Adaptive Output Consensus of Heterogeneous Nonlinear Multi-agent Systems: A improved sliding mode approach

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***Abstract*—Achieving output consensus in heterogeneous nonlinear multi-agent systems (MAS) presents significant challenges due to the diversity in agent dynamics and the inherent nonlinearity of their interactions. This paper proposes an improved sliding mode control (SMC) approach to address these challenges and achieve adaptive output consensus in such systems. By integrating adaptive techniques with traditional SMC, the proposed method dynamically adjusts control parameters in response to the systems varying conditions, ensuring robust performance even in the presence of model uncertainties and external disturbances. The adaptive mechanism enhances the system's resilience by reducing chattering effects commonly associated with SMC while maintaining high precision in consensus achievement. The efficacy of the proposed approach is validated through rigorous theoretical analysis and simulation studies, demonstrating its superior performance in achieving output consensus in heterogeneous nonlinear MAS compared to existing methods.**

***Index Terms*—Multi-agent systems, sliding mode control, consensus, adaptive control.**

I. Introduction

The study of multiagent systems (MAS) has gained considerable attention over the past few decades due to their wide-ranging applications in areas such as robotics, autonomous vehicles, sensor networks, and power systems. In a MAS, multiple agents interact and cooperate to achieve a common objective, which can range from synchronized motion to distributed decision-making. One of the central problems in MAS is achieving consensus, where all agents agree on certain states or outputs despite differences in their initial conditions, dynamics, or local information.

When dealing with heterogeneous nonlinear MAS, the consensus problem becomes particularly challenging. Heterogeneity refers to the fact that different agents in the system may have different dynamics, possibly due to varying physical properties, control objectives, or operational environments. Nonlinearity further complicates the problem, as the relationship between the agents' inputs and outputs is not linear, making traditional linear control methods inadequate.

This work is supported in part by the National Natural Science Foundation of China under Grants 51939001, 62273072, 62203088, the Natural Science Foundation of Sichuan Province under Grant 2022NSFSC0903.

Output consensus is a specific type of consensus where the agents' outputs (which could represent physical quantities like position, velocity, or voltage) are required to converge to a common value over time. This problem is crucial in many practical applications. For example, in a fleet of autonomous drones, achieving output consensus could involve ensuring that all drones reach the same altitude or speed. In a power grid, it might involve ensuring that different generators output the same voltage level to maintain grid stability.

1. The Challenge of Heterogeneous Nonlinear MAS

In heterogeneous nonlinear MAS, each agent is governed by its unique dynamics, which are typically modeled by nonlinear differential equations. These dynamics can vary significantly from one agent to another, making it difficult to design a unified control strategy that ensures all agents reach output consensus. The nonlinearity of the agents' dynamics introduces additional challenges, as it can lead to complex behaviors such as bifurcations, chaos, or multiple equilibrium points.

Traditional control methods, which often rely on linear models or assume homogeneity among agents, are not well-suited to handling the complexities of heterogeneous nonlinear MAS. Moreover, real-world systems are often subject to uncertainties and disturbances, further complicating the consensus problem. These uncertainties may arise from modeling errors, environmental changes, or external disturbances, and can significantly affect the performance of the control system.

To address these challenges, researchers have developed various control strategies, including adaptive control, robust control, and sliding mode control (SMC). Each of these approaches has its strengths and weaknesses. Adaptive control is well-suited for systems with unknown or time-varying parameters, as it can adjust the control law in real-time based on the observed behavior of the system. Robust control, on the other hand, is designed to maintain performance in the presence of bounded uncertainties and disturbances. SMC is particularly attractive for nonlinear systems due to its ability to handle system uncertainties and its inherent robustness.

2. Sliding Mode Control and Its Limitations

Sliding mode control (SMC) is a powerful nonlinear control technique that has been widely used in MAS. The key idea behind SMC is to force the system's state trajectory to "slide" along a predefined surface in the state space, known as the sliding surface. Once the system's state reaches this surface, it remains on it for the rest of the operation, leading to desirable properties such as robustness to disturbances and invariance to certain types of system uncertainties.

However, SMC also has some limitations, particularly when applied to heterogeneous nonlinear MAS. One of the most significant drawbacks of traditional SMC is the chattering phenomenon, which is characterized by high-frequency oscillations in the control signal. Chattering can cause undesirable effects such as excessive wear in mechanical systems, increased energy consumption, and reduced control accuracy. This is especially problematic in systems with high heterogeneity, where the differences in agent dynamics can exacerbate the chattering effect.

Furthermore, traditional SMC methods are often designed for homogeneous systems or systems with relatively simple nonlinearities. When applied to heterogeneous nonlinear MAS, these methods may not perform well, as they do not account for the differences in agent dynamics or the complex interactions between agents. This can lead to suboptimal performance or even failure to achieve consensus.