
2 \int \varphi(x_1) dx_1 \\
\end{bmatrix}
\]

where \( k_1 > 1, k_2 > 0 \). Then equation (2) can be re-written as follows:

5292
\[
\dot{z} = \begin{bmatrix}
0 & -\frac{\partial \beta_1}{\partial x_1} & 0 \\
-1 & -\frac{\partial \beta_2}{\partial x_1} & \frac{2\varphi(x_1)}{m} \\
0 & -\frac{\partial \beta_3}{\partial x_1} & -\frac{2R}{L}
\end{bmatrix} z
\] (28)

Then the system (28) is uniformly globally asymptotically stable with Lyapunov function
\[
V(z) = \frac{1}{2} z_1^2 + \frac{1}{2} z_2^2 + \frac{1}{2} z_3^2.
\]

Hence, the rest part of the voltage-controlled position tracking controller for (26) can be designed by following the procedure in section 3.

Remark 2. Applicability of the proposed method which is shown in subsections B and C gives a choice to engineer for nonlinear control of magnetic levitation systems which were dealt with by several existing methods in [17, 18, 20] and references therein.

V. CONCLUSION AND AN OPEN PROBLEM

In this paper, we have presented a new method for the design of adaptive dynamic controller to achieve global asymptotic tracking of a class of nonlinear systems which are globally diffeomorphic into generalized output-feedback canonical form. This class of systems is allowed to contain unknown parameters multiplying output-dependent nonlinearities. Its output-dependent nonlinearities are allowed to enter both additively and multiplicatively.

It is shown in the paper the proposed design has three distinctive features not present in the known designs. First, the parameter estimator and state observer does not follow the canonical form. This class of systems is allowed to contain unknown parameters multiplying output-dependent nonlinearities and no bounds on it are known. In this paper, we consider a priori constant parameter and no bounds on it are known. In this case, the adaptive control algorithm requires no over-parametrization.

It is therefore that the global adaptive output feedback control of this class of systems is still an open problem. In is an open problem to both the existing methods, using certainty equivalent principle in estimation [19], and to the here proposed method of ours within the framework of the I&I adaptive control philosophy.

REFERENCES

[6] P. Krishnamurthy, F. Khorrami, “Global adaptive control of this class of systems is still an open problem. In is an open problem to both the existing methods, using certainty equivalent principle in estimation [19], and to the here proposed method of ours within the framework of the I&I adaptive control philosophy.

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