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Research Article

A Review of Event-Triggered Control of Fractional-Order Multi-Agent Systems

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Abstract

The application of control theory to fractional-order systems has demonstrated superior performance in aspects such as system stability, observability, and controllability. Although extensive research has been conducted on multi-agent systems based on integer-order dynamics, it has been shown that in certain scenarios, ensuring system stability using integer-order models becomes problematic. In such cases, fractional-order modeling provides a more reliable alternative. This paper presents a comprehensive review of recent advances in event-triggered control strategies for fractional-order multi-agent systems. Event-triggered mechanisms are categorized into static and dynamic schemes, based on the nature of the system's dynamic dependencies. Accordingly, the study focuses on key challenges such as the Zeno phenomenon, performance degradation due to increased triggering thresholds, and communication resource constraints. To address these challenges, dynamic and adaptive event-triggered control mechanisms are proposed and discussed.

Keywords: Event-triggered mechanism, Multi-agent system, Fractional-order system, Event-based control.

Highlights

- A review of event-based control for fractional-order multi-agent systems is presented.
- Types of event-based control in systems are classified according to the nature of dependency.
- The importance of event-based control, especially for multi-agent systems, is examined.

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1. Introduction

In previous studies, the design of control algorithms has often been based on the assumption of continuous access to communication resources, so that the optimization of multi-agent systems has mainly focused on reducing tracking error or improving stability. However, recent research shows that in operational environments, especially in large-scale networks with distributed sensors and actuators, the requirements of intelligent management of resources such as bandwidth and energy are as critical as the system dynamics themselves. Control approaches are usually designed based on unlimited communication resources, and therefore the exchange of information in control loops is carried out periodically with the startup time of sensors and actuators. Recently, the investigation of event-based control strategies has been considered due to their potential applications in various fields. In the field of control of multi-agent systems, due to the large number of devices, it is very practical and necessary to make the best use of computational, communication, sampling and data transfer resources or control updates. An event-driven control system is a sampling data system in which sampling times are determined by events generated by the system state. Event-driven control requires sampling based on the minimum requirement to maintain desired control performance. Despite the advantages of event-driven control, implementing event-driven control for systems is not without challenges. Issues such as input saturation, fault occurrence, and controller design complexity can compromise performance and stability [1-7].

2. Innovation and contributions

In this review article, event-based control for fractional-order multi-agent systems is briefly discussed, and the evolutionary path of proposed control approaches in recent years is examined. First, a background of the application of event-based control is presented, and then, in continuation of the review of previous research, event-based approaches in integer-order and fractional-order multi-agent systems are examined. Also, the advantages and disadvantages of the approaches used are stated. In summary, the highlights of this study are:
- An examination of event-based control for fractional-order multi-agent systems is presented.
- Types of event-based control in systems are classified according to the nature of dependency.
- The importance of event-based control, especially for multi-agent systems, is examined.

3. Materials and Methods

Event-based control plays a fundamental role in reducing resource consumption and reducing operator depreciation. Each event structure consists of two parts: an error function and a threshold function. Based on the type of event threshold function, it is classified into two categories: static and dynamic. In terms of the nature of the dependence or non-dependence of the event structure on the system dynamics, event-based control can be classified into two categories: static event-based control and dynamic event-based control [8-13].

Zeno phenomenon is one of the challenges of event-based control. This phenomenon occurs when the system is out of equilibrium and the number of controller updates increases indefinitely. In such a case, an infinite number of events occur in a very short time interval, and in this case, event-based control becomes inefficient. Therefore, during the controller design, it must be proven analytically that Zeno phenomenon does not occur [14-16].

