Nonlinear adaptive control using neural networks and its application to CSTR systems

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Abstract

In this paper, adaptive tracking control is considered for a class of general nonlinear systems using multilayer neural networks (MNNs). Firstly, the existence of an ideal implicit feedback linearization control (IFLC) is established based on implicit function theory. Then, MNNs are introduced to reconstruct this ideal IFLC to approximately realize feedback linearization. The proposed adaptive controller ensures that the system output tracks a given bounded reference signal and the tracking error converges to an ε-neighborhood of zero with ε being a small design parameter, while stability of the closed-loop system is guaranteed. The effectiveness of the proposed controller is illustrated through an application to composition control in a continuously stirred tank reactor (CSTR) system. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Nonlinear systems; Input–output feedback linearisation; Adaptive control; Multilayer neural networks; CSTR

1. Introduction

Recently, active research has been carried out on neural network control for nonlinear dynamic systems [1–16]. The massive parallelism, natural fault tolerance and implicit programming of neural network computing architectures suggest that they are good candidates for implementing real-time adaptive control for nonlinear dynamical systems. In the NN control design based on backpropagation (BP) learning algorithm [1–3], sufficient off-line training is required before control action is initiated for achieving a stable closed-loop system. To deal with such a requirement, stable adaptive NN design methods have been proposed based on Lyapunov stability theory in [4–9], which are applicable to affine nonlinear system described by

$$\begin{cases} \dot{x} = f_1(x) + g_1(x)u \\ y = h(x) \end{cases} \tag{1}$$

where $f_1(x)$ and $g_1(x)$ are smooth vector fields. In practice, many physical systems such as chemical reactions, PH neutralization and distillation columns are inherently nonlinear, whose input variables may enter in the systems nonlinearly as described by the general form

$$\begin{cases} \dot{x} = f(x, u) \\ y = h(x) \end{cases} \tag{2}$$

where $x \in R^n$ is the state vector, $u \in R$ is the input and $y \in R$ is the output, and $f(\cdot)$ and $h(\cdot)$ are smooth vector fields. To solve the control problem for general nonlinear systems, neural networks have been used in [10–13] for emulating the 'inverse controller' to achieve tracking control through off-line training. It has been shown that the adaptive controller proposed in [13] can guarantee the stability of the closed-loop system when the uniformly persistently exciting (PE) condition is satisfied.

Multilayer neural networks are general tools for modelling nonlinear functions since they can approximate any continuous nonlinear function to any desired accuracy over a compact set [17]. In this work, a new direct adaptive controller is developed for non-affine system (2) using MNNs and Lyapunov stability technique. It is shown that the tracking error converges to a small neighborhood of zero and the closed-loop stability is guaranteed without the requirement for off-line training and PE condition. The paper is organized as follows. Section 2 describes the class of nonlinear systems under study and the concept of input–output

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Application Of Neural Networks To Adaptive Control Of Nonlinear

Adam Grzech

Application Of Neural Networks To Adaptive Control Of Nonlinear:

Application of Neural Networks to Adaptive Control of Nonlinear Systems Gee Wah Ng,1997 This book investigates the ability of a neural network NN to learn how to control an unknown nonlinear in general system using data acquired on line that is during the process of attempting to exert control Two algorithms are developed to train the neural network for real time control applications The first algorithm is known as Learning by Recursive Least Squares LRLS algorithm and the second algorithm is known as Integrated Gradient and Least Squares IGLS algorithm The ability of these algorithms to train the NN controller for real time control is demonstrated on practical applications and the local convergence and stability requirements of these algorithms are analysed In addition network topology learning algorithms particularly supervised learning and neural network control strategies are presented *Applications Of Neural Adaptive Control Technology* Andrzej Dzielinski,Jens Kalkkuhl,Rafal Zbikowski,Kenneth J Hunt,1997-09-02 This book presents the results of the second workshop on Neural Adaptive Control Technology NACT II held on September 9 10 1996 in Berlin The workshop was organised in connection with a three year European Union funded Basic Research Project in the ESPRIT framework called NACT a collaboration between Daimler Benz Germany and the University of Glasgow Scotland The NACT project which began on 1 April 1994 is a study of the fundamental properties of neural network based adaptive control systems Where possible links with traditional adaptive control systems are exploited A major aim is to develop a systematic engineering procedure for designing neural controllers for nonlinear dynamic systems The techniques developed are being evaluated on concrete industrial problems from within the Daimler Benz group of companies The aim of the workshop was to bring together selected invited specialists in the fields of adaptive control nonlinear systems and neural networks The first workshop NACT I took place in Glasgow in May 1995 and was mainly devoted to theoretical issues of neural adaptive control Besides monitoring further development of theory the NACT II workshop was focused on industrial applications and software tools This context dictated the focus of the book and guided the editors in the choice of the papers and their subsequent reshaping into substantive book chapters Thus with the project having progressed into its applications stage emphasis is put on the transfer of theory of neural adaptive engineering into industrial practice The contributors are therefore both renowned academics and practitioners from major industrial users of neurocontrol **Neural Network-Based Adaptive Control of Uncertain Nonlinear Systems** Kasra Esfandiari,Farzaneh Abdollahi,Heidar A. Talebi,2021-06-18 The focus of this book is the application of artificial neural networks in uncertain dynamical systems It explains how to use neural networks in concert with adaptive techniques for system identification state estimation and control problems The authors begin with a brief historical overview of adaptive control followed by a review of mathematical preliminaries In the subsequent chapters they present several neural network based control schemes Each chapter starts with a concise introduction to the problem under study and a neural network based control strategy is designed for the simplest case

