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Practical fixed-time adaptive fuzzy control of uncertain nonlinear systems with time-varying asymmetric constraints: a unified barrier function based approach

Key words: Unified barrier function; Time-varying asymmetric state constraints; Fuzzy logic systems; Fixed-time control; Command filter

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Motivation

- A widely used method for solving a state constrained problem is the barrier Lyapunov function method. However, this type of method works only if one finds a set of parameters satisfying special conditions, which results in a huge design difficulty. How to solve the state constraint problem is always a hot topic in the control field.

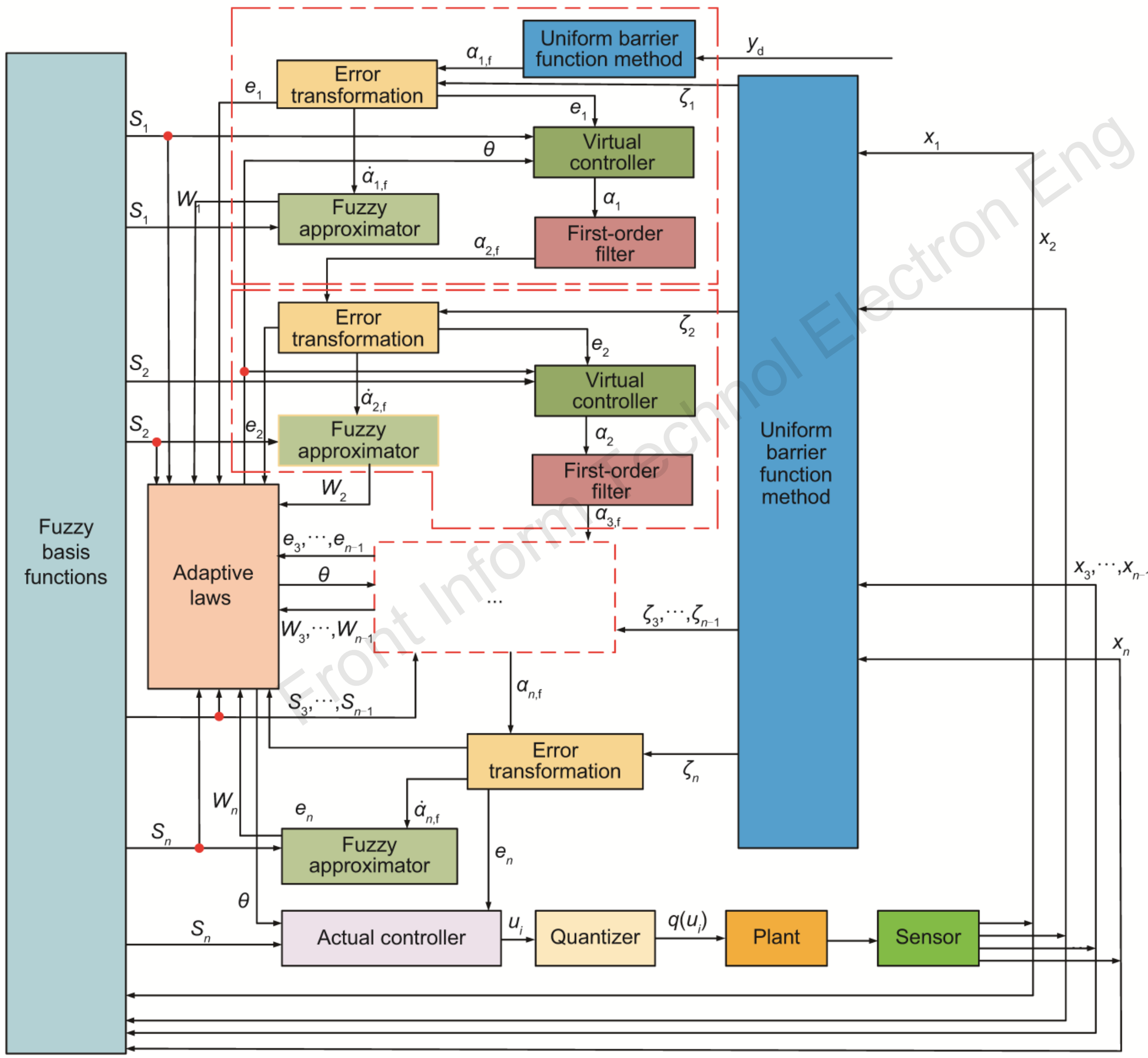
- Most control schemes are proposed under the framework of asymptotic stability; namely, they can guarantee the system to be stable only when time tends to infinity. In practical engineering, however, the system is generally required to reach stability in a finite time. How to improve the convergence speed of the system is also a research hotspot.

