QUASAR: AN EXPERIMENTAL TEST BED FOR AUTONOMOUS MULTI-AGENT CONTROL

ERIC PADILLA†, MARK BEACH‡; ADVISOR - DR. WILLIAM MACKUNIS, PHD.
EMBRY-RIDDLE AERONAUTICAL UNIVERSITY - *DAYTONA BEACH, FL ~ COLLEGE OF ARTS AND SCIENCES*

INTRODUCTION

This research project deals with the development and testing of the **QUA**drotor **S**warm **AR**ena (**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. Our initial multi-agent UAV complement, (our "swarm"), consisted of four CrazyFlie quadrotors relying on RF communication protocols that have since been replaced by custom built quadrotor agents with onboard PID controlled actuators, multiple accelerometers, WiFi communication modules, and various external sensors.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.

CONTACT

‡B.S. Engineering Physics Program: Spacecraft Systems, & B.S. Computational Mathematics Program: Physics AOC - Undergraduate Studies
Email: padille3@my.erau.edu

‡Accelerated M.S. Engineering Physics Program: Spacecraft Systems - Undergraduate Studies
Email: beachm3@my.erau.edu

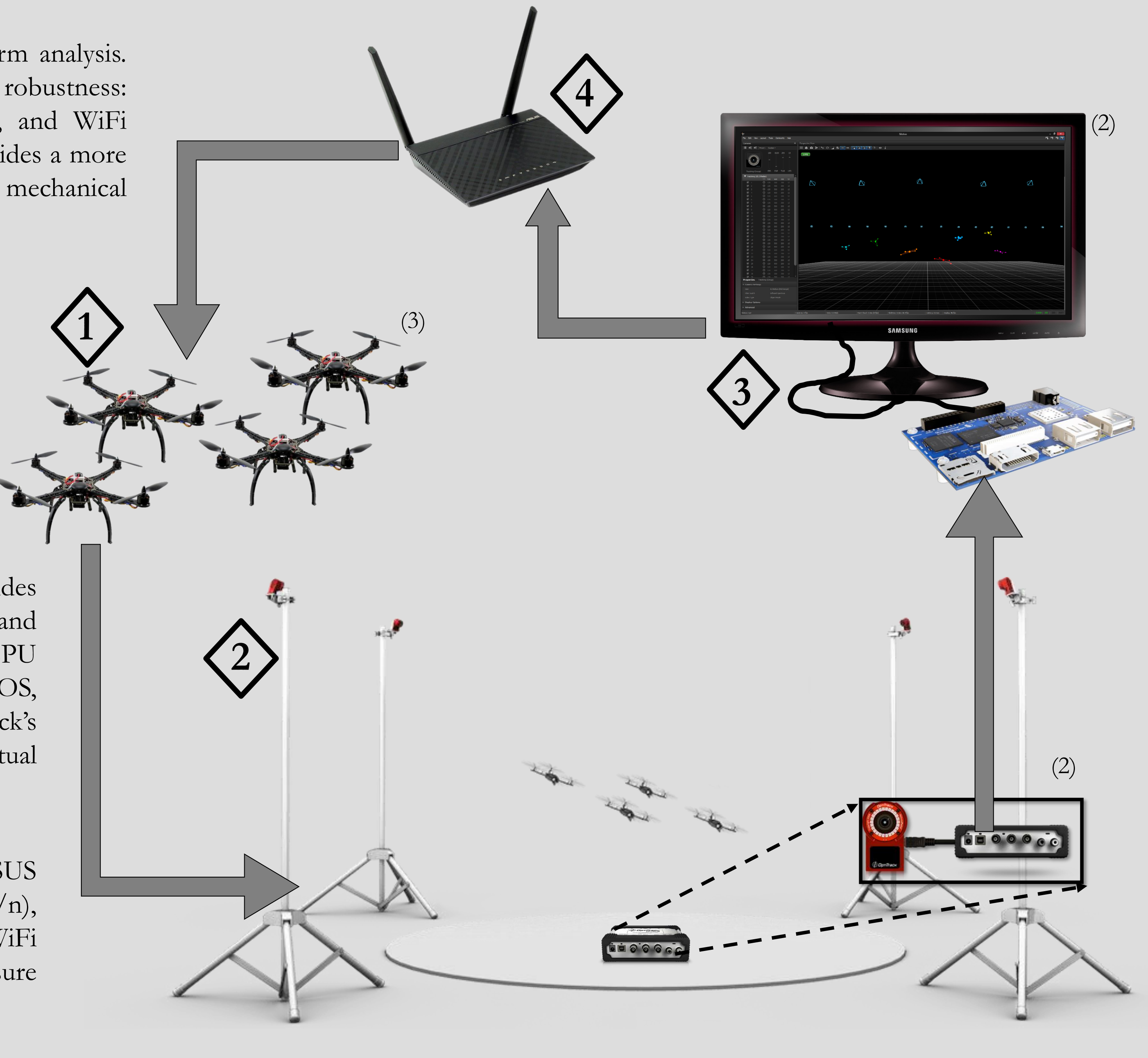
EXPERIMENTAL TEST BED

1. Multi-agent quadrotor drones for unmanned UAV/satellite swarm analysis. Two different models were used to test communication protocol robustness: 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 8', securely 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 broker"), provides a graphical user interface and data analysis for live position and altitude determination. Comprised of a powerful CPU (Dragonboard 410c development Board) with a Linux installed OS, position data is analyzed 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-N300 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

