A Brief Introduction to Distributed Formation of MAS

Class：2023 Control Class No.1 Student ID：23S053067 Name：Fang Yao 方尧

Unmanned aerial vehicle (UAV) technology has become increasingly integral to modern military and civilian applications, evolving from simple military training devices to multi-functional aerial robots. The versatility of UAVs now extends to scientific research, transportation, agricultural automation, geological exploration, and natural disaster relief. However, single UAV systems encounter limitations in complex tasks, such as restricted reconnaissance capabilities and mission interruption upon system failure. To address these issues, researchers are exploring the cooperative control of multi-UAV systems to enhance task efficiency and robustness through swarm intelligence.

Inspiration from natural group behaviors, like bird formation flight and ant cooperative transport, has led to the development of collaborative control strategies for drones. Multi-agent systems (MAS) mimic these phenomena to achieve greater flexibility and adaptability in drone operations. This paper focuses on the theoretical underpinnings and key technologies of multi-UAV cooperative control to improve UAV formation control performance.

I. Research Background and Significance

The growth of UAV technology presents broad application prospects but also reveals the limitations of single UAV systems. Single UAVs face challenges in fully covering target areas during reconnaissance missions due to sensor and communication constraints. Moreover, system failure can jeopardize entire missions. Multi-UAV cooperative control offers a solution by enabling broader reconnaissance, higher mission success rates, and enhanced adaptability and robustness through UAV collaboration.

II. Method Research

Three key technical issues in multi-UAV cooperative control are communication strategy, formation control strategy, and collision avoidance strategy. Centralized, distributed, and decentralized communication strategies each have their advantages and disadvantages. Centralized communication offers high precision but relies heavily on a central unit, potentially impacting system expansion and stability. Distributed communication, favored for its reduced bandwidth requirements and design flexibility, is becoming a research focus. Decentralized communication is fully decentralized but requires additional collision avoidance measures. This paper adopts a distributed communication strategy to facilitate effective UAV collaboration.

Formation control strategies include the pilot-following method, virtual structure method, behavior method, and consistency theory control method. The pilot-following method, while common, is overly dependent on a lead unit. The virtual structure method addresses this by using a virtual center point but requires further optimization. The behavior method, based on basic behaviors, is simple but lacks precise dynamic control. The consistency theory control method, which achieves state consistency among all agents through a control program, is selected for its low communication bandwidth requirement and effective control, aligning well with distributed control.

Collision avoidance strategies include optimization methods, artificial potential field methods, and perceptual evasion methods. The optimization method is challenging for real-time control. The artificial potential field method, widely used, may encounter equilibrium points leading to oscillations or suboptimal solutions. The perceptual evasion method demands high communication bandwidth. The artificial potential field method is chosen for collision avoidance to ensure safe UAV flight in complex environments.

III. Research Plan

The research plan is structured as follows:

Quadrotor UAV Modeling and Trajectory Tracking Control Algorithm Design: Accurate mathematical modeling of quadrotor UAVs is essential for designing trajectory tracking control algorithms, ensuring precise flight along predetermined paths.

Distributed Formation Control Algorithm Design: Building on UAV modeling, a distributed formation control algorithm is designed to consider UAV communication and collaboration for coordinated fleet control.

Simulation Experiments: The designed control algorithms are tested and verified through simulation software under various conditions to assess performance and robustness.

Physical Experiment Verification: Following simulation, physical flight experiments are conducted to further validate the control algorithms' effectiveness and gather practical data.

Algorithm Optimization and Application Expansion: Based on simulation and real-world results, the control algorithms are optimized and their potential for application in other fields, such as logistics and environmental monitoring, is explored. This research aims to provide a theoretical basis and technical support for the field of multi-UAV cooperative control, promoting the broader application of UAV technology.