Haiyun ZHANG, Deyuan MENG, Jin WANG, Guodong LU, 2021. Indirect adaptive fuzzy-regulated optimal control for unknown continuous-time nonlinear systems. *Frontiers of Information Technology & Electronic Engineering*, 22(2):155-169. https://doi.org/10.1631/FITEE.1900610

Indirect adaptive fuzzy-regulated optimal control for unknown continuous-time nonlinear systems

Key words: Indirect adaptive optimal control; Hamilton-Jacobi-Bellman equation; Fuzzy-regulated critic; Adaptive optimal control actor; Actor-critic structure; Unknown nonlinear systems

Corresponding author: Jin WANG
E-mail: dwjcom@zju.edu.cn
ORCID: https://orcid.org/0000-0003-3106-021X

Motivation

1. In the optimal control framework, Bellman's optimality principle and the Hamilton-Jacobi-Bellman (HJB) equation play the most important roles in finding solutions subject to various dynamics and constraints.
2. For unknown nonlinear systems with uncertain dynamics, mismatches, and disturbances, where the optimal problem is governed by the nonlinear HJB equation, the adaptive dynamic programming (ADP) solution has turned out to be much more computationally complex and difficult.
3. Recently adaptive fuzzy control has likewise become a productive research field for unknown nonlinear systems because of the powerful modeling and approximating capacities of fuzzy logic systems (FLSs).

Main idea

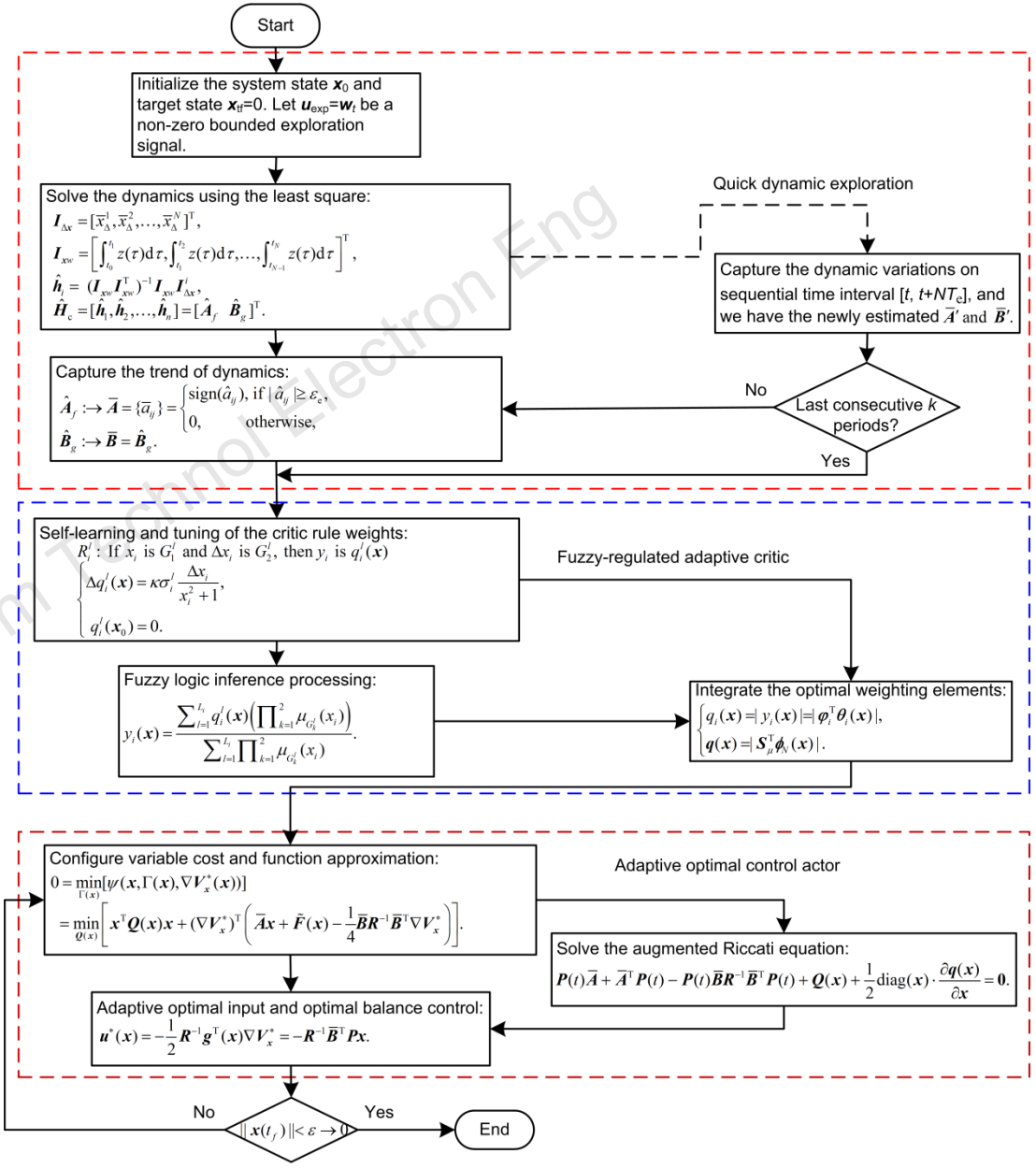
1. Implemented in an adaptive actor-critic architecture, our methodology is extended to an alternative pattern of using the HJB equation aiming to approximate the optimal balancing control solution subject to optimal control cost and system dynamics in a Lyapunov sense.
2. Different from previous work, this method effectively yields an indirect adaptive optimal balancing control scheme, which finds the adaptive approximation and balance between the optimal cost and optimal control policy in real time, while guaranteeing closed-loop stability.

