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GUEST EDITORIAL

Guest editorial: Resilient fuzzy control synthesis of non-linear networked systems against various cyber-attacks

In recent years, there has been a growing interest in non-linear networked systems. They have a wide range of applications, many of which are security-critical. This has triggered a great deal of interest in non-linear network systems where attacks exist, bringing the issue of network security into control theory.

Fuzzy control theory transforms the handling of non-linear network systems under attack, addressing security issues like spoofing and DoS attacks. It enhances resource utilization efficiency through resilient triggering mechanisms suited for frequency/duration-limited attacks. As a rule-based approach using linguistic control rules, it operates on potentially erroneous data without needing an exact mathematical model, simplifying design and application. This special issue focuses on research ideas, articles, and experimental studies related to "Resilient fuzzy control synthesis of non-linear networked systems against various cyber-attacks" in order to learn, analyse, and predict the application of fuzzy control theory in non-linear networked systems against cyber-attacks by deep learning.

In this special issue, the final 17 accepted papers have been peer-reviewed. These papers can be categorized into three main groups, and the following is a brief description of each paper in this special issue.

1 | TOPIC A: CONTROL AND SECURITY OF INFORMATION PHYSICAL SYSTEMS

Arunagirinathan et al., in their paper 'Robust T-S fuzzy-model-based non-fragile sampled-data control for cyber-physical systems with stochastic delay and cyber-attacks', proposed a non-vulnerable sampled-data control strategy based on the Takagi-Sugeno fuzzy model for cyber-physical systems under cyber-attack. A T-S fuzzy system with augmented state vectors is designed by using random variables conforming to the Bernoulli distribution to characterize random delays and attack effects in data transmission. A new stability criterion is developed by utilizing the fractional delayed state looped functional method, and its effectiveness against periodic and non-periodic attacks is verified in simulations. The study also demonstrates its superiority over existing methods through three numerical models.

Guo et al., in their paper 'Resilient control design for large-scale networked control systems under denial-of-service attacks', explore the exponential stability of large-scale networked control systems under denial-of-service attacks and design a resilient state feedback controller. The prediction-based controller is used to compensate for large input delays within the system to improve system performance, and a stability criterion for large-scale networked control systems under denial-of-service attacks is obtained. In addition, a criterion based on linear matrix inequalities is proposed for designing a controller against denial-of-service attacks and the effectiveness of the proposed method is verified by an interconnected power system in two regions.

Sun et al., in their paper 'Event-based reduced-order H_∞ estimation for switched complex networks based on T-S fuzzy model', propose a memory-based adaptive trigger mechanism that utilizes the T-S fuzzy model to decompose a non-linear complex network into a set of linear components, which provides a sufficient condition for estimating the exponential stability of the error system under the given constraints. In addition, the study combines an event-triggered communication scheme with a fuzzy reduced-order filter to design a memory-type adaptive event-triggered scheme to provide adaptive functionality and thus reduce the utilization of limited network resources. Numerical simulation results show that the step-down system is effective in practice.

Zhu et al., in their paper 'Fuzzy functional observer-based sliding mode control for T-S fuzzy cyber-physical systems subject to disturbances and deception attacks', explore a fuzzy functional observer-based sliding mode control for T-S fuzzy cyber-physical systems has been investigated. The attack is modelled as an unknown non-linear exogenous system. A fuzzy learning functional observer is designed to estimate unavailable states, attacks, and disturbances, using fuzzy logic to learn unknown non-linearities and ensure accuracy. A fuzzy sliding mode controller is then developed for robust compensation against attacks and disturbances. Sufficient conditions ensure exponential convergence of the closed-loop system. Simulations verify the effectiveness of the algorithm.

Liu et al., in their paper 'Event-based dynamic output feedback control of fuzzy systems against DoS attacks', explore event-triggered dynamic output feedback control for fuzzy

systems against denial-of-service (DoS) attacks. A robust framework is developed to consider random DoS attacks and actuator failures to enhance the resilience of the controller, and a probabilistic event-triggered protocol with uncertain probability is introduced to reduce network communication overhead. In addition, a dual-asynchronous dynamic output feedback controller is designed by considering the potential mismatches between premise variables and modes in fuzzy system and controller, and the effectiveness of the proposed approach is verified through comprehensive numerical examples, emphasizing its effectiveness in handling asynchronous control scenarios and resilience to DoS attacks in fuzzy systems.

