Human-in-the-loop mixed event-triggered formation control for QUAVs With quantized communication

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***Abstract*—This paper presents a novel approach to Distributed Adaptive Human-in-the-Loop Event-Triggered Formation Control (DAHIL-ETFC) for Quadrotor Unmanned Aerial Vehicles (QUAVs) under conditions of quantized communication. The proposed framework integrates adaptive control strategies with human intervention capabilities, enabling QUAVs to autonomously form desired formations while adapting to dynamic environmental changes. Utilizing event-triggered communication protocols minimizes the frequency of information exchange, conserving communication resources without compromising control performance. Simulation results demonstrate the effectiveness of the DAHIL-ETFC approach in achieving robust formation control amidst communication constraints.**

***Index Terms*—Multi-agent systems, human-in-the-loop, formation control, quantized communication.**

I. Introduction

Unmanned Aerial Vehicles (UAVs) have revolutionized various fields, including surveillance, disaster response, and precision agriculture, due to their agility and versatility. Among UAVs, Quadrotor UAVs (QUAVs) stand out for their ability to perform agile maneuvers and hover in place, making them ideal for tasks requiring precise spatial coordination and dynamic formation control. Formation control, wherein multiple QUAVs autonomously maintain specified spatial configurations, is critical for applications such as aerial surveillance, where maintaining a constant relative position among UAVs enhances coverage and operational efficiency.

Traditional approaches to formation control often rely on centralized or decentralized control strategies with continuous communication among vehicles. However, these methods are susceptible to communication delays, bandwidth limitations, and potential signal quantization effects, particularly in environments with constrained communication resources. To address these challenges, this paper proposes a novel approach: Distributed Adaptive Human-in-the-Loop Event-Triggered Formation Control (DAHIL-ETFC) for QUAVs with Quantized Communication.

Motivation and Objectives The motivation behind developing DAHIL-ETFC stems from the need to enhance the autonomy and robustness of QUAV formations while mitigating the impact of communication constraints. Traditional approaches either require high-frequency communication updates or do not effectively handle scenarios where communication is intermittent or subject to delays. By integrating adaptive control mechanisms and event-triggered communication protocols, DAHIL-ETFC aims to achieve robust formation control capabilities that are resilient to communication disruptions and quantization effects.

Contributions The primary contributions of this research can be summarized as follows:

Adaptive Control Integration: Incorporating adaptive control techniques enables QUAVs to dynamically adjust their formation strategies based on real-time environmental feedback and variations.

Event-Triggered Communication: Implementing event-triggered communication protocols reduces communication overhead by transmitting data only when necessary, thereby conserving energy and bandwidth resources.

Human-in-the-Loop Capability: Introducing human intervention into the control loop allows operators to influence formation behaviors, enhancing the flexibility and adaptability of the system to unforeseen circumstances or mission-specific requirements.

Structure of the Paper This paper is structured as follows: Section 2 provides a comprehensive review of related work in UAV formation control, adaptive control strategies, and event-triggered communication protocols. Section 3 details the theoretical framework and methodology of DAHIL-ETFC, including the mathematical formulations of adaptive control laws and event-triggering conditions. Section 4 presents simulation results and performance evaluations to validate the proposed approach under various scenarios of communication quantization and environmental dynamics. Section 5 discusses practical implications, limitations, and future research directions, while Section 6 concludes the paper with a summary of findings and contributions.

Organization Overview In summary, this introduction sets the stage for exploring the innovative DAHIL-ETFC framework, highlighting its potential to advance the state-of-the-art in QUAV formation control by leveraging adaptive strategies and event-triggered communication. The subsequent sections delve deeper into the technical aspects, simulations, and discussions necessary to substantiate the efficacy and practicality of the proposed approach in real-world applications. However,

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.

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