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THESIS

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Efficient UAV Swarm Coordination via Graph-Based Multi-Agent Reinforcement Learning

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Abstract

Unmanned aerial vehicle (UAV) swarms promise robust, scalable, and flexible solutions for missions such as search-and-rescue, surveillance, and disaster response. Realising this promise, however, raises a difficult coordination problem: the drones must co-operate using only local information, without a central controller, while the size of the team and the communication topology change continuously. Classical analytical strategies—flocking rules, potential fields, and consensus—behave predictably but depend on hand-tuned models and adapt poorly to dynamic conditions, whereas generic multi-agent reinforcement learning (MARL) scales badly and generalises poorly as the number of agents varies. Graph neural networks (GNNs) have recently emerged as a natural remedy, because their permutation equivariance, support for a variable number of agents, and reliance on local neighbourhoods match the structure of a swarm.

This thesis presents a structured study of the integration of graph neural networks with multi-agent reinforcement learning for UAV-swarm coordination. It surveys and classifies the state-of-the-art graph-based methods, organised by GNN architecture (graph-convolutional, graph-attention, and other families) and by training and execution paradigm. A critical comparison along the axes of scalability, decentralisation, robustness, and communication cost shows that learned graph attention combined with centralised-training and decentralised-execution (CTDE) is the dominant and most effective recipe, that locality is the key enabler of scalability, and that the diversity of simulators and reward designs makes published results hard to compare directly. The study concludes that coupling GNNs with MARL is a well-founded and promising direction for scalable and robust UAV-swarm coordination, and it identifies the open challenges that should guide future work.

Keywords: UAV swarms; multi-agent reinforcement learning; graph neural networks; decentralised coordination; centralised training with decentralised execution (CTDE); Dec-POMDP.