Method

1. Within the actor-critic framework, the interest of this study is to find a new adaptive optimal control method to manipulate and use the HJB function arising in the uncertain nonlinear circumstance.
2. Considering the unknown and unpredictable nonlinear characteristics of the controlled system, we introduce a new self-learning fuzzy logic critic structure for the regulation and adaptation of the performance function $\Gamma(\boldsymbol{x})$ to approximately balance and minimize the HJB value function $\boldsymbol{\psi}(\boldsymbol{x})$.
3. According to Bellman's principle, the performance function (index) $\Gamma(\boldsymbol{x})$ stands for the optimal strategy, and its adaptation correspondingly adjusts and alters the structure and performance of the optimal control policy $\boldsymbol{u}^*(\boldsymbol{x})$ for the adaptive control actor.

Major results

The proposed indirect adaptive fuzzy-regulated optimal control (IAFOC) scheme



Major results (Cont'd)

1. Test results of our IAFOC and ADP methods in case 1

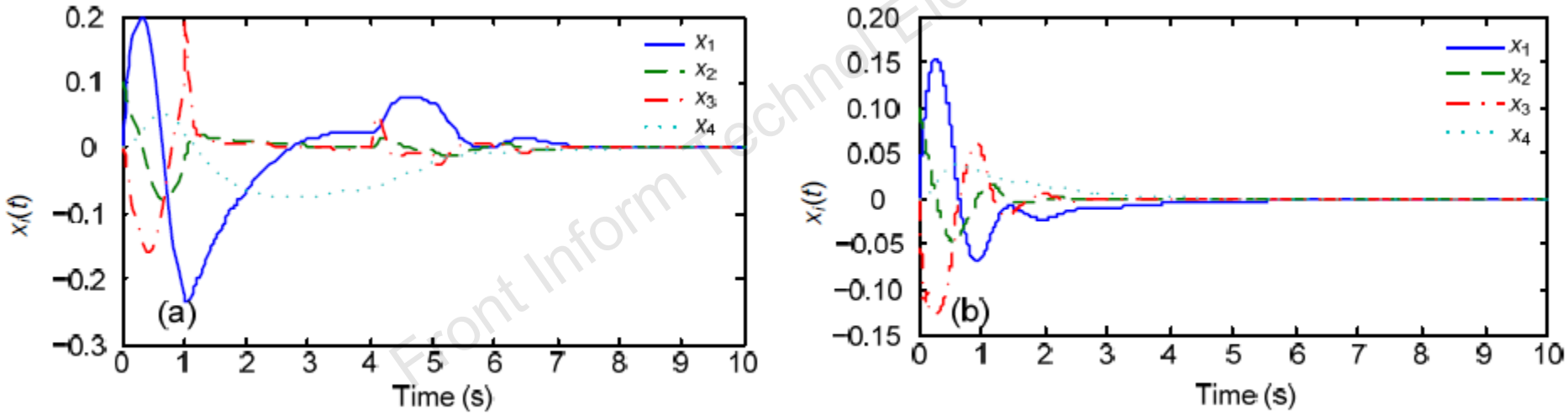


Fig. 3 Power system responses of ADP (a) and IAFOC (b) in case 1

Major results (Cont'd)