- Due to physical constraints, communication resources in the system are generally limited. If communication resources are not considered in the design process of the controller, there will be loss of valid information, resulting in damage to the system.

Main idea

- By modifying the structure of the virtual control signal, the actual control signal, and the adaptive law (adding two exponential terms), so that the form of the finally constructed Lyapunov function satisfies the practical fixed-time stability condition, the control system can achieve stability in a fixed time.
- A new unified barrier function method is used to overcome the difficulties caused by state constraints for designing controllers. This method constructs an unconstrained system model of the original constrained system, so that the restrictions on system states are relaxed and the feasibility conditions of virtual control signals are completely eliminated.
- A modified hysteretic quantizer is constructed to save communication resources, and it has extra quantization levels to alleviate the high-frequency chatter.

Framework



Closed-loop control structure of the controlled system

Method

1. A uniform barrier function method is used to solve the state constraint problem. In this method, an unconstrained auxiliary variable is constructed by combining the system state and its constraint function, and then an unconstrained system model is obtained, eliminating the difficulties caused by state constraints on the controller design process and removing the feasibility conditions for virtual control signals.

$$\begin{cases} \dot{x}_i = x_{i+1} + f_i(\bar{x}_n), \\ \dot{x}_n = g(\bar{x}_n) q(u) + f_n(\bar{x}_n), \\ y = x_1, \qquad i = 1, \ldots, n-1, \end{cases}$$

Original constrained system

$$\zeta_i = \frac{x_i - \bar{k}_{il}}{x_i - k_{il}(t)} + \frac{x_i - \underline{k}_{ih}}{k_{ih}(t) - x_i}$$

$$\begin{cases} \dot{\zeta}_i = \eta_{i,1}\left(f_i(\bar{x}_n) + \frac{\zeta_{i+1}}{\zeta_{i+1,1}} - \zeta_{i+1,3}\right) + \eta_{i,2}, \\ \dot{\zeta}_n = \eta_{n,1}\left(f_n(\bar{x}_n) + g q(u)\right) + \eta_{n,2}, \end{cases}$$

Unconstrained system

Method

2. By adding two exponential terms to the virtual controller, the actual controller, and the adaptive law, the final constructed Lyapunov function satisfies the practical fixed-time stability theory. Then the control system can achieve stability in a fixed time, and an upper bound of settling time of the system can be calculated.

Discriminant equation for practical fixed-time stabilization:

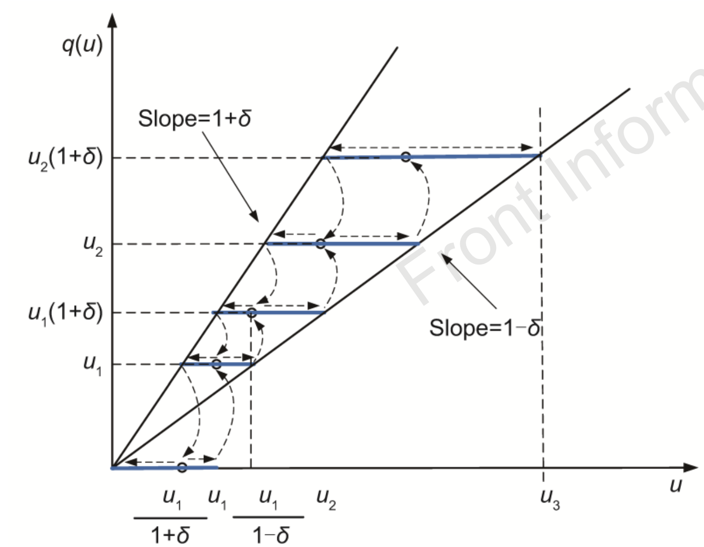
$$\dot{V}(x) \le -c_1 V^p(x) - c_2 V^q(x) + b$$

