Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 125 (2018) 25–33

Procedia Computer Science

www.elsevier.com/locate/procedia

6th International Conference on Smart Computing and Communications, ICSCC 2017, 7-8 December 2017, Kurukshetra, India

RBF Neural Control Design for SISO Nonaffine Nonlinear Systems

Pramendra Kumar[a], Naveen Kumar[b,*], Vikas Panwar[a]

[a]Department of Applied Mathematics, Gautam Buddha University, Greater Noida-201308, India
[b]Department of Mathematics, National Institute of Technology (NIT), Kurukshetra, Kurukshetra-136119, Haryana, India

Abstract

In the present paper, an RBF neural control scheme is designed for regulatory control of SISO nonaffine systems facing unknown nonlinearities. Using Taylor series expansion, the nonaffine part of the system is converted into affine form. RBF network is utilized to estimate the equivalent affine system. The parameters of RBF network are updated online based on Lyapunov stability theory. To avoid the requirement of measurement of the states of the system, an observer is designed, which provides the estimated values of the system's states. Using Lyapunov theory, the signals of the system are shown to be asymptotically stable. To validate the effectiveness of the presented scheme, numerical simulation study has been performed.

Peer-review under responsibility of the scientific committee of the 6th International Conference on Smart Computing and Communications.

Keywords: Nonaffine Nonlinear System, RBF Neural Network, Lyapunov stability theory.

1. Introduction

During last decade, a large number of control schemes are developed for uncertain systems with the assumption that the the system is affine (linear) in the control input. However in many industrial applications such as flight control[1], chemical systems [2], wind turbines [3], tank reactors [4] etc., the system to be controlled is nonaffine. Therefore controller design for nonaffine systems has evolved as a challenging problem. Many remarkable controllers are designed for nonaffine systems. Previously control schemes incorporated backstepping techniques for control of nonaffine systems[5, 6, 7, 8, 9, 10]. In [5] an adaptive scheme was discussed for non-affine systems using neural networks. By utilizing time-scale seperation to estimate the inversion of nonaffine system, a novel method was presented by singular perturbation method in [6] and [7]. In [8] a neural control based synthesis approach was used for nonaffine systems and the assumption of fixed-point was eliminated. A disturbance observer was designed for nonaffine system in [9] to estimate the compounded disturbances of the system. In [10] a control scheme was designed for hysteretic systems by combining the merits of hysteresis model with backstepping technique with no requirement of hysteresis inverse.

* Corresponding author. Tel.: +91-1744-233508
E-mail address: navindma@gmail.com (Naveen Kumar).

1877-0509
Peer-review under responsibility of the scientific committee of the 6th International Conference on Smart Computing and Communications
10.1016/j.procs.2017.12.006

However, in backstepping design the complexity of the control design increases with the system order as a result of the recurring differentiation of the control input. To overcome this issue, another technique named as dynamic surface control (DSC), was used for control of nonaffine system[11, 12, 13]. In [11] novel DSC scheme was presented using multilayer neural networks and a filter was utilized to eliminate the aforementioned issue of the repeated differentiation. In [12] by incorporating DSC approach with NN based approach, backstepping based controller was designed for nonlinear systems. However, it is a recursive method while requiring O(n) number of NNs and auxiliary low-pass filters for an n^{th} order system. Adaptive backstepping-free controllers were also studied [14, 15, 16, 17, 18, 19, 20]. In [14], an adaptive backstepping-free controller was presented. To approximate the states and unknown nonlinearities, NN observer was proposed. In [15] an adaptive scheme was proposed for nonaffine systems. A fuzzy logic based recurrent scheme was presented for non-affine system by utilizing observer for the states. in [16]. In [17] an adaptive controller, based on observer, was presented for uncertain SISO non-affine systems. In [18] neural network based control scheme was proposed for non-affine systems by considering the delay problem of the system. In [19], different optimal control schemes were presented for systems having nonlinearities. For a nonaffine system with nonlinearities of dead-zone and facing external disturbances, an asymptotically stable control scheme was presented in [20].

In the present paper, we have designed an RBF neural network based control scheme for nonaffine systems. Firstly nonaffine part of the system is transformed into affine form by utilizing taylor series approach. Then RBF neural network is utilized to estimate the equivalent affine system. In many industrial applications, the exact knowledge of the states of the system are not available. Therefore the states of the system are estimated by using the designed observer. Lyapunov approach is utilized for the purpose of stability analysis and based on the analysis, all signals of the system are shown to be bounded. Finally the scheme is validated through numerical simulation studies.

The paper is organized as follows. In Section 2, the problem is formulated together with the description of RBF neural network. In Section 3, the design of control system are described in details. In Section 4, the detailed stability analysis is presented. Numerical simulation studies are performed in Section 5. Finally conclusive remark are described in Section 6.

2. Problem Formulation

We Consider the following form of SISO nonaffine nonlinear system

$$\begin{aligned} \dot{x}(t) &= Mx(t) + NG(x(t), u(t)) \\ y(t) &= Dx(t) \end{aligned} \tag{1}$$

where $M \in R^{n\times n}, N \in R^{n\times n}$ and $D \in R^{n\times n}$ are system matrices (known). Also $u(t) \in R$ is the input of the system and $y(t) \in R$ is the output of the system. The the measurement of the state vector $x(t) \in R^n$, is not available and $G(x, u)$ is smooth function (unknown).
The following commonly found assumptions are used:
Assumption 1: $G(x, u) \in C^1 \ \forall \ (x, u) \in R^{n+1}$.
Assumption 2: $\frac{\partial G}{\partial u} \neq 0 \ \forall \ (x, u) \in R^{n+1}$.
The objective of the present study is to outline a state feedback control scheme for SISO nonaffine system so that the output of the system follows a reference signal, keeping all signals of system to be bounded.
In the presented work, RBFNN is utilized to design the control scheme. In the area of control engineering, NN is being used to compensate the unknown function. It has been shown in the literature that a linear combination of Gaussian functions can approximate any continuous function[21]. In RBFNN, the input space is mapped into an intermediate space by a nonlinear transformation performed by hidden layer. Then the output of the network is obtained by linearly combining the outputs of the intermediate layer. We can described RBFNN as

$$h(x) = W_h^t(x)\theta_h^{\dagger} + \epsilon_h(x) \tag{2}$$

$\epsilon_h(x)$ is the NN reconstruction errors.