2. Test results of our IAFOC and ADP methods in case 2

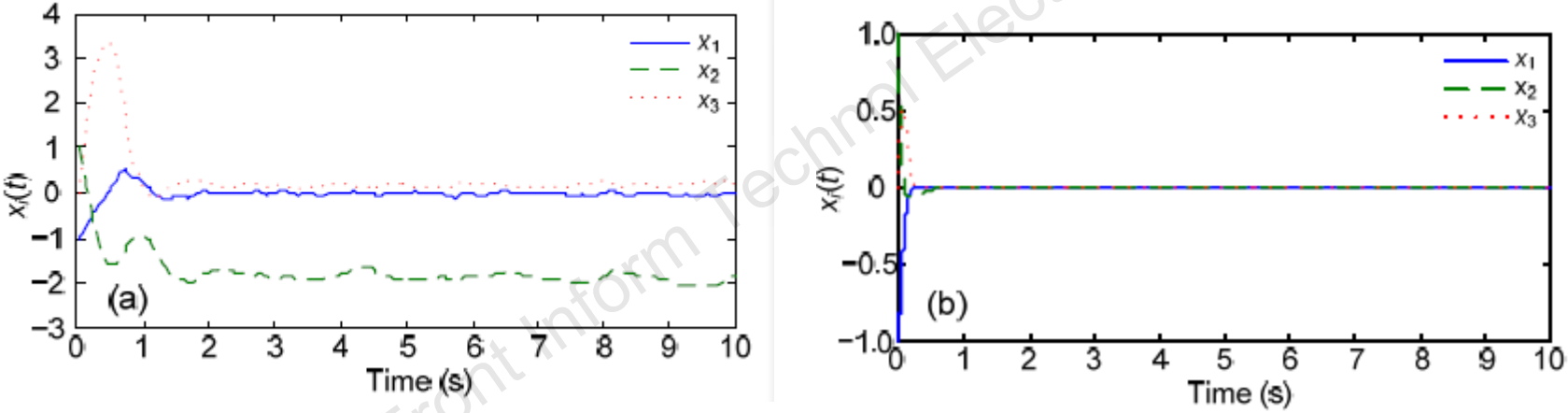
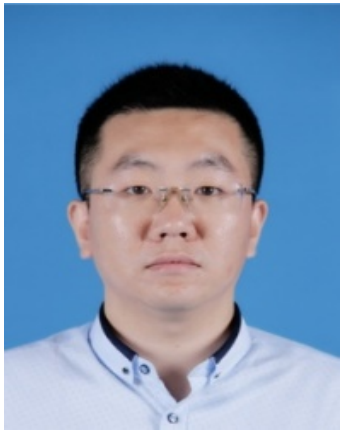


Fig. 6 Chua's circuit responses of ADP (a) and IAFOC (b) in case 2

Conclusions

1. Without iteratively solving the HJB equation, a novel indirect adaptation methodology of approximately minimizing and balancing the nonlinear HJB equation has been proposed for the first time using the actor-critic architecture in the proposed scheme.
2. Using a fuzzy-regulated performance function as reinforcement medium, the supervisory adaptive critic associated with the self-organizing weight learning law ensured online approximation and simultaneous adjustment of both the optimal cost and the optimal control policy.
3. For the control actor, an adaptive optimal feedback controller has been constructed with a new augmented Riccati governing equation, and fast and stable convergence of nonlinear system states and parameters have been achieved autonomously under diverse conditions.



Haiyun ZHANG received his BS and DS degrees from College of Mechanical Engineering of Zhejiang University, Hangzhou, China, in 2009 and 2014, respectively. He is currently a postdoctor at the Robotics Institute of Zhejiang University. His research interests include robotics, mechatronic systems and control, optimal control and optimality methods, and adaptive theory and applications. His research has received the support of the National Natural Science Foundation of China, the Natural Science Foundation of Jiangsu Province, China, and the China Postdoctoral Science Foundation.

Deyuan MENG received his BS and MS degrees from China University of Mining and Technology, Xuzhou, China, in 2003 and 2006, respectively, and his PhD degree from Mechatronic Control Engineering from Zhejiang University, Hangzhou, China, in 2013. He is currently an associate professor with the Department of Mechatronic Engineering, China University of Mining and Technology, China. His research interests include servo control of pneumatic systems, adaptive and robust control, and MRI-compatible robots.

Jin WANG is currently an associate professor at the College of Mechanical Engineering, Zhejiang University, China. He received his BS and PhD degrees in mechanical engineering of Zhejiang University, China, in 2003 and 2008, respectively. His research interests include design automation and optimization, industrial robotic offline planning, industrial robot intelligent control, and multi-robot coordinated control and application.

Guodong LU is currently a professor at the College of Mechanical Engineering, Zhejiang University, China. He is a deputy director of the Engineering and Computer Graphics Institute at Zhejiang University. He received his BS, MS, and PhD degrees from Zhejiang University in 1983, 1990, and 2000, respectively. His research interests include CAD/CAM, robotic offline planning, and robotics technology and application.