

PhD Defence

Fateme Aghaee
presents her thesis

Title: *Intelligent and Robust Control of UAV Systems with Uncertain Dynamics: From Slung-Load Transport to LLM-Driven Multi-Agent Coordination*

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Abstract

Autonomous aerial and multi-agent systems are increasingly expected to operate in uncertain and dynamic environments while maintaining safety, robustness, and performance. In such settings, precise system models, full-state measurements, and reliable fault information are often unavailable. These limitations are particularly critical in underactuated aerial load-transportation and distributed coordination problems, where disturbances, unknown payload dynamics, and actuator faults can significantly degrade control performance. At the same time, recent advances in artificial intelligence, especially large language models (LLMs), have created new opportunities for adaptive decision-making in control systems, while also raising important challenges related to safety, interpretability, and stability. This thesis contributes to the development of robust and intelligent control architectures for operation under uncertainty. The work follows a continuous progression from practical model-based control of slung-load unmanned aerial vehicles (UAVs) to AI-augmented decision-layer control for fault-tolerant multi-agent systems.

The thesis first develops a practical modeling, motion-planning, and control framework for a UAV transporting a cable-suspended payload. By exploiting differential flatness on reduced models of the UAV-payload system, feasible payload-centered trajectories are generated without requiring payload-mass or cable-deflection-angle measurements. Robust feedback control structures are then combined with the planning layer to achieve stable payload transportation despite unknown payload dynamics and external disturbances. The framework is further extended to real-time, operator-in-the-loop trajectory generation using filtering-based methods that transform operator-defined velocity commands into smooth, dynamically feasible payload and UAV trajectories while reducing payload oscillations. The work is then generalized to cooperative transportation by multiple UAVs carrying a rigid slung load. The resulting framework enables coordinated control of both payload position and orientation under modeling uncertainty, without requiring knowledge of load-mass distribution or cable-force measurements. These results demonstrate that the proposed approach scales from single-UAV to cooperative multi-UAV transport.

In addition, the thesis investigates the intelligent augmentation of control systems using LLMs. A rule-based LLM integration framework is proposed in which the LLM operates as a constrained decision-level reasoning module, while a classical stabilizing controller remains responsible for low-level feedback control. This framework enables adaptive tuning, disturbance-aware decision support, and safety-oriented behaviors such as emergency handling, while preserving the stability properties of the underlying control loop. Building on this idea, the thesis also introduces an LLM-augmented distributed fault-tolerant consensus framework for multi-agent systems. In this framework, LLM-based decision modules provide bounded corrective actions for actuator-fault compensation without requiring explicit fault estimation, fault bounds, or global information. Control-theoretic analysis establishes closed-loop boundedness, and comparative simulations show improved consensus performance under actuator faults.

In conclusion, the thesis demonstrates that robust autonomy under uncertainty can be advanced through a combination of practical flatness-based planning, robust feedback control, cooperative aerial transport, and constrained decision-layer intelligence. The presented methods reduce reliance on precise models, extensive sensing, and manual supervision, while preserving dynamic feasibility in trajectory generation and stability guarantees in feedback control for aerial and multi-agent systems.

Keywords: unmanned aerial vehicles, slung-load transportation, differential flatness, robust control, cooperative multi-UAV transport, large language models, intelligent control, fault-tolerant consensus, multi-agent systems