Asymptotic tracking by a reinforcement learning-based adaptive critic controller

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Abstract: Adaptive critic (AC) based controllers are typically discrete and/or yield a uniformly ultimately bounded stability result because of the presence of disturbances and unknown approximation errors. A continuous-time AC controller is developed that yields asymptotic tracking of a class of uncertain nonlinear systems with bounded disturbances. The proposed AC-based controller consists of two neural networks (NNs) – an action NN, also called the actor, which approximates the plant dynamics and generates appropriate control actions; and a critic NN, which evaluates the performance of the actor based on some performance index. The reinforcement signal from the critic is used to develop a composite weight tuning law for the action NN based on Lyapunov stability analysis. A recently developed robust feedback technique, robust integral of the sign of the error (RISE), is used in conjunction with the feedforward action neural network to yield a semiglobal asymptotic result. Experimental results are provided that illustrate the performance of the developed controller.

Keywords: Adaptive critic; Reinforcement learning; Neural network-based control

1 Introduction

First used to explain animal behavior and psychology, reinforcement learning (RL) is now a useful computational tool for learning by experience in many engineering applications, such as computer game playing, industrial manufacturing, traffic management, robotics and control, etc. RL involves learning by interacting with the environment, sensing the states, and choosing actions based on these interactions, with the aim of maximizing a numerical reward [1]. Unlike supervised learning where learning is instructional and based on a set of examples of correct input/output behavior, RL is more evaluative and indicates only the measure of goodness of a particular action. Because interaction is done without a teacher, RL is particularly effective in situations where examples of desired behavior are not available but it is possible to evaluate the performance of actions based on some performance criterion.

Actor-critic or adaptive critic (AC) architectures have been proposed as models of RL [1, 2]. In AC-based RL, an actor network learns to select actions based on evaluative feedback from the critic in order to maximize future rewards. Because of the success of neural networks (NNs) as universal approximators [3, 4], they have become a natural choice in AC architectures for approximating unknown plant dynamics and cost functions [5, 6]. Typically, the AC architecture consists of two NNs – an action NN and a critic NN. The critic NN approximates the evaluation function, mapping states to an estimated measure of the value function, while the action NN approximates an optimal control law and generates actions or control signals. Following the works of Werbos [7], Watkins [8], Barto [9] and Sut-

ton [10], current research focuses on the relationship between RL and dynamic programming (DP) [11] methods for solving optimal control problems. Because of the curse of dimensionality associated with using DP, Werbos [12] introduced an alternative approximate dynamic programming (ADP) approach that gives an approximate solution to the DP problem (or the Hamiltonian-Jacobi-Bellman equation for optimal control). A detailed review of AC designs can be found in [13]. Various modifications to ADP-based algorithms have since been proposed [14–16].

The performance of AC-based controllers has been successfully tested on various nonlinear plants with unknown dynamics. Venayagamoorthy et al. used AC for control of turbogenerators, synchronous generators, and power systems [17, 18]. Ferrari and Stengel [19] used a dual heuristic programming (DHP) based AC approach to control a nonlinear simulation of a jet aircraft in the presence of parameter variations and control failures. Jagannathan et al. [20] used ACs for grasping control of a three-finger-gripper. Some other interesting applications are missile control [21], HVAC control [22], and control of distributed parameter systems [23].

The convergence of algorithms for ADP-based RL controllers is studied in [14, 24–27]. Most of this work has been focused on convergence analysis for discrete-time systems. The fact that continuous-time ADP requires knowledge of the system dynamics has hampered the development of continuous-time extensions to ADP-based AC controllers. Recent results in [28–30] have made new inroads by addressing the problem for partially unknown nonlinear systems. However, the inherently iterative nature of the ADP

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Asymptotic Tracking By A Reinforcement Learning Based:

