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Autonomous Aircraft Flight Control For Constrained Environments

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I. Introduction

The Real-time indoor Autonomous Vehicle test ENvironment (RAVEN) at MIT's Aerospace Controls Laboratory is home to a diverse fleet of aircraft, from a styrofoam and cellophane dragonfly to a set of quadrotor *Draganflyer* helicopters. The helicopters are used primarily for swarm and health management research [1], [2]. Alongside these machines is a set of more conventional aircraft designed to study autonomous aircraft flight control in constrained environments. The objectives of this work are to develop and validate flight control concepts for aggressive (aerobatic) maneuvers, and, in particular, to identify the sensor suites needed, and the likely limits of achievable performance. Our work is motivated by the future goals of flying micro (or nano) air vehicles in constrained (e.g., urban or indoors) environments.

II. RAVEN

A key feature of RAVEN is the Vicon MX camera system [3] that can accurately track all vehicles in the room in real-time. By attaching lightweight reflective balls to the vehicle's structure, the Vicon system can track and compute the vehicle's position and attitude information at rates up to 120 Hz, with approximately a 10 ms delay, and sub-mm accuracy [3]. Just as GPS spurred the development of large-scale UAVs, we expect this new sensing capability to have a significant impact on 3D indoor flight.

The RAVEN facility follows the same design philosophy used in the previous MIT ACL testbeds [4] in that the perception and planning computation is done off-board. RAVEN takes this philosophy one step further by computing vehicle flight control commands off-board. These commands are sent from ground-based computers to the vehicles via standard R/C transmitters at rates that exceed 50 Hz. An important feature of this setup is that we can use small, inexpensive, essentially unmodified, radio-controlled vehicles. This enables researchers to avoid being overly conservative during flight testing. The configuration shown in Fig. 1 with perception, planning, and control processing all done in linked ground computers, as if it were being done onboard. The combination of simple vehicles, a fast and accurate external metrology/control system, modular onboard payloads, and a very well structured software infrastructure provides a very robust testbed environment that has enabled the demonstration of more than 3000 multi-UAV flights in the past 36 months.

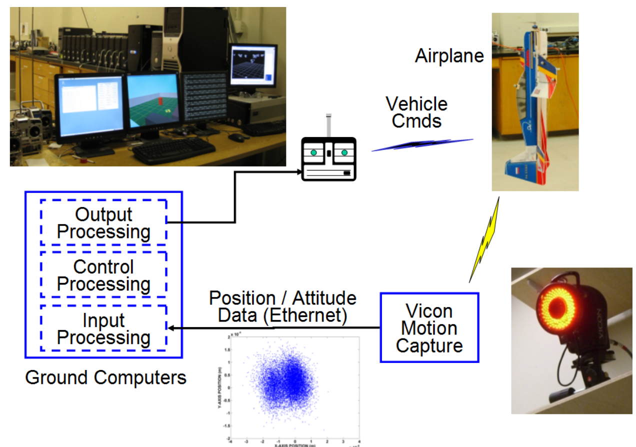

Fig. 1: RAVEN architecture for aircraft flight control

III. Ikarus Yak 54

The Ikarus Shock Flyer, modeled on the Yak 54 aerobatic monoplane, is our current testbed for globally applicable inner-loop control. Past work has focused on switched linear control, and individual controllers have been developed to:

- Hover
- Fly conventionally
- Transition from conventional flight to hover
- Transition from hover to conventional flight
- Take off
- Perch on a stand (from hover)

Linear controllers are designed for each operating mode, and the entire system operates as the aircraft flight controller. The control mode switching is primarily based on the aircraft pitch angle and the commanded maneuver [5].

IV. Flight Results

Typical flight results are shown in Figures 2–4. Figure 2 shows results from a 5 min hover. The control in this case is complex. The elevator and rudder are used to control the horizontal position, but they do so using airflow from the propeller that is transient and impacted by the deflection of the ailerons, which themselves are used to control the aircraft roll.