Since most of the studies initially used a fixed event structure, these structures are simple to design but less efficient in dealing with dynamic system changes. On the other hand, with the reduction in resource usage, it is not far from the fact that the overall performance of the control system will decrease to some extent, because less data is transmitted from the controller to the actuator. To address the challenge of reducing system performance with increasing threshold parameter, researchers have been looking for a way to reduce the number of events without sacrificing too much control performance, one solution being to increase the threshold function for the startup condition by adding a non-negative auxiliary dynamic variable. In fact, the difference between static and dynamic event-based control is in the event structure of each. Static event-based control is based on a fixed error threshold or a decreasing exponential function [17-19].

Fractional calculus is a growing research area due to its many applications in various fields of science and engineering. Since the advent of fractional calculus tools, countless literatures have been written, which have also improved the efficiency of control loops due to the improvement of modeling and improving the efficiency of controllers. Due to the high accuracy of fractional-order modeling for systems, many applications of applied systems, such as social networks and a fleet of spacecraft, unmanned underwater vehicles moving in the depths of the sea, and unmanned aircraft flying in dust storms, rain, or snow, can be considered as fractional-order systems. Also, many approaches to control integer-order nonlinear systems have been generalized to fractional-order nonlinear systems [20-23].

Multi-agent systems have attracted the attention of researchers in recent decades due to their wide applications in various sciences including applied mathematics, computer science and engineering. The collaborative control of these systems includes issues such as consensus, orchestration, containment, etc. Multi-agent systems with orchestration mode are systems in which agents are organized in a structured manner to achieve common goals. This configuration can be fixed or variable. Containment also means the control or restriction of agents by several leader agents to prevent undesirable and inconsistent behaviors. Consensus is also one of the important and vital areas in the collaborative control of multi-agent systems, which is achieved when the follower agents agree on a common desired point by following the control rules and communicating with their neighbors. Leader-controlled consensus and leaderless consensus are two distinct approaches to achieving group consensus [24-32].

In recent years, the distributed event-based control approach for fractional-order multi-agent systems has attracted much attention from researchers and scholars in the control community due to its various advantages compared to the conventional time-based approach. Due to some limitations and technical challenges in controller design and stability analysis in fractional-order systems, the extension of event-based control protocols from integer-order multi-agent systems to fractional-order multi-agent systems has been slow, and very few research results have been reported in this field so far.

4. Results and Discussion

Despite the significant growth of research in the field of event-based control, this approach still faces several fundamental challenges, which prevent its widespread and practical implementation in industrial and complex applications. The most important of these challenges are the lack of a comprehensive theoretical framework for analyzing stability and efficiency, especially in distributed nonlinear fractional-order multi-agent systems, with guaranteed stability in the presence of delay and noise, prevention of Zeno behavior, robust designs, and the lack of experimental results and key practical challenges such as time delays and operator defects remain as major obstacles. On the other hand, the lack of practical experiments and experimental results and practical scenarios indicate a significant gap between theory and application. These challenges indicate that despite theoretical advances, the field for further research towards the practical realization of this approach is still vast and vital.

In summary, the research path based on the existing challenges can be stated as follows:

- Development of dynamic event-based methods for complex fractional-order systems
- Designs resistant to time delays and operator defects
- Development of frameworks that can be implemented in industry
- Increasing real-world experiences and practical tests to prove theoretical benefits in industrial conditions

5. Conclusion

By reviewing the research background in the field of event-based control of fractional-order multi-agent systems, it is observed that most of the existing studies have focused on simple linear or nonlinear systems, therefore, the design of event-based controllers for complex fractional-order nonlinear multi-agent systems can be investigated. Another limitation in previous research is the use of static event structures in most cases, which leads to unnecessary updates, and another gap in this regard is the lack of investigation of the effect of hardware defects such as locking defects or loss of efficiency defects in operators on the stability of fractional-order multi-agent systems has rarely been analyzed. Therefore, the investigation of dynamic event-based control for fractional-order multi-agent systems in the presence of operator defects can be considered. According to the research conducted, the application of dynamic event-based methods in fractional-order systems with complex structures, the expansion of implementation in industry, and robust design can be mentioned as challenges and future research directions.

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