Calculation formula for the upper bound of the settling time:

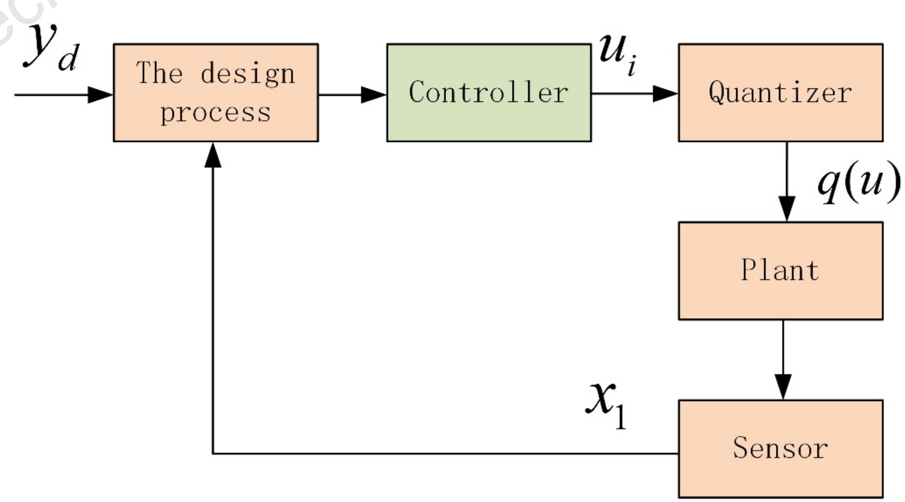
$$T \le T_m = \frac{1}{\xi c_1 (1-p)} + \frac{1}{\xi c_2 (q-1)}$$

Method

3. Considering the limited communication resources of the system, a modified hysteresis quantizer is introduced between the controller and the actuator to quantize the control signals, which reduces the communication resources of the system and the high-frequency chatter.



