Advances in Asynchronous Fuzzy Observer-Based Output Feedback Control for Networked Nonlinear Systems Utilizing Quantized Measurements

Ximing Yang
School of Automation Engineering
University of Electronic Science and Technology of China
Chengdu 611731, China
yxm961115123@163.com

***Abstract*—This study focuses on asynchronous observer-based output feedback control for continuous-time networked nonlinear systems using Takagi-Sugeno (T-S) fuzzy affine models with quantized measurements. To address the asynchronous phenomena in the premise variables between the original plant and the observer/controller, an asynchronous piecewise fuzzy affine observer design method is introduced to estimate the immeasurable system state vectors. By leveraging advanced matrix inequalities, a novel existence criterion for the asynchronous observer-based piecewise output feedback controller is derived within a unified convex optimization framework, relaxing the constraint that the control input matrices must be common and uncertainty-free under each fuzzy rule. The proposed method's effectiveness is validated through simulation studies.**

***Index Terms*—Asynchronous observers, convex optimization, fuzzy control, networked nonlinear systems, output feedback.**

I. Introduction

Complex nonlinearities are a ubiquitous challenge in a vast array of real-world industrial systems and engineering applications. These systems encompass a wide spectrum of fields, including astronautics, distributed networks, electric motors, electronic circuits, and chemical processing plants. The inherent complexities in these systems arise from their nonlinear behaviors, which can be highly sensitive to initial conditions and system parameters, leading to significant challenges in control and stability analysis. Precise mathematical modeling of such nonlinearities is often essential but typically requires the introduction of specific constraints or rigorous assumptions, making the modeling process both intricate and demanding.

As the need to effectively manage and control these nonlinearities has become increasingly critical, the field of nonlinear control theory has witnessed the development of various advanced control strategies. Among the most notable methods are sliding mode control, known for its robustness against disturbances and uncertainties, and adaptive control, which dynamically adjusts controller parameters in response to changes in system dynamics. However, one approach that has gained particular prominence is fuzzy logic control (FLC), which leverages the concept of linguistic variables and fuzzy sets to model, analyze, and synthesize control systems in a manner that mimics human reasoning and decision-making.

Within the domain of fuzzy logic control, Takagi-Sugeno (T-S) fuzzy models have attracted substantial research attention. The T-S fuzzy models are particularly valued for their ability to approximate a wide range of smooth nonlinear systems with high precision, thereby offering a versatile and powerful tool for nonlinear system control. Over the past few decades, a substantial body of research has emerged, focusing on the systematic analysis and design of control systems using T-S fuzzy models. This research has led to the development of numerous innovative control strategies, including the design and implementation of T-S-type fuzzy controllers for various applications, such as the control of mobile robots, the management of flexible spacecraft, and the stabilization of power systems. Furthermore, interval type-2 fuzzy sliding mode control has been explored as a means to handle uncertainties in nonlinear systems more effectively.

Despite the advances made, practical applications of T-S fuzzy models, especially in networked control systems, present additional challenges. In many real-world scenarios, the complete measurement of all system state variables is often impractical or impossible. This limitation necessitates the use of state observers-algorithms designed to estimate the unmeasurable states of a system based on available measurements. Observer-based output feedback control (OFC) has thus become a critical area of research within T-S fuzzy dynamic systems. In recent years, considerable efforts have been devoted to the design of fuzzy observer-based OFC for systems characterized by various complexities, including those involving quantized measurements that are transmitted over potentially unreliable communication networks. These systems are particularly relevant in the context of modern cyber-physical systems, where data transmission constraints and network-induced delays are common.

However, the existing approaches to fuzzy observer-based OFC often operate under the assumption that premise variables are fully measurable and that control input matrices are both common across different fuzzy rules and free of uncertainties. These assumptions can lead to conservative designs that limit the practical applicability of the controllers in more complex and realistic scenarios. Moreover, such assumptions may not hold in many networked control systems, where communication constraints, sensor limitations, and environmental disturbances can introduce significant uncertainties.

This study seeks to address these limitations by proposing an advanced asynchronous observer-based output feedback control method tailored for networked nonlinear systems modeled using T-S fuzzy affine frameworks with quantized measurements. The proposed method departs from the traditional constraints on control input matrices, allowing for the presence of parameter uncertainties and variations across different fuzzy rules. By employing sophisticated convexification techniques and leveraging advanced matrix inequalities, the proposed approach significantly reduces design conservatism and enhances the robustness of the control system in the face of uncertainties and operational variability. The effectiveness and practical utility of the proposed method are demonstrated through rigorous simulation studies, showcasing its potential for application in complex networked systems where traditional control strategies may fall short.