scenario After these designs are discussed different practical limitations i e saturation constraints and unavailability of all system states are gradually added and other control schemes are developed based on the primary scenario Through these exercises the authors present structures that not only provide mathematical tools for navigating control problems but also supply solutions that are pertinent to real life systems **Adaptive Control with Recurrent High-order Neural Networks** George A. Rovithakis,Manolis A. Christodoulou,2000 The primary purpose of this book is to present a set of techniques which allow the design of controllers able to guarantee stability convergence and robustness for dynamical systems with unknown nonlinearities and of manufacturing systems To compensate for the significant amount of uncertainty in system structure a neural network model developed recently namely the Recurrent High Order Neural Network RHONN is employed Real applications are provided with illustrations and tables for clarification the book contains material on RHONN structure and approximation capabilities indirect adaptive control direct adaptive control scheduling for manufacturing systems test case for scheduling using RHONNs The book is primarily intended for industrial and institutional practitioners but should be of significant interest to undergraduate and graduate students and academic scientists working with neural networks and their applications in engineering **Adaptive Control of Nonlinear Systems Using Neural Networks** Pravin Natarajan,1995 *Adaptive Control of Non-linear Systems Using Neural Networks* Fu-Chuang Chen,1990 Layered neural networks are used in the adaptive control of nonlinear discrete time systems The control algorithm is described and two convergence results are provided *Stable Adaptive Neural Network Control* S.S. Ge,C.C. Hang,T.H. Lee,Tao Zhang,2013-03-09 Recent years have seen a rapid development of neural network control tech niques and their successful applications Numerous simulation studies and actual industrial implementations show that artificial neural network is a good candidate for function approximation and control system design in solving the control problems of complex nonlinear systems in the presence of different kinds of uncertainties Many control approaches methods reporting inventions and control applications within the fields of adaptive control neural control and fuzzy systems have been published in various books journals and conference proceedings In spite of these remarkable advances in neural control field due to the complexity of nonlinear systems the present research on adaptive neural control is still focused on the development of fundamental methodologies From a theoretical viewpoint there is in general lack of a firmly mathematical basis in stability robustness and performance analysis of neural network adaptive control systems This book is motivated by the need for systematic design approaches for stable adaptive control using approximation based techniques The main objec tives of the book are to develop stable adaptive neural control strategies and to perform transient performance analysis of the resulted neural control systems analytically Other linear in the parameter function approximators can replace the linear in the parameter neural networks in the controllers presented in the book without any difficulty which include polynomials splines fuzzy systems wavelet networks among others Stability is one of the most important issues being concerned if an adaptive neural network