    Robust Adaptive Dynamic Programming Yu Jiang,Zhong-Ping Jiang,2017-04-25 A comprehensive look at state of the art ADP theory and real world applications This book fills a gap in the literature by providing a theoretical framework for integrating techniques from adaptive dynamic programming ADP and modern nonlinear control to address data driven optimal control design challenges arising from both parametric and dynamic uncertainties Traditional model based approaches leave much to be desired when addressing the challenges posed by the ever increasing complexity of real world engineering systems An alternative which has received much interest in recent years are biologically inspired approaches primarily RADP Despite their growing popularity worldwide until now books on ADP have focused nearly exclusively on analysis and design with scant consideration given to how it can be applied to address robustness issues a new challenge arising from dynamic uncertainties encountered in common engineering problems Robust Adaptive Dynamic Programming zeros in on the practical concerns of engineers The authors develop RADP theory from linear systems to partially linear large scale and completely nonlinear systems They provide in depth coverage of state of the art applications in power systems supplemented with numerous real world examples implemented in MATLAB They also explore fascinating reverse engineering topics such how ADP theory can be applied to the study of the human brain and cognition In addition the book Covers the latest developments in RADP theory and applications for solving a range of systems complexity problems Explores multiple real world implementations in power systems with illustrative examples backed up by reusable MATLAB code and Simulink block sets Provides an overview of nonlinear control machine learning and dynamic control Features discussions of novel applications for RADP theory including an entire chapter on how it can be used as a computational mechanism of human movement control Robust Adaptive Dynamic Programming is both a valuable working resource and an intriguing exploration of contemporary ADP theory and applications for practicing engineers and advanced students in systems theory control engineering computer science and applied mathematics *Adaptive Dynamic Programming for Control* Huaguang Zhang,Derong Liu,Yanhong Luo,Ding Wang,2012-12-14 There are many methods of stable controller design for nonlinear systems In seeking to go beyond the minimum requirement of stability Adaptive Dynamic Programming in Discrete Time approaches the challenging topic of optimal control for nonlinear systems using the tools of adaptive dynamic programming ADP The range of systems treated is extensive affine switched singularly perturbed and time delay nonlinear systems are discussed as are the uses of neural networks and techniques of value and policy iteration The text features three main aspects of ADP in which the methods proposed for stabilization and for tracking and games benefit from the incorporation of optimal control methods infinite horizon control for which the difficulty of solving partial differential Hamilton Jacobi Bellman equations directly is overcome and proof provided that the iterative value function updating sequence converges to the infimum of all the value functions obtained by admissible control law sequences finite horizon control implemented in

discrete time nonlinear systems showing the reader how to obtain suboptimal control solutions within a fixed number of control steps and with results more easily applied in real systems than those usually gained from infinite horizon control nonlinear games for which a pair of mixed optimal policies are derived for solving games both when the saddle point does not exist and when it does avoiding the existence conditions of the saddle point Non zero sum games are studied in the context of a single network scheme in which policies are obtained guaranteeing system stability and minimizing the individual performance function yielding a Nash equilibrium In order to make the coverage suitable for the student as well as for the expert reader Adaptive Dynamic Programming in Discrete Time establishes the fundamental theory involved clearly with each chapter devoted to aclearly identifiable control paradigm demonstrates convergence proofs of the ADP algorithms to deepen understanding of the derivation of stability and convergence with the iterative computational methods used and shows how ADP methods can be put to use both in simulation and in real applications This text will be of considerable interest to researchers interested in optimal control and its applications in operations research applied mathematics computational intelligence and engineering Graduate students working in control and operations research will also find the ideas presented here to be a source of powerful methods for furthering their study   Neural Information Processing Sabri Arik,Tingwen Huang,Weng Kin Lai,Qingshan Liu,2015-12-08 The four volume set LNCS 9489 LNCS 9490 LNCS 9491 and LNCS 9492 constitutes the proceedings of the 22nd International Conference on Neural Information Processing ICONIP 2015 held in Istanbul Turkey in November 2015 The 231 full papers presented were carefully reviewed and selected from 375 submissions The 4 volumes represent topical sections containing articles on Learning Algorithms and Classification Systems Artificial Intelligence and Neural Networks Theory Design and Applications Image and Signal Processing and Intelligent Social Networks   International Conference on Security, Surveillance and Artificial Intelligence (ICSSAI-2023) Debasis Chaudhuri,Jan Harm Pretorius,Debashis Das,Sauvik Bal,2024-05-23 The International Conference on Security Surveillance Artificial Intelligence ICSSAI2023 was held in West Bengal India during December 1 2 2023 The conference was organized by the Techno India University one of the renowned universities in the state of West Bengal which is committed for generating disseminating and preserving knowledge   Robot Control 2003 (SYROCO '03) Ignacy Dulęba,Jurek Sasiadek,2004   **Wescon/95** ,1995   International Aerospace Abstracts ,1999   Index to IEEE Publications Institute of Electrical and Electronics Engineers,1998 Issues for 1973 cover the entire IEEE technical literature   China World Bank,1993 The Republic of Korea s industrial policy has directed that nation s economy through nearly three decades of spectacular growth But the authors of this paper maintain that this policy is showing signs of being outmoded The time has come the authors argue for the Korean government to stop managing the economy s structural development and to redefine the responsibilities of business and government Under this proposed compact the allocation of resources would shift from the government to the private industrial and financial sectors The transformation of the government bureaucracy from an ad hoc

policy role to one of a transparent and predictable regulator is a key to the success of this undertaking These new directions would present the government with enormous challenges Greater competitive discipline and regulatory oversight would be required While dealing with the complexities of the transition the government would have to maintain macroeconomic stability and the momentum of savings and investment For comparison the study examines the industrial economies of France Germany Japan and the United States which underwent similar shifts   Government Reports Announcements & Index ,1993   Computer & Control Abstracts ,1996   *Science Abstracts* ,1995   **Index to Theses with Abstracts Accepted for Higher Degrees by the Universities of Great Britain and Ireland and the Council for National Academic Awards** ,2005   **Proceedings of the ... International Joint Conference on Artificial Intelligence** ,2001

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