

Adaptive, Robust, and Learning-Based Control of Quadrotor UAVs under Partial-State Feedback

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Abstract

QUADROTORS have become ubiquitous aerial platforms in many applications, including inspection, delivery, search and rescue, and infrastructure monitoring. However, their control is inherently challenging: the dynamics are highly nonlinear and underactuated, with only four control inputs available to govern six degrees of freedom, and the attitude evolves on the special orthogonal group $SO(3)$, a compact three-dimensional Lie group that is not a vector space. To fly safely, their controllers rely on accurate feedback of the vehicle's state, including position, linear velocity, and angular velocity. In practice, this information may not always be available or reliable: GPS signals can be blocked or spoofed. Algorithms such as visual-inertial odometry can reconstruct the missing states, but their performance degrades in low-feature environments, rendering the state estimate, and consequently the controller, unreliable. Observer-based output-feedback controllers offer one remedy; however, high-gain observers induce the well-known peaking phenomenon, and the coupled position–attitude structure requires the observer and control gains to be tuned jointly, a task that is notoriously difficult in practice.

In this seminar, this problem is tackled from a control-theoretic perspective, in which the controller itself does not require full state information and can operate reliably under partial state feedback. In particular, robustness, adaptation, and learning are incorporated into the control design to ensure precise tracking, and rigorous stability guarantees are established. Several contributions are discussed in this context, related to robustness, adaptation, and learning, including reinforcement learning with certified mathematical guarantees, to ensure precise tracking under partial state feedback. In addition, a sound-based fault detection framework is presented, in which propeller and motor faults are detected in real time from the acoustic signature captured by a single onboard microphone, using only recordings from nominal flights. Experimental validation is carried out on a Quadrotor platform running the PX4 autopilot with the ModalAI VOXL 2 onboard computer. Figure 1 shows a trajectory-tracking task along a circular path using only position and attitude feedback.

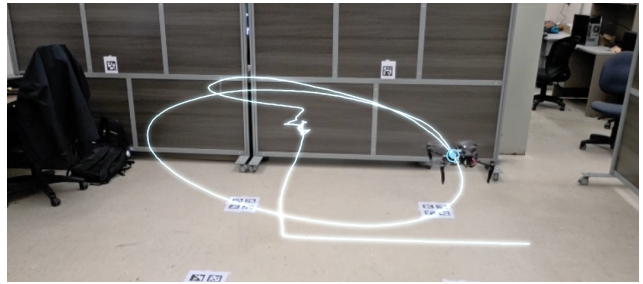


Figure 1: Trajectory tracking of a Quadrotor using only position and attitude measurements, with no knowledge of linear or angular velocity.

Speaker Bio

Ali Mohamed Ali (Graduate Student Member, IEEE) received in 2022 the M.Sc. degree in Control Engineering from the Department of Computer, Control, and Management Engineering (DIAG), Sapienza University of Rome, Rome, Italy. Since 2023, he has been pursuing the Ph.D. degree with the Department of Mechanical and Aerospace Engineering, Carleton University, Ottawa, ON, Canada. His current research interests include nonlinear control, reinforcement learning, and applied AI.