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Prescribed-time Adaptive Fuzzy Tracking Control Of UAV Swarms Under Deception Attack

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Abstract. In addressing the tracking control problem for unmanned aerial vehicle (UAV) swarms, we consider several challenges: the unmeasurable state of the swarm system, potential deception attacks on actuators, external random disturbances, and the nonlinear dynamics of each UAV. To tackle these issues, we first introduce a time-varying function and utilize a coordinate transformation method to convert the time tracking problem into an error variable constraint problem. Next, we propose an adaptive time tracking control method employing one-to-one mapping and inversion techniques, aimed at achieving system convergence to a specified accuracy within a designated time frame. To mitigate the impact of possible deception attacks on actuators, we design an attack compensator that removes disturbances caused by time-varying attack gains. Additionally, we implement an observer to estimate the unmeasurable state of the system and utilize a fuzzy logic system to manage unknown functions. Finally, we validate the effectiveness of our control method through simulations.

AMS subject classifications: 93D15, 93C10

Key words: UAV swarm control, Deception attack, Prescribed-time control, Fuzzy logic system.

1 Introduction

With the rapid development of unmanned air vehicle technology, the application of UAV swarms has become increasingly widespread in fields such as military, agriculture, and logistics. However, the complexity and diversity of UAV swarm systems have led to significant control issues, which are increasingly important and challenging to address. The

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utilization of trajectory tracking technology enables multiple UAVs to commence their journey from a variety of arbitrary initial positions and subsequently maintain the desired trajectory motion. This technology has already achieved significant results [1, 2] in practical systems. However, due to various disturbances in the external environment, there are inevitably uncertain parts in the modeling of (unmanned aerial vehicle)UAVs. Swarm control methods are constrained by nonlinear systems, requiring the internal nonlinear dynamics of the system to be known. Currently, a plethora of solutions exists, among which neural networks and fuzzy logic systems (FLS) [3, 4] are efficacious instruments for the management of the unknown and uncertain components of the controlled system. For example, in [5], an adaptive neural control method was designed for UAV formation. Nevertheless, in the majority of practical systems, the state of the controlled UAVs cannot be directly measured. Furthermore, the high costs associated with obtaining this data during the control design process render it impractical. Therefore, for nonlinear systems with unmeasurable states, appropriate fuzzy network state observers are employed. These observers are used to propose an observer-based leader-follower consensus controller [6]. The aforementioned control scheme only considers deterministic nonlinear systems. Due to the extreme complexity of the actual environment, additional consideration of stochastic disturbances brought by the environment is necessary.

It is well-known that stochastic disturbances can destabilize the entire system. Consequently, there has been a notable increase in the focus on the design of controllers for stochastic nonlinear systems. Wu et al. [7, 8] respectively studied the adaptive control of stochastic nonlinear systems with measurable and unmeasurable states. Subsequently, Ren et al. [9] further considered fuzzy leader-follower control based on local information.

Compared to traditional control systems, UAVs need to operate in network environments, where most of their data is susceptible to various types of cyber-attacks, such as stochastic attacks [10], denial-of-service (DoS) attacks [11], and deception attacks [12]. Once the system is attacked, it becomes difficult to transmit signals completely. Therefore, the cybersecurity of UAV systems is an important research topic. This paper focuses on deception attacks, which primarily aim to intercept the signals of the system's actuators and inject false signals [13], thereby destabilizing the system. In their study, Han et al. [14] devised a consensus control scheme on the premise that the probability of deception attacks was a constant, known quantity. In addition, Han et al. [15] considered the case where deception attacks are multiplicative gains. Subsequently, it was proposed that a leaderless consensus controller be employed under direct communication conditions, with the objective of ensuring that all closed-loop signals are bounded. To mitigate attacks on the actuator channels, Jin et al. [16] designed an adaptive control method for linear systems.

In addition to considering abnormal factors in the system (such as stochastic disturbances and deception attacks), the convergence speed of the system is also an important criterion in the design of controllers. Bhat and Bernstein [17] proposed a finite-time control method, which has stronger anti-disturbance capability and better robustness compared to asymptotic convergence controllers. Min et al. [18] studied the trajectory tracking prob-