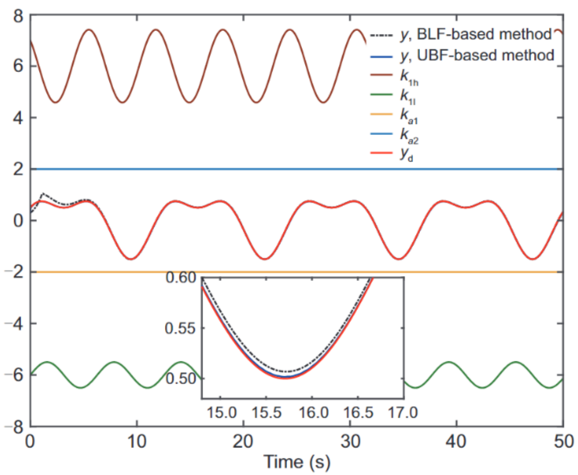
Map of the hysteresis quantizer

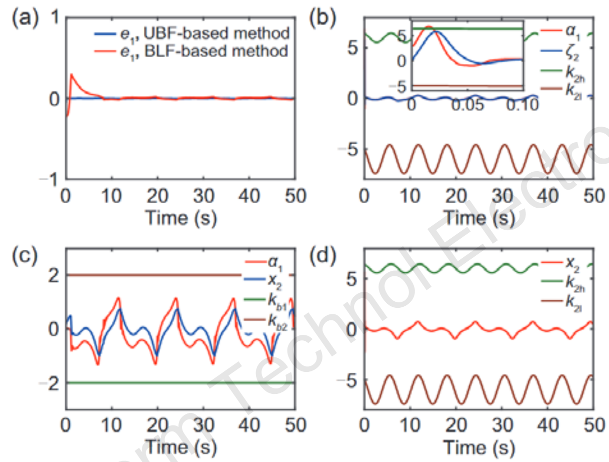


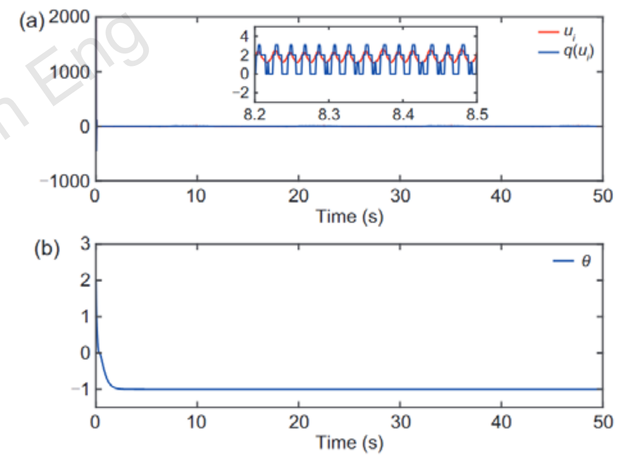
Position of the quantizer

Major results

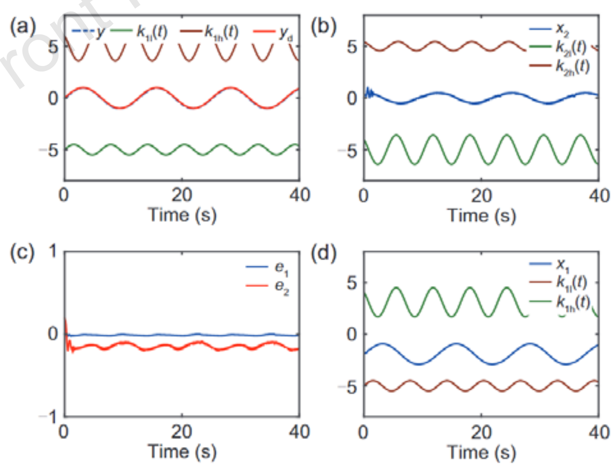
Simulation of a numerical example

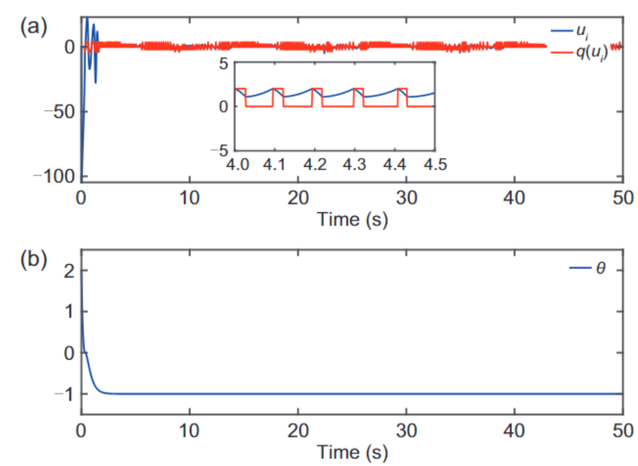






Simulation of a practical example





Conclusions

- By applying the unified barrier function method, the state constraint problem of the system is solved, and the system state does not violate the state constraints during the system operation. Compared to the traditional barrier Lyapunov function method, the feasibility condition of the virtual control signal is removed and the difficulty of the design is reduced.
- By using the practical fixed-time stability theory, the system can achieve stability in a fixed time, and the upper bound of the setting time can be computed. It can be verified from numerical simulation.

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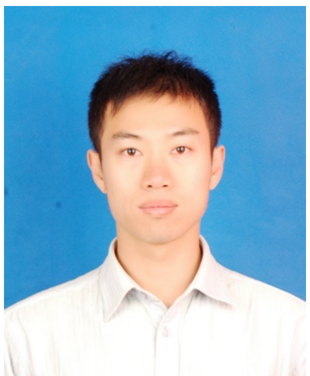

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