2 | TOPIC B: RESILIENT FUZZY CONTROL AND ADAPTIVE CONTROL

Liu et al., in their paper 'Adaptive fuzzy fault-tolerant control for cooperative output regulation with unknown non-linear disturbances and actuator faults', propose an adaptive fuzzy fault-tolerant controller that utilizes a fuzzy logic system to approximate unknown non-linear disturbances. The controller not only can successfully handle actuator failures and effectively track references in the presence of unknown non-linear disturbances but also has superior convergence speed and tracking performance.

Lu et al., in their paper 'Finite-time adaptive fuzzy tracking control for high-order non-linear time-delay systems with dead-zone', explore the adaptive fuzzy finite-time tracking control problem by introducing a fuzzy logic system to approximate the uncertain non-linear function in the system, which allows the tracking error to converge to a small neighbourhood near the origin in finite time. Experimental results show that the control scheme is effective.

Gong et al., in their paper 'Leaky echo state network based on methane topology applied to time series prediction', propose an echo state network model called F-ESN based on methane topology, which changes the connection pattern of neurons in the initial reservoir layer, not only improving the transmission efficiency of neurons but also increasing the stability of the system structure. In addition, the MFO with adaptive dynamic operator optimization is also used to optimize three parameters of the ESN. The effectiveness of the proposed method is verified by simulating the low-frequency SIN time series, the high-frequency SIN time series, and the MG time series, and the methane topology can further improve the prediction accuracy of the leaky echo state network.

Lun et al., in their paper 'A long-term memory enhanced echo state network and its optimization', propose a novel and improved leaky integral echo state network (Leaky-ESN) model called long-term memory enhanced echo state network (LTME-ESN), the basic concept of which is to update the states of neurons in the repository by integrating the input gate and forget gate concepts of LSTM into the echo state network. Low-frequency sinusoidal, high-frequency sinusoidal time and chaotic time series were used to evaluate the effectiveness of the Leaky-ESN model. According to all the results of the simulation experiments, the LTME-ESN model exhibits better prediction accuracy and lower volatility.

Pan et al., in their paper 'Optimal frequency fault-tolerant control of virtual synchronous generator based on adaptive dynamic programming with fuzzy critic estimator', propose a frequency fault-tolerant control method in the distributed generation system utilizing adaptive dynamic programming combined with fuzzy critic estimation, which combines adaptive dynamic programming and fuzzy comprehensive evaluation to achieve optimal control performance in the presence of actuator faults. The highly coupled non-linear Hamilton–Jacobi–Bellman equation is solved efficiently by using an adaptive dynamic planning method based on fuzzy critic estimation, which ensures the state convergence and uniform limit boundedness of the system. Simulation results verify the effectiveness of the proposed optimal control method and demonstrate its ability to maintain finite frequency error even in the presence of faults.

Jiang et al., in their paper 'Design of fuzzy sliding mode controller for islanded AC/DC hybrid microgrid with cyber-attacks', propose a T-S fuzzy system control method combining sliding mode control and fuzzy logic control under an islanded AC/DC hybrid microgrid. To facilitate the controller design process, the T-S fuzzy system is proposed to approximate the original non-linear dynamic model of the AC/DC hybrid microgrid with high accuracy. To reduce the influence of external disturbance and cyber-attacks, an integral sliding mode controller is considered. In addition, to eliminate the chattering performance of the sliding mode control theory, a fuzzy logic controller is designed to optimize the switching region in the boundary layer of the saturation function. The robustness and effectiveness of the designed fuzzy sliding mode control method are verified based on the microgrid system state response simulation results.

