Distributed Adaptive Output Synchronization of Nonlinear Multi-Agent Systems Under DoS Attacks and Disturbance

Yancheng Yan
School of Automation Engineering
University of Electronic Science and Technology of China
Chengdu 611731, China
yanchyan@126.com

***Abstract*—In this study, we explore the issue of output synchronization for a class of state-constrained nonlinear multi-agent systems (MASs) influenced by exogenous disturbances and subjected to denial-of-service (DoS) attacks originating in the sensor-controller (S-C) channel. Initially, we construct a nonlinear state-dependent function based solely on the restricted states to address the asymmetric state constraints. Moreover, by introducing a coordinate transformation and incorporating it into each phase of the backstepping technique, we completely circumvent the feasibility condition imposed on the virtual control signals. Consequently, a novel adaptive synchronization control scheme is formulated, which effectively manages both exogenous disturbances and DoS attacks simultaneously. Notably, the proposed control architecture not only ensures that all synchronization errors converge within a predefined small region around the equilibrium point but also guarantees that all signals within the closed-loop system adhere to the corresponding state constraints. Ultimately, the advantages and superiority of the proposed control framework are theoretically validated and practically demonstrated through a representative example.**

***Index Terms*—Output synchronization, Denial-of-service (DoS) attacks, Adaptive control, Constraint control.**

I. Introduction

The study of multi-agent systems (MASs) has garnered significant attention in recent years due to their widespread applications in various fields, including robotics, power grids, and autonomous vehicles. However, ensuring the synchronization of outputs in state-constrained nonlinear MASs remains a challenging task, particularly when these systems are subjected to external disturbances and cyber-physical threats such as denial-of-service (DoS) attacks. These attacks, especially when occurring in the sensor-controller (S-C) communication channel, can severely compromise the system's stability and performance.

Traditional approaches to synchronization often assume ideal communication channels and neglect the presence of state constraints, which may lead to infeasibility or suboptimal performance in practical scenarios. Furthermore, existing methods typically impose stringent feasibility conditions on the virtual control signals, limiting their applicability in real-world systems with asymmetric state constraints. To address these limitations, this study proposes a novel adaptive synchronization control framework that simultaneously manages external disturbances and DoS attacks while ensuring adherence to state constraints in nonlinear MASs.

This paper makes the following key contributions:

1. **Novel Control Design:** We introduce a nonlinear state-dependent function that explicitly accounts for asymmetric state constraints in nonlinear MASs. This function is constructed using only the restricted states, effectively addressing the challenges posed by such constraints.
2. **Coordinate Transformation and Backstepping Integration:** By incorporating a coordinate transformation into each phase of the backstepping technique, we overcome the conventional feasibility conditions imposed on virtual control signals. This approach enhances the flexibility and robustness of the control scheme in managing complex state-constrained systems.
3. **Adaptive Synchronization Control:** A new adaptive synchronization control strategy is developed, capable of handling both exogenous disturbances and DoS attacks. The proposed scheme ensures that all synchronization errors converge within a predefined small region around the equilibrium point, while simultaneously maintaining all signals within the closed-loop system within the prescribed state constraints.
4. **Theoretical and Practical Validation:** The superiority and effectiveness of the proposed control framework are rigorously validated through theoretical analysis and practical demonstrations. A representative example is provided to illustrate the practical applicability of the developed control strategy.

II. Conclusion

In conclusion, this paper presents a comprehensive adaptive synchronization control framework for state-constrained nonlinear MASs under the influence of exogenous disturbances and DoS attacks. The proposed approach effectively addresses the challenges associated with asymmetric state constraints and the feasibility conditions of virtual control signals. Through a novel combination of coordinate transformation and backstepping techniques, we develop a robust control strategy that ensures synchronization while adhering to the system's state constraints. Theoretical analysis and practical examples demonstrate the effectiveness and advantages of the proposed method, providing a significant contribution to the field of MAS synchronization. Future work may extend this framework to more complex scenarios, including time-varying state constraints and other forms of cyber-physical threats.

REFERENCES

[1] X. Xie, C. Wei, Z. Gu, and K. Shi, "Relaxed resilient fuzzy stabilization of discrete-time TakagiCSugeno systems via a higher order time-variant balanced matrix method," IEEE Trans. Fuzzy Syst., vol. 30, no. 11, pp. 5044-5050, 2022.

[2] J. Dong, Q. Hou, and M. Ren, "Control synthesis for discrete-time T-S fuzzy systems based on membership function-dependent H performance," IEEE Trans. Fuzzy Syst., vol. 28, no. 12, pp. 3360-3366, Dec. 2020.

[3] H. Yang, M. Shi, Y. Xia, and P. Zhang, "Security research on wireless networked control systems subject to jamming attacks," IEEE Trans. Cybern., vol. 49, no. 6, pp. 2022-2031, Jun. 2019.