Formation flight control for UAVs – a state of the art study.

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Abstract.

Formation flight control for unmanned aerial vehicles (UAVs) is a central problem in cooperative robotics, enabling applications such as distributed sensing, environmental monitoring, surveillance, communication relays, and cooperative transport. Over the past two decades, a broad spectrum of formation control strategies has been developed, differing in architectural assumptions, control-theoretic foundations, scalability, robustness, and computational complexity [1]. This article provides a structured comparative review of the most prominent approaches—leader–follower [2] [3], virtual structure, consensus-based control, artificial potential fields, behavior-based (flocking) methods, model predictive control (MPC), and graph rigidity–based distance control—while synthesizing current state-of-the-art trends in distributed autonomy and resilient swarm coordination.

Beyond comparing these methods, the article characterizes the state of the art as increasingly distributed, optimization-driven, and resilience-focused. Contemporary research moves away from purely centralized architectures toward hybrid frameworks that combine local consensus or rigidity maintenance with decentralized collision avoidance and distributed MPC [4]. Emphasis is placed on robustness to communication delays, packet loss, and dynamic topology changes [5]. Scalability to dozens or hundreds of UAVs is one of the driving factors [6] [7].

Emerging trends include distributed nonlinear MPC, game-theoretic coordination, learning-enhanced adaptive formation control, and integration of perception-driven feedback in GPS-denied environments. The state of the art thus reflects a shift from idealized kinematic models toward dynamically feasible, safety-critical, and computation-aware multi-agent control frameworks [8]. The article concludes that no single paradigm dominates across all criteria; instead, hybrid distributed architectures that balance theoretical rigor, robustness, and computational tractability represent the most promising direction for next-generation autonomous UAV formations operating in uncertain and dynamic environments [9].