controller is to be used in practical applications   Real-time Adaptive Control of Nonlinear Systems Using Neural Networks John F Glenn (Jr.),1996   *Algorithms and Architectures for Real-Time Control 1991* P.J. Fleming,D.I. Jones,2014-07-22 Computer scientists have long appreciated that the relationship between algorithms and architecture is crucial Broadly speaking the more specialized the architecture is to a particular algorithm then the more efficient will be the computation The penalty is that the architecture will become useless for computing anything other than that algorithm This message holds for the algorithms used in real time automatic control as much as any other field These Proceedings will provide researchers in this field with a useful up to date reference source of recent developments   *Stable Adaptive Control of Unknown Nonlinear Dynamic Systems Using Neural Networks* Olawale Adetona,1998   *Identification and Adaptive Control for Nonlinear Systems and Applications* Jianhua Zhang,Yang Li,Qiang Chen,2022-03-15 Identification and Adaptive Control for Nonlinear Systems and Applications Applied Mathematics in Control Engineering introduces nonlinear systems concepts system analysis system control methods and applications in various fields The major contribution of the book includes 1 The basic concepts of nonlinear systems stability analysis and nonlinear systems control method 2 The stability analysis of complex nonlinear system with adaptive neural networks control 3 The nonlinear systems adaptive sliding mode controller design of complex nonlinear systems 4 Some industrial application The book gives an introduction to basic nonlinear systems architectures for adaptive control methods Emphasis is placed on the mathematical analysis of these systems on methods of controlling them for adaptive control and on their application to practical engineering problems in such areas as aircraft path planning This book enables audience to understand the basic architectures of control science and engineering and to master classical and advanced design method for nonlinear system Introduces nonlinear systems concepts system analysis system control methods and applications in various fields Presents basic concepts of nonlinear systems stability analysis and nonlinear systems control method Offers practical examples   **Agent and Multi-Agent Systems: Technologies and Applications** Adam Grzech,2007-07-07 This book constitutes the refereed proceedings of the First International Symposium on Agent and Multi Agent Systems Technologies and Applications KES AMSTA 2007 held in Wroclaw Poland in May June 2007 Coverage includes agent oriented Web applications mobility aspects of agent systems agents for network management agent approaches to robotic systems as well as intelligent and secure agents for digital content management   **Adaptive Control of Nonlinear Dynamical Systems by Artificial Neural Networks** Siddik Murat Yesiloglu,1993   **Deep Reinforcement Learning with Guaranteed Performance** Yinyan Zhang,Shuai Li,Xuefeng Zhou,2019-11-09 This book discusses methods and algorithms for the near optimal adaptive control of nonlinear systems including the corresponding theoretical analysis and simulative examples and presents two innovative methods for the redundancy resolution of redundant manipulators with consideration of parameter uncertainty and periodic disturbances It also reports on a series of systematic investigations on a near optimal adaptive control method based on the Taylor expansion neural networks

estimator design approaches and the idea of sliding mode control focusing on the tracking control problem of nonlinear systems under different scenarios The book culminates with a presentation of two new redundancy resolution methods one addresses adaptive kinematic control of redundant manipulators and the other centers on the effect of periodic input disturbance on redundancy resolution Each self contained chapter is clearly written making the book accessible to graduate students as well as academic and industrial researchers in the fields of adaptive and optimal control robotics and dynamic neural networks   <u>Proceedings of the International Symposium on Manufacturing Science and Technology for the 21st Century</u> Zhou Zhaoying,1994   **Neural Network Enhanced Self Tuning Adaptive Control Application for Non-linear Control of Dynamic Systems** Bal Krishna Thapa,2001   *Proceedings of the 1999 IEEE International Conference on Control Applications* ,1999   *1995 IEEE Conference on Control Applications* IEEE Control Systems Society,1995   **Neural Network Based Adaptive Control for Nonlinear Dynamic Regimes** Yoonghyun Shin,2005 Adaptive control designs using neural networks NNs based on dynamic inversion are investigated for aerospace vehicles which are operated at highly nonlinear dynamic regimes NNs play a key role as the principal element of adaptation to approximately cancel the effect of inversion error which subsequently improves robustness to parametric uncertainty and unmodeled dynamics in nonlinear regimes An adaptive control scheme previously named composite model reference adaptive control is further developed so that it can be applied to multi input multi output output feedback dynamic inversion It can have adaptive elements in both the dynamic compensator linear controller part and or in the conventional adaptive controller part also utilizing state estimation information for NN adaptation This methodology has more flexibility and thus hopefully greater potential than conventional adaptive designs for adaptive flight control in highly nonlinear flight regimes The stability of the control system is proved through Lyapunov theorems and validated with simulations The control designs in this thesis also include the use of pseudo control hedging techniques which are introduced to prevent the NNs from attempting to adapt to various actuation nonlinearities such as actuator position and rate saturations Control allocation is introduced for the case of redundant control effectors including thrust vectoring nozzles A thorough comparison study of conventional and NN based adaptive designs for a system under a limit cycle wing rock is included in this research and the NN based adaptive control designs demonstrate their performances for two highly maneuverable aerial vehicles NASA F 15 ACTIVE and FQM 117B unmanned aerial vehicle UAV operated under various nonlinearities and uncertainties   *Proceedings of the 1995 American Control Conference* American Automatic Control Council,1995

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