Yan WEI, Mingshuang HAO, Xinyi YU, Linlin OU, 2024. Asymmetric time-varying integral barrier Lyapunov function based adaptive optimal control for nonlinear systems with dynamic state constraints. *Frontiers of Information Technology & Electronic Engineering,* 25(6):887-902. https://doi.org/10.1631/FITEE.2300675

Asymmetric time-varying integral barrier Lyapunov function based adaptive optimal control for nonlinear systems with dynamic state constraints

Key words: State constraints; Asymmetric time-varying integral barrier Lyapunov function (ATIBLF); Adaptive optimal control; Nonlinear systems

Corresponding author: Linlin OU
E-mail: linlinou@zjut.edu.cn
ORCID: https://orcid.org/0000-0002-8589-9961

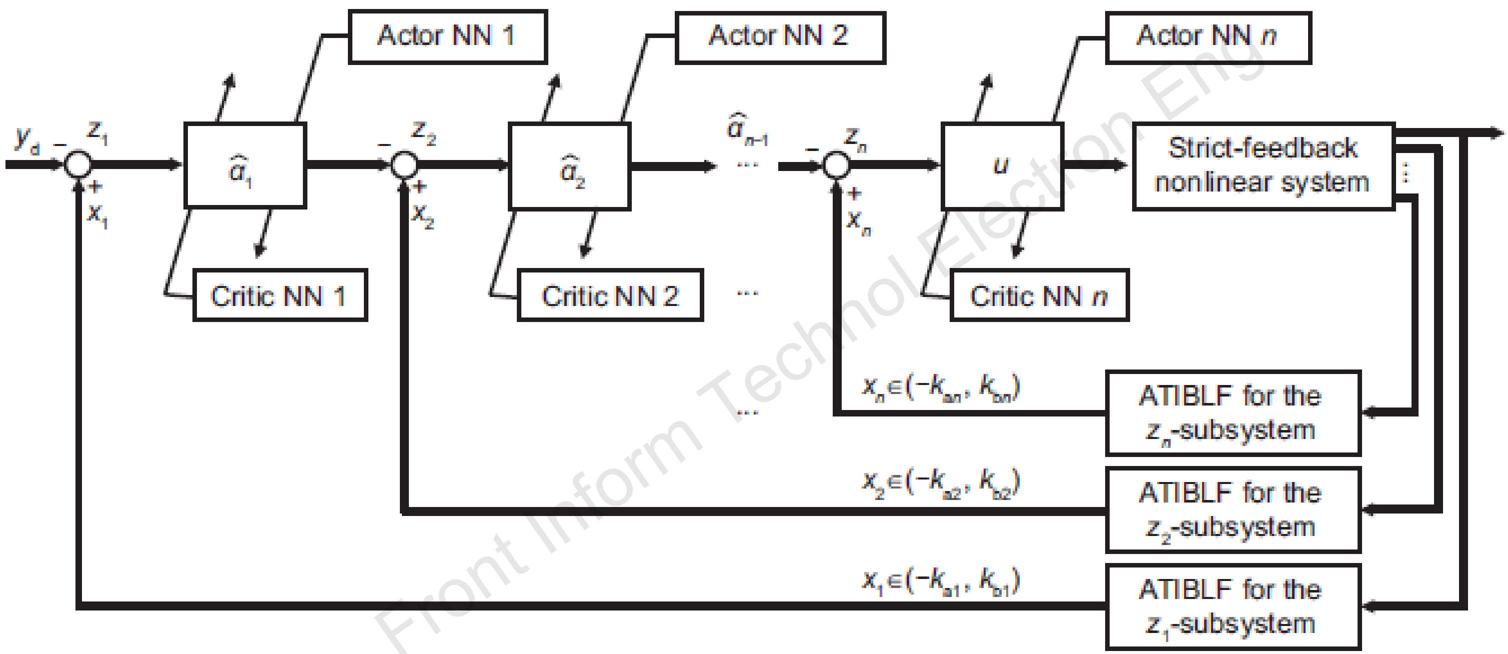
Motivation

1. Under the optimal performance requirements, the optimal tracking control problem of nonlinear systems with dynamic constraints has not been studied.
2. It is important for nonlinear systems, like autonomous vehicles and robots which are required to perform complex and variable tasks, to have safe control performance in complex obstacle scenarios, as this can improve their utility while preventing injuries to operators or damage to equipment.

Main idea

1. An ATIBLF-based adaptive optimal tracking control scheme for strict-feedback nonlinear systems is first proposed. In contrast with existing BLF-based studies, the proposed method can handle dynamic state constraints directly without error transformation, and the feasible region of the initial state value can be expanded.
2. Different from existing traditional ATIBLF-based studies, the ATIBLF items are appropriately arranged in every step of the optimized backstepping control design. The integral-type barrier optimal cost functions are first constructed for subsystems. Under the actor–critic framework, the ATIBLF-based optimal virtual and actual controllers are presented.

Framework



In each step, a learning algorithm is implemented via an actor–critic network architecture, which is used to construct adaptive laws. The ATIBLF items are appropriately arranged in every subsystem of the optimized backstepping control design to ensure that all states do not violate the dynamic constraints.

Method

1. The ATIBLF items are appropriately arranged in every step of the optimized backstepping control design to ensure that the dynamic full-state constraints are never violated.

2. Optimal virtual/actual control in every backstepping subsystem is decomposed with ATIBLF items and also with an adaptive optimized item, and neural networks are used to approximate the gradient value functions.

3. According to the Lyapunov stability theorem, the boundedness of all signals of the closed-loop system is proved, and the effectiveness of the proposed control approach is validated by simulations.

Conclusions

In this paper, an ATIBLF-based adaptive optimal control scheme for a class of strict-feedback nonlinear systems with dynamic state constraints was proposed. The controller was designed under the optimal learning algorithm. Specifically, novel integral barrier optimal performance index functions and the actor–critic framework were employed in the controller design. Subsequently, the stability of the closed-loop system was proven via the Lyapunov stability theorem. Simulation results showed that dynamic state constraints are not violated, and that all signals of the closed-loop system remain bounded. Future work will focus on the adaptive optimal control problems for physical human–robot interaction systems with dynamic state constraints.

Yan WEI received the Ph.D. degree in aeronautical and astronautical science and technology from Shanghai Jiao Tong University, Shanghai, China, in 2021. He is currently a Lecturer with the College of Information Engineering, Zhejiang University of Technology, Hangzhou, China. His current research interests include adaptive learning control, robotics, and human–robot interaction.

Mingshuang HAO received the B.S. degree in electrical engineering and automation from Shandong Jianzhu University, Jinan, China, in 2021. He is currently pursuing the M.S. degree in control science and engineering from Zhejiang University of Technology in Hangzhou, China. His current research interests include nonlinear adaptive control, state constraints, optimal control, and robot-physical systems.

Xinyi YU received the Ph.D. degree in mechanical design and theory from the Harbin Institute of Technology, Harbin, China, in 2009. He is currently an Associate Professor with the College of Information Engineering, Zhejiang University of Technology, Hangzhou, China. His research interests include robotics and automation, especially the development and industrialization of industrial robots.

Linlin OU received the Ph.D. degree in control theory and engineering from Shanghai Jiao Tong University, Shanghai, China, in 2006. She is currently a Professor with the College of Information Engineering, Zhejiang University of Technology, Hangzhou, China. Her research interests include robot control and cooperative control.