

# 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 (RISF), 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 Sat-

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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## **Table of Contents Asymptotic Tracking By A Reinforcement Learning Based**

1. Understanding the eBook Asymptotic Tracking By A Reinforcement Learning Based
  - The Rise of Digital Reading Asymptotic Tracking By A Reinforcement Learning Based
  - Advantages of eBooks Over Traditional Books
2. Identifying Asymptotic Tracking By A Reinforcement Learning Based
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Asymptotic Tracking By A Reinforcement Learning Based
  - User-Friendly Interface
4. Exploring eBook Recommendations from Asymptotic Tracking By A Reinforcement Learning Based
  - Personalized Recommendations
  - Asymptotic Tracking By A Reinforcement Learning Based User Reviews and Ratings
  - Asymptotic Tracking By A Reinforcement Learning Based and Bestseller Lists
5. Accessing Asymptotic Tracking By A Reinforcement Learning Based Free and Paid eBooks
  - Asymptotic Tracking By A Reinforcement Learning Based Public Domain eBooks
  - Asymptotic Tracking By A Reinforcement Learning Based eBook Subscription Services
  - Asymptotic Tracking By A Reinforcement Learning Based Budget-Friendly Options
6. Navigating Asymptotic Tracking By A Reinforcement Learning Based eBook Formats

- ePub, PDF, MOBI, and More
  - Asymptotic Tracking By A Reinforcement Learning Based Compatibility with Devices
  - Asymptotic Tracking By A Reinforcement Learning Based Enhanced eBook Features
7. Enhancing Your Reading Experience
    - Adjustable Fonts and Text Sizes of Asymptotic Tracking By A Reinforcement Learning Based
    - Highlighting and Note-Taking Asymptotic Tracking By A Reinforcement Learning Based
    - Interactive Elements Asymptotic Tracking By A Reinforcement Learning Based
  8. Staying Engaged with Asymptotic Tracking By A Reinforcement Learning Based
    - Joining Online Reading Communities
    - Participating in Virtual Book Clubs
    - Following Authors and Publishers Asymptotic Tracking By A Reinforcement Learning Based
  9. Balancing eBooks and Physical Books Asymptotic Tracking By A Reinforcement Learning Based
    - Benefits of a Digital Library
    - Creating a Diverse Reading Collection Asymptotic Tracking By A Reinforcement Learning Based
  10. Overcoming Reading Challenges
    - Dealing with Digital Eye Strain
    - Minimizing Distractions
    - Managing Screen Time
  11. Cultivating a Reading Routine Asymptotic Tracking By A Reinforcement Learning Based
    - Setting Reading Goals Asymptotic Tracking By A Reinforcement Learning Based
    - Carving Out Dedicated Reading Time
  12. Sourcing Reliable Information of Asymptotic Tracking By A Reinforcement Learning Based
    - Fact-Checking eBook Content of Asymptotic Tracking By A Reinforcement Learning Based
    - Distinguishing Credible Sources
  13. Promoting Lifelong Learning
    - Utilizing eBooks for Skill Development
    - Exploring Educational eBooks
  14. Embracing eBook Trends
    - Integration of Multimedia Elements
    - Interactive and Gamified eBooks

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