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 $f(.)$ and $h()$ 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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Nonlinear Adaptive Control

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Nonlinear Adaptive Control:

Nonlinear and Adaptive Control Design Miroslav Krstic,Ioannis Kanellakopoulos,Petar V. Kokotovic,1995-06-14 Using a pedagogical style along with detailed proofs and illustrative examples this book opens a view to the largely unexplored area of nonlinear systems with uncertainties The focus is on adaptive nonlinear control results introduced with the new recursive design methodology adaptive backstepping Describes basic tools for nonadaptive backstepping design with state and output feedbacks   Nonlinear and Adaptive Control of Complex Systems A.L. Fradkov,I.V. Miroshnik,V.O. Nikiforov,2013-06-29 This volume presents a theoretical framework and control methodology for a class of complex dynamical systems characterised by high state space dimension multiple inputs and outputs significant nonlinearity parametric uncertainty and unmodeled dynamics A unique feature of the authors approach is the combination of rigorous concepts and methods of nonlinear control invariant and attracting submanifolds Lyapunov functions exact linearisation passification with approximate decomposition results based on singular perturbations and decentralisation Some results published previously in the Russian literature and not well known in the West are brought to light Basic concepts of modern nonlinear control and motivating examples are given Audience This book will be useful for researchers engineers university lecturers and postgraduate students specialising in the fields of applied mathematics and engineering such as automatic control robotics and control of vibrations   Adaptive Dual Control Nikolai Michailovich Filatov,Heinz Unbehauen,2004-04-20 This monograph demonstrates how the performance of various well known adaptive controllers can be improved significantly using the dual effect The modifications to incorporate dual control are realized separately and independently of the main adaptive controller without complicating the algorithms A new bicriterial approach for dual control is developed and applied to various types of popular linear and nonlinear adaptive controllers Practical applications of the designed controllers to several real time problems are presented This monograph is the first book providing a complete exposition on the dual control problem from the inception in the early 1960s to the present state of the art aiming at students and researchers in adaptive control as well as design engineers in industry   **Nonlinear and Adaptive Control with Applications** Alessandro Astolfi,Dimitrios Karagiannis,Romeo Ortega,2007-12-06 The authors here provide a detailed treatment of the design of robust adaptive controllers for nonlinear systems with uncertainties They employ a new tool based on the ideas of system immersion and manifold invariance New algorithms are delivered for the construction of robust asymptotically stabilizing and adaptive control laws for nonlinear systems The methods proposed lead to modular schemes that are easier to tune than their counterparts obtained from Lyapunov redesign   Nonlinear and Adaptive Control Alan S.I. Zinober,David H. Owens,2002-09-12 The objective of the EU Nonlinear Control Network Workshop was to bring together scientists who are already active in nonlinear control and young researchers working in this field This book presents selectively invited contributions from the workshop some describing state of the art subjects that already have a status of maturity while others

propose promising future directions in nonlinear control Amongst others following topics of nonlinear and adaptive control are included adaptive and robust control applications in physical systems distributed parameter systems disturbance attenuation dynamic feedback optimal control sliding mode control and tracking and motion planning **Nonlinear And Adaptive Control: Tools And Algorithms For The User** Alessandro Astolfi,2005-12-15 This book summarizes the main results achieved in a four year European Project on nonlinear and adaptive control The project involves leading researchers from top notch institutions Imperial College London Prof A Astolfi Lund University Prof A Rantzer Supelec Paris Prof R Ortega University of Technology of Compiegne Prof R Lozano Grenoble Polytechnic Prof C Canudas de Wit University of Twente Prof A van der Schaft Politecnico of Milan Prof S Bittanti and Polytechnic University of Valencia Prof P Albertos The book also provides an introduction to theoretical advances in nonlinear and adaptive control and an overview of novel applications of advanced control theory particularly topics on the control of partially known systems under actuated systems and bioreactors a Nonlinear Adaptive Control of Highly Maneuverable High Performance Aircraft Sul Cho,1993 This thesis presents an effective control design methodology using a one step ahead prediction adaptive control law and an adaptive control law based on a Lyapunov function These control law were applied to a highly maneuverable high performance aircraft in particular a modified F A 18 An adaptive controller is developed to maneuver an aircraft at a high angle of attack even if the aircraft is required to fly over a highly nonlinear flight regime The adaptive controller presented in this thesis is based on linear bilinear and nonlinear prediction models with input constraints It is shown that the linear bilinear and nonlinear adaptive controllers can be constructed to minimize the given cost function or Lyapunov function with respect to the control input at each step The control is calculated such that the system follows the reference trajectory and such that control signal remains within its constraints From several simulation results the nonlinear controller is controller is better than the linear controller A nonlinear adaptive control law based on a Lyapunov function is designed such that control inputs are smoother than for the one step ahead prediction adaptive controller *Nonlinear Adaptive Control with Application to Flexible Structures* Ouassima Akhrif,1989 *Nonlinear Adaptive Control Systems with Storage* Naresh K. Sinha,1964 Nonlinear and Adaptive Control Systems Zhengtao Ding,2013-04-04 Nonlinear and Adaptive Control Systems treats nonlinear control and adaptive control in a unified framework presenting the major results at a moderate mathematical level suitable for MSc students and engineers with undergraduate degrees Nonlinear and Adaptive Control Systems Zhengato Ding,2013 **Some Problems in Nonlinear Adaptive Control** Pawel Podsialdo,1994 *Periodic Nonlinear Adaptive Control of Rapidly Time-varying Linear Systems* Joel David Simard,2018 In adaptive control the goal is to deal with systems that have unknown and or time varying parameters Most techniques are proven for the case in which any time variation is slow with results for systems with fast time variations limited to those for which the time variation is of a known form or for which the plant has stable zero dynamics Here we propose a new adaptive controller design methodology for