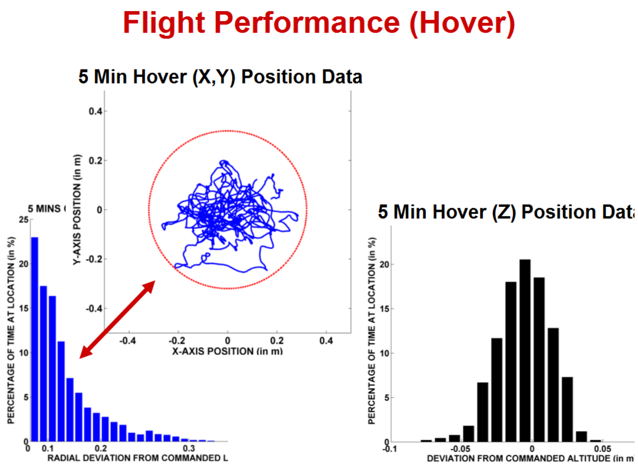

Fig. 2: Aircraft flight results (hover).

The histograms show the radial distance error for the vehicle from $(x, y) = (0, 0)$ m and the vehicle's altitude error from $z = 1.5$ m. These plots confirm that the vehicle was within a 20 cm circle for over 87% of the 5 minute flight. These plots also show that the vehicle precisely maintained its altitude (staying between 1.4 to 1.6 m) during the entire hover test.

Figures 3 and 4 show results from a sequence in which the aircraft: takes-off vertically and hovers over to the start point; transitions to horizontal flight (speed approximately 6 m/s); tracks a very tight circular path (radius 2 m) for three laps; and transitions back to a vertical hover. Figure 4 shows the results from two experiments, confirming the repeatability and performance of the control system.

V. Video

The accompanying video opens with a motivating flight sequence (hand flown), discusses the RAVEN system in Figure 1, and the presents three main sets of autonomous results using the Yak:

1) Vertical take-off, hover flight, and perch.
2) Horizontal take-off to vertical hover.
3) Vertical take-off to hover flight, transition to horizontal flight, track a circle, transition back to vertical hover.

The video concludes by showing two new platforms that are being developed for future adaptive flight control research.

VI. Summary

The ability to use low-cost aircraft with very simple onboard electronics has enabled us to demonstrate several very aggressive flight maneuvers using RAVEN. These experiments highlighted the need for more adaptive flight controllers, which is the topic of current research. Future work also continues on developing flight control systems for micro and nano-air vehicles, as well as flapping vehicles. We are also using the rapid prototyping facilities of RAVEN to investigate sensor suites that can provide the necessary data to complete these maneuvers in field experiments.

Fig. 3: Aircraft performing a three-lap maneuver after transitioning from hover flight.

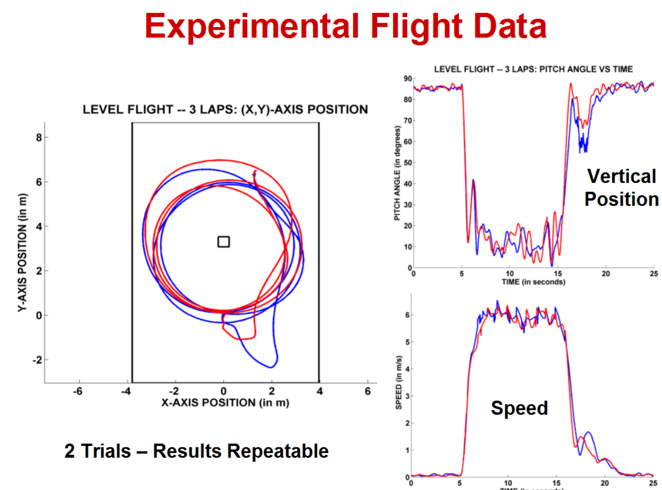

Fig. 4: Aircraft flight results (commanded to follow a circle for three-laps.

VII. Acknowledgments

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