Lun et al., in their paper 'Fixed-time adaptive tracking control for MIMO non-linear system with input delay saturation based on echo state network', propose a fixed-time adaptive tracking control based on echo state networks for a multi-input multi-output non-linear strict-feedback system with input delayed saturation. Based on the feature that echoes state networks can obtain better estimation performance at lower computational cost, the unknown non-linear function is approximated during the controller design process. The time-delay system with input saturation is eliminated by constructing an auxiliary system. The closed-loop system is proved to be semi-globally practical and fixed-time stabilized by simulation, and the proposed scheme is effective.

3 | TOPIC C: NON-LINEAR MULTI-AGENT SYSTEMS AND ENERGY SECURITY MANAGEMENT

Visakamoorthi et al., in their paper 'Reachable set estimation and H_∞ performance for delayed fuzzy multi-agent systems under false data injection attacks', investigate the reachable set estimation (RSE) problem for fuzzy-model-based leader-follower multi-agent systems (MASs) that are subject to

time-varying delays and false data injection (FDI) attacks. Both leader and follower agents are assumed to have time-varying delays and randomly occurring false data attacks are considered in the proposed sampled data controller for follower agents. New stability and reachable set boundary conditions are implemented in the form of linear matrix inequalities (LMIs) based on Lyapunov theory, Kronecker product, and cyclic generalized information. Control parameters and desired performance metrics are obtained by solving matrix inequalities.

Miao et al., in their paper 'Tangent barrier Lyapunov function based adaptive event-triggered control for CPS under false data injection attacks', present an adaptive event-triggered control scheme for a class of continuous-time linear cyber-physical systems (CPS) with unknown false data injection attacks (FDIA) and state constraints. A two-step backstepping control, an adaptive boundary estimation mechanism, and a Nussbaum-type function are combined to deal with FDIA on sensors and actuators. The tangent barrier Lyapunov function (TBLF) is used while state constraints are imposed, and communication limitations are overcome by designing an event-triggered mechanism (ETM). Simulation results validate its effectiveness.

Dai et al., in their paper 'Fuzzy high order differentiator observer based resilient control for distributed battery energy storage systems against unbounded FDI attacks', propose a fuzzy high order differentiator (FHOD) observer for distributed resilient control in distributed battery energy storage systems (BESSs), addressing frequency recovery and the balancing of the state of charge (SOC) after secondary control inputs have been subjected to false data injection attacks (FDI). The FHOD mitigates performance issues from traditional sliding mode observers by using fuzzy logic to optimize differentiator coefficients, reducing transient overshoot during attack signal changes for improved response and accuracy. Simulations show the strategy's effectiveness against FDI attacks and superior transient performance over standard HOD observers.

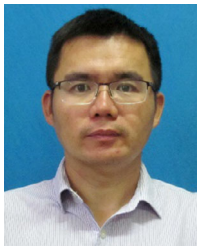
Wang et al., in their paper 'Smart meter privacy control strategy based on multi-agent hidden Markov energy management model under low trust communication', present a multi-agent hidden Markov model for energy management to enhance consumer privacy. It features a Bayesian risk model accounting for privacy and ESS losses, coupled with a lithium battery model to evaluate ESS degradation. The approach, integrating a Bayesian-hidden Markov simulation of attackers, is validated using the ECO dataset, demonstrating that it can prolong the ESS lifespan by factoring in multi-agent strategies and ESS degradation.

Liu et al., in their paper 'Event-triggered adaptive fuzzy bipartite containment control for switched non-linear multi-agent systems with actuator attacks', investigate a switched non-linear multi-agent systems (MASs) with actuator attacks and propose an event-triggered adaptive fuzzy bipartite containment control strategy. Fuzzy logic systems (FLSs) are applied to approximate the unknown non-linear functions, and an adaptive bipartite containment control approach is designed to deal with the actuator attacks and reduce the communication burden. The adaptive bipartite containment control scheme ensures all signals are semi-globally uniformly ultimately bounded, with followers reaching bipartite consensus and aligning with leaders' convex set despite actuator attacks. A simulation example confirms the strategy's effectiveness.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

GUEST EDITOR BIOGRAPHIES



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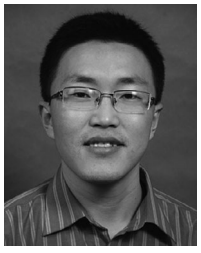

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