which the time variation can be rapid While the plant is allowed to have unstable zero dynamics it must satisfy several structural conditions which have been proven to be necessary in the literature we also impose some mild regularity conditions The proposed controller is nonlinear and periodic and in each period the parameter values are estimated and an appropriate stabilizing control signal is applied Under the technical assumptions that the plant is relative degree one and that the plant uncertainty is in terms of a single scalar variable it is proven that the closed loop system is stable under fast parameter variations with persistent jumps **Adaptive Control Systems** Gang Feng,Rogelio Lozano,1999-05-10 Adaptive control is no longer just an important theoretical field of study but is also providing solutions to real world problems Adaptive techniques will transform the world of control The leading world practitioners of adaptive control have contributed to this handbook which is the most important work yet in this field Not only are techniques described in theory but detailed control algorithms are given making this a practical cookbook of adaptive control for both control professionals and practising engineers The book presents the most advanced techniques and algorithms of adaptive control These include various robust techniques performance enhancement techniques techniques with less a priori knowledge nonlinear adaptive control techniques and intelligent adaptive techniques Each technique described has been developed to provide a practical solution to a real life problem This volume will therefore not only advance the field of adaptive control as an area of study but will also show how the potential of this technology can be realised and offer significant benefits Practical cookbook of adaptive control Contains important research **Nonlinear Adaptive Control and Applications in Power Systems** Lin Jiang,University of Liverpool,2001 **Robustness and Performance of Nonlinear Adaptive Control Systems** Youping Zhang,1996 *Adaptive Identification and Control of Uncertain Systems with Non-smooth Dynamics* Jing Na,Qiang Chen,Xuemei Ren,2018-06-12 Adaptive Identification and Control of Uncertain Systems with Nonsmooth Dynamics reports some of the latest research on modeling identification and adaptive control for systems with nonsmooth dynamics e g backlash dead zone friction saturation etc The authors present recent research results for the modelling and control designs of uncertain systems with nonsmooth dynamics such as friction dead zone saturation and hysteresis etc with particular applications in servo systems The book is organized into 19 chapters distributed in five parts concerning the four types of nonsmooth characteristics namely friction dead zone saturation and hysteresis respectively Practical experiments are also included to validate and exemplify the proposed approaches This valuable resource can help both researchers and practitioners to learn and understand nonlinear adaptive control designs Academics engineers and graduate students in the fields of electrical engineering control systems mechanical engineering applied mathematics and computer science can benefit from the book It can be also used as a reference book on adaptive control for servo systems for students with some background in control engineering Explains the latest research outputs on modeling identification and adaptive control for systems with nonsmooth dynamics Provides practical application and experimental results for robotic systems and servo motors **Delay**

Compensation for Nonlinear, Adaptive, and PDE Systems Miroslav Krstic,2010-01-23 Some of the most common dynamic phenomena that arise in engineering practice actuator and sensor delays fall outside the scope of standard finite dimensional system theory The first attempt at infinite dimensional feedback design in the field of control systems the Smith predictor has remained limited to linear finite dimensional plants over the last five decades Shedding light on new opportunities in predictor feedback this book significantly broadens the set of techniques available to a mathematician or engineer working on delay systems The book is a collection of tools and techniques that make predictor feedback ideas applicable to nonlinear systems systems modeled by PDEs systems with highly uncertain or completely unknown input output delays and systems whose actuator or sensor dynamics are modeled by more general hyperbolic or parabolic PDEs rather than by pure delay Numerous examples and a detailed treatment of individual classes of problems will help the reader master the techniques Delay Compensation for Nonlinear Adaptive and PDE Systems is an excellent reference guide for graduate students researchers and professionals in mathematics systems control as well as chemical mechanical electrical computer aerospace and civil structural engineering Parts of the book may be used in graduate courses on general distributed parameter systems linear delay systems PDEs nonlinear control state estimator and observers adaptive control robust control or linear time varying systems   **Stable Adaptive Control and Estimation for Nonlinear Systems** Jeffrey T. Spooner,Manfredi Maggiore,Raúl Ordóñez,Kevin M. Passino,2004-03-24 Thema dieses Buches ist die Anwendung neuronaler Netze und Fuzzy Logic Methoden zur Identifikation und Steuerung nichtlinear dynamischer Systeme Dabei werden fortgeschrittene Konzepte der herk mmlichen Steuerungstheorie mit den intuitiven Eigenschaften intelligenter Systeme kombiniert um praxisrelevante Steuerungsaufgaben zu l sen Die Autoren bieten viel Hintergrundmaterial ausgearbeitete Beispiele und bungsaufgaben helfen Studenten und Praktikern beim Vertiefen des Stoffes L sungen zu den Aufgaben sowie MATLAB Codebeispiele sind ebenfalls enthalten   **Adaptive Control of Nonsmooth Dynamic Systems** Gang Tao,Frank L. Lewis,2013-04-17 A complete reference to adaptive control of systems with nonsmooth industrial nonlinearities such as backlash dead zones component failure friction hysteresis saturation and time delays Actuator nonlinearities are ubiquitous in engineering practice and limit control system performance While standard feedback control alone cannot handle these nonsmooth nonlinearities effectively this book shows how such nonlinear characteristics can be compensated for by using adaptive and intelligent control techniques This allows desired system performance to be achieved in the presence of uncertain nonlinearities With surveys of literature and summaries of various design methods the contributors present new solutions to some important issues in adaptive control of systems with various sorts of nonsmooth nonlinearities The book motivates more research activities in the field of adaptive control of nonsmooth nonlinear industrial systems by formulating several challenging open problems in related areas

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