Robotic Augmentation of UAV Navigation in Cluttered Environments

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Abstract. This document proposes an investigation into variably augmented (i.e. fully and semi-autonomous) navigation of Micro Unmanned Air Vehicles (MAV) in visually and aerodynamically cluttered environments. The proposal is motivated by recent advances in MAV airframe technology that have yielded performance improvements (in speed and acceleration) beyond the ability of human operators to reliably exploit.

Biographical notes: Dr Stephen Wright is currently a Senior Lecturer in Avionics and Aircraft Systems at the University of West of England, UK, after 25 years as a software, electronics and systems engineer in the aerospace industry, at Rolls-Royce, ST Microelectronics, and Airbus. His doctorate investigated the application of modern Formal Methods to microprocessor Instruction Set Architectures, and his research now focuses on development of avionics and support systems for Small and Micro Unmanned Air Vehicles.

1. Context

The proposed investigation is framed as part of a broader UAV robotics Research and Development programme envisaged for UWE and BRL, seeking to explore all aspects of autonomous and semi-autonomous operation of MAVs in inhabited spaces, encompassing technical, safety, reliability, operational and regulatory implications. The programme is summarised in Figure 1.

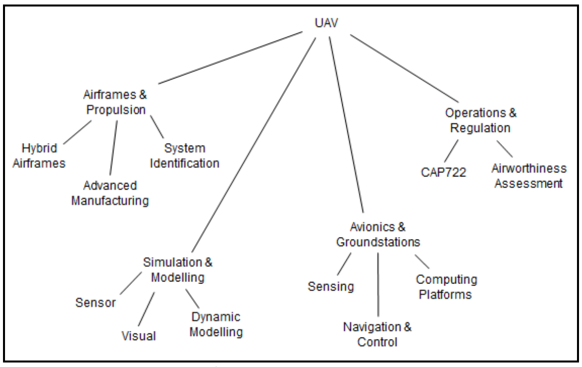

Figure 1: Summary of Integrated UWE Research Programme

The specific proposal here seeks to leverage expertise and resources within the Bristol Robotics Laboratory by focusing on robotic sensing, control and actuation aspects in order to exploit pre-existing airframe capabilities. The work is directly motivated by ongoing research being conducted for industrial partners to produce UAV sensor demonstration platforms, such as that shown in Figure 2 [1].

The investigation is also intended to benefit current projects with Airbus UK and various SMEs, and potential future projects such as that proposed in [2], in response to an invitation to bid on a Capability Concept Demonstrator, called jointly by Leonardo Helicopter and the UK Ministry of Defense.

Figure 2: Phase One MBDA-UWE Quadcopter

2. Review of Current State of the Art (SOTA)

Current MAV technology is enabled by recent advances in low-cost consumer rotorcraft and their associated propulsion, control and communication systems. An example of a typical airframe from this market, used for aerial racing via system-assisted manual piloting, is shown in Figure 3.

Figure 3: High Performance COTS Airframe

Such advances have been enabled by convergence of a number of separate technologies developed for various consumer applications. In the domain of avionics and systems, technologies include high energy-density batteries capable of high-current delivery, controllable high-torque motors and associated electrical switching equipment, low-cost stabilisation avionics, and low-cost digital communication links to ground equipment. Specific technologies include:

open-source implementations of basic control laws, LiDAR, sonar and video sensors, open-source sensor interfacing support, and simulated physical models and visual environments for Hardware-in-Loop testing.

The consumer-market origins of these technologies imply a number of challenges and opportunities. For example, the described motor and battery technologies allow accelerations of up to 20g and maximum airspeeds beyond 100 mph to be achieved by vehicles costing less than £1000. Conversely, the use of consumer grade hardware and simplex architectures results in low reliability (i.e. of the order of less than 100 hours mean time between vehicle-loss failures).

Initial development of MAV technology has focused on provision of thrust-actuated stabilisation of airframes in pitch, roll, and yaw via gyroscope and accelerometer attitude sensing, and subsequently on stabilisation of longitudinal, lateral, and altitude position via Global Positioning Systems (GPS) and visual techniques. Large-scale navigation via GPS is well established, but local navigation is still largely dependent on skilled human operators, via direct line of sight (LOS) or telemeterised first-person view (FPV) video streaming. The proposal therefore seeks to contribute to this emerging field.

3. Anticipated Objectives & Approaches

The proposal has a direct requirement from an industrial customer to investigate the feasibility of navigation through urban environments at speeds up to 80 mph, and achieving lateral and longitudinal accelerations and decelerations of up to 20g. Thus the project is highly speculative and presents multiple opportunities in extending SOTA. In order to achieve the stated goal, three intermediate research goals have been identified, all of which have general application to the field of robotics:

1) Real-time acquisition of sufficient environmental information to enable local navigation decision-making. This goal is expected to require fusion of multiple sensor sources using a variety of sensing techniques (e.g. Laser/Sonar range finding, and machine-vision), with sensing/computing periods in the order of 2 milliseconds. It is hoped that the goal may be achieved by integration and scaling of existing techniques (e.g. Sonar/LiDAR sensing, ground-based image recognition), plus more speculative work (e.g. high-performance airborne computing platforms, creation of reliable digital video streaming, telemetry, and communications).

2) High-speed real-time heuristic decision-making, based on acquired environmental data and known airframe performance constraints. Based on customer-requested performance and SOTA airframe performance, required sensing/decision/actuation periods in the order of 100-200 milliseconds are anticipated. Consideration of variable airframe performance, dependent on operational environments and airframe configuration, and decomposition of decision making activities, dependent on time-criticality, is expected. This goal is expected to require integration of a variety of deterministic (e.g. modal control of under-actuated airframes) and artificial intelligence techniques (e.g. artificial neural networks).

3) Methods for staged imposition of robotic authority in a manner acceptable to human operators, and provision of suitable Human-Machine Interfaces to allow operators to exploit augmented piloting whilst also maintaining situational awareness during high-speed flight.

All of these intermediate goals are expected to be enabled by further development of environmental and dynamic airframe simulations. Prior operation experience has shown this to be an essential aid to productivity and reproducibility, but requiring of detailed verification by appropriate flight-testing. To this end the indoor MAV flying facilities available are an essential part of the project.

4. Further Applications

As stated in Section 1, the proposal is part of a broader roadmap to address the multiple issues implicit in operation of MAVs in public and cluttered environments. It therefore addresses generic issues in the field of robotic operation of MAVs and enables a variety of future applications to be implemented.

Future applications exploiting these research themes that are already planned include expansion of the operational envelope for fully autonomous high-speed low-level flight, maintaining static positioned hover in turbulence-prone locations (e.g. inspection of bridge and building structures), video monitoring of Landing Gear Mechanical Test Rigs (in association with Airbus UK), and large-scale cleaning of solar panels (in association with CleanDrone Ltd).

5. Summary

This research is appropriate to the goals and resources of the BRL, and leverages resources available at the UWE and current development already in progress for UK aerospace organisations. The proposal promises to be feasible, useful, and capable of future expansion.

References

[1] Wright S “Proposal for Phase 2 UWE/____ UAV Testbed Development” UWE 2016 (attached)
[2] Wright S ““A Proposed Investigation into Landing Area Reconnaissance UAVs” 2017 (attached)