QUASAR: An Experimental Test Bed for Autonomous Multi-Agent Control

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INTRODUCTION

This research project deals with the development and testing of the QUASAR Swarm AEA: QUASAR experimental test bed for autonomous multi-agent unmanned aerial vehicle (UAV) control systems. The QUASAR test bed consists of four high-speed OptiTrack Flex 13 motion capture cameras, an enclosed experimental area, a communication ground station for graphical user interface and data analysis, and inter-agent wireless communication electronics. The initial multi-agent UAV complement, (our “swarms”), consisted of four CrazyFlie quadrotors relying on RF communication protocols that have since been replaced by custom built quadrotor agents with on-board RF controlled actuators, multiple accelerometers, WiFi communication modules, and various external sensors. The development of QUASAR is motivated by the desire to experimentally test and validate new hardware-in-the-loop multi-agent control methods.

A key focus of the project investigates the performance comparisons between linear and nonlinear multi-agent control methods under realistic operating conditions. Preliminary numerical simulations using MATLAB/Simulink indicate that nonlinear control methods more effectively compensate for unpredictable disturbances and dynamic model uncertainty. However, the results also suggest that standard linear control methods offer the benefit of ease of implementation. In addition to the control design trade-offs, preliminary experimental results have demonstrated the practical trade-offs that exist in using different inter-agent wireless communication protocols (e.g., radio versus WiFi).

Ongoing research efforts include experimentally testing new hardware-in-the-loop multi-agent UAV control methods that effectively compensate for disturbances and uncertain dynamics (e.g., unmodelled wind gusts). It is expected that this research project will provide increased potential for multi-agent UAV and satellite implementation in military and civilian applications, which achieve reliable performance under the unpredictable and potentially adversarial operating conditions encountered in nature.

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EXPERIMENTAL TEST BED

1. Multi-agent quadrotor drones for unmanned UAV/satellite swarm analysis.
   Two different models were used to test communication protocols: RF transmitters, CrazyFlie Quadcopter with radio antennas, and WiFi modules, (current custom built quadrotors). Current swarm provides a more capable and robust communication network with greater inherent mechanical stability and maneuverability within test bed.

2. Enclosed experimental arena for flight testing and motion capture. The PVC constructed 10' x 10' x 6', security-netted, arena provides ample capture volume and defined bounded region for controlled disturbance inputs for closed-loop flight testing. Four OptiTrack Flex 13 motion capture cameras, (1280 x 1024 resolution, 120 fps, 8.33 ms nominal latency), provide accurate position measurements with 28 infrared LEDs.

3. Central communications ground station, (i.e., “the Intima”), provides a graphical user interface and data analysis for live position and attitude determination. Comprised of a powerful CPU (Dragonboard 410x development Board) with a Linux installed OS, position data is acquired and streamed in real-time using OptiTrack’s Motive, (motion capture software), on Windows 10 using a virtual machine and streamed to the WiFi router.

4. Designed to increase data streaming security and speed, an ASUS RT-N530 Wireless Router, (300 Mbps, 2.4 GHz, 802.11b/g/n), allows the position data for each drone to be published to a WiFi network using unique IP addresses for each data packet to ensure proper drone RX protocols are satisfied.

THEORY AND METHODS

QUASAR relies on the use of 4 high-speed OptiTrack Flex13 cameras to provide discretized real-time position and attitude data for onboard control actuators. The system architecture outlined above illustrates the closed loop cycle but does not fully detail the internal system of the applied control laws within each quadrotor agent.

In order to stabilize each agent and send constant control commands to each of the rotors amidst external disturbances and still maintain a leader-follower relationship and trajectory, each agent is equipped with an onboard processing unit to react to the position data packets from the established WiFi network. The simulations and control functions utilize a simple connected “nearest-neighbor” topology in order to achieve universal agent cohesion and dynamic system control. This is achieved with a control design algorithm of the basic form:

\[
\begin{align*}
\ddot{\mathbf{v}} &= -B^{-1}(\mathbf{e}_a + J \mathbf{e} + \mathbf{f}(\mathbf{e}))
\end{align*}
\]

\[
\mathbf{u}(t) = -B^{-1}(\mathbf{e}_a + J \mathbf{e} + \mathbf{f}(\mathbf{e}))
\]

Where \( \mathbf{u} \) contains adaptive estimates of uncertain parameters in the dynamic model (e.g. mass, inertia, geometric parameters). Using the following dynamic equations of motion for 6-degrees of freedom, the resulting state space matrices in MATLAB are modeled with Simulink to structure a comparison between the effects of a linear vs. nonlinear control algorithm.

REFERENCES