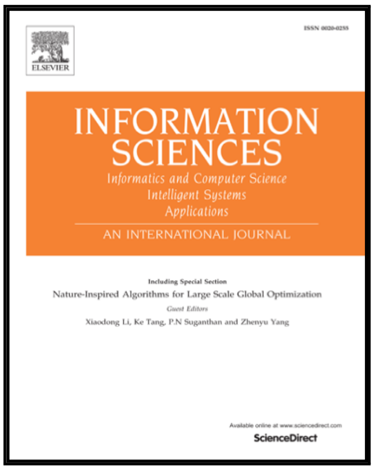


# Output feedback tracking control of a class of continuous-time nonlinear systems via adaptive dynamic programming approach

Yang Yang, Chuang Xu, Dong Yue, Xiangpeng Xie

PII: S0020-0255(18)30566-8
DOI: 10.1016/j.ins.2018.07.047
Reference: INS 13814

To appear in: *Information Sciences*

Received date: 24 July 2016
Revised date: 12 July 2018
Accepted date: 24 July 2018

Please cite this article as: Yang Yang, Chuang Xu, Dong Yue, Xiangpeng Xie, Output feedback tracking control of a class of continuous-time nonlinear systems via adaptive dynamic programming approach, *Information Sciences* (2018), doi: 10.1016/j.ins.2018.07.047

# Output feedback tracking control of a class of continuous-time nonlinear systems via adaptive dynamic programming approach

Yang Yang[a*], Chuang Xu[a], Dong Yue[a,b], Xiangpeng Xie[b]

[a]*College of Automation & College of Artificial Intelligence, Nanjing University of Posts and Telecommunications, Nanjing 210023, PR China*
[b]*Institute of Advanced Technology, Nanjing University of Posts and Telecommunications, Nanjing 210023, PR China*

**Abstract**

In this paper, we propose an output-based tracking control scheme for a class of continuous-time nonlinear systems via the adaptive dynamic programming (ADP) technique. A neural networks (NNs) observer is constructed to reconstruct immeasurable information of the nonlinear systems, and, by introducing a new state vector and appropriate coordinate transformation, tracking control issues are converted into optimal regulation problems where critic-actor neural networks structures are developed for the solution of Hamilton-Jacobi-Bellman (HJB) equation corresponding to tracking errors. In addition, a robust term is introduced to eliminate effects from approximation errors. It is proven that all signals in the closed-loop system are uniformly ultimately bounded (UUB) by the Lyapunov approach. Finally, simulation examples are provided for illustration of the theoretical claims.

*Keywords:* Output Feedback, Adaptive Dynamic Programming, Neural Networks, Nonlinear Systems

## 1. Introduction

The optimal control of continuous-time nonlinear systems is a challenging task that requires solving the nonlinear Hamilton-Jacobi-Bellman (HJB) equation which is actually a nonlinear partial differential equation (PDE) and is usually intractable to solve via analytical methods. To cope with this problem, Bellman [6] developed the dynamic programming (DP) theory, and the drawback of DP was that it was implemented backward-in-time and made the computation untenable along with increasing dimension of nonlinear systems. With the recent development of the neural networks (NNs), the adaptive dynamic programming (ADP) methods [10, 43, 45, 48] were reported to provide approximate solutions of the HJB equation forward-in-time by employing NNs, and then extensive efforts were dedicated to develop this methodology from the cybernetics community [9, 36, 41, 22, 35, 44, 40, 29, 15, 7, 26, 13, 25, 27, 21, 17, 28, 10, 39, 46, 23]. In [34], an ADP strategy was studied for continuous-time nonlinear systems with partially unknown dynamics with the Galerkins approach [5]. In the presence of disturbance inputs, ADP methods in game theory were brought together to solve $H_\infty$ robust control problems for uncertain systems in [2] and [4]. In [26], Mu et al. reported a tracking control approach for a kind of typical second-order continuous-time nonlinear systems using the goal representation heuristic dynamic programming (GrHDP) architecture and integrating a new filter into the action network. Adhyaru et al. [3] transformed the robust control problem to the constrained optimal control problem by selecting a suitable value function for the nominal system. The algorithm in [3] was constructed utilizing the least squares method and performed offline, and the stability analysis of the closed-loop optimal control system was not addressed. Jiang et al. [16] presented a robust ADP algorithm by getting the optimal control solution with the infinite horizon cost for the original uncertain nonlinear systems, and it had an advantage over the algorithm given in [3]. A novel formulation for the optimal tracking control problem was presented in [25] with consideration of the input constraints. A near optimal control policy was reported in [29] using an actor-critic framework and ADP with event sampled state vectors. Dong et al. designed a novel adaptive event-triggered control method for nonlinear discrete-time systems with unknown system dynamics in [9] based on the heuristic dynamic programming (HDP)

*Corresponding author. Email: yyang@njupt.edu.cn, Tel: +86 18951088267.