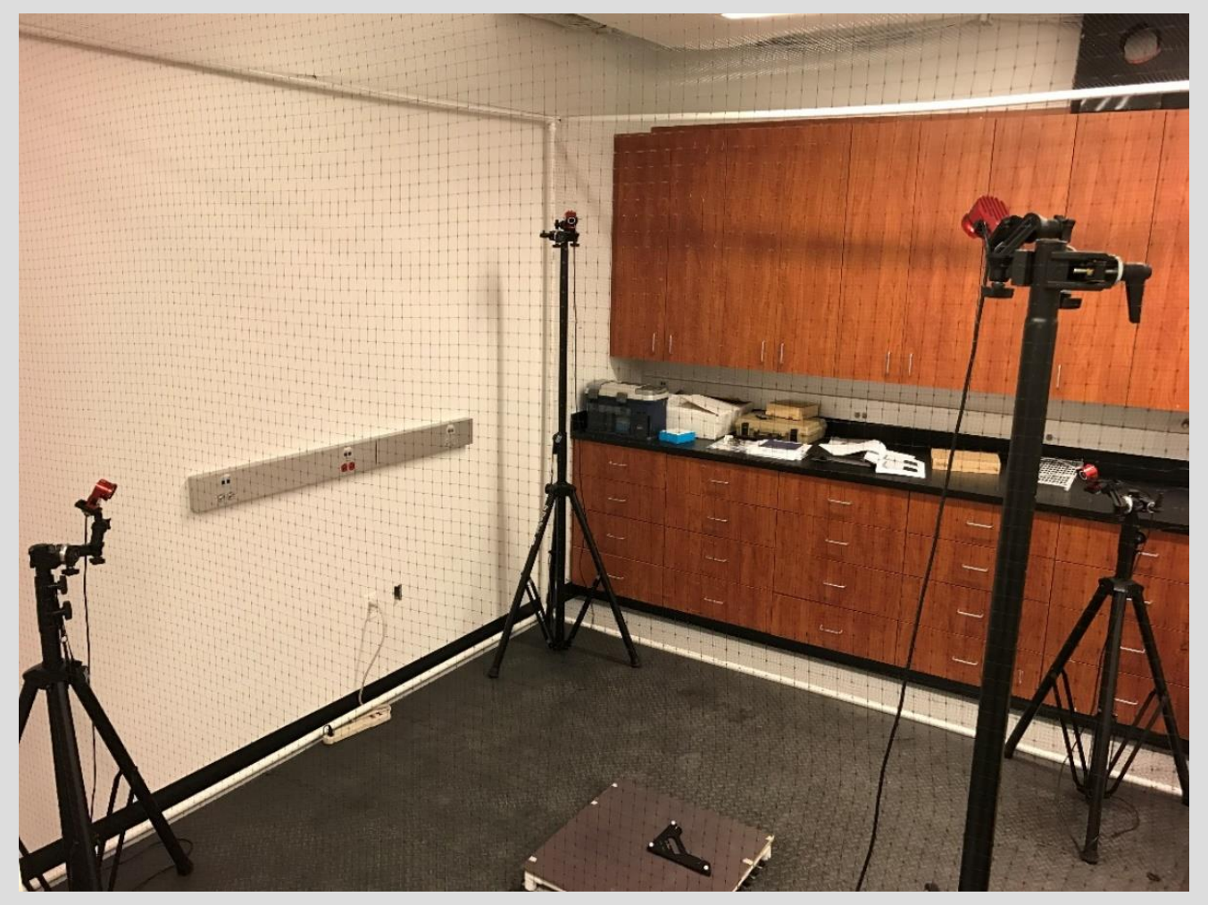


Figure 1: *Experimental test bed.*

Quasar relies on the use of 4 high speed OptiTrack Flex13 cameras to provide discretized real-time position and altitude 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 receive the position data packages from the established WiFi network. The simulations and control functions used assume 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 from:

$$u(t) = -\hat{\boldsymbol{B}}^{-1}\big((k_s + 1)r + \beta sgn(e)\big).$$

Where $\hat{B}$ 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 modelled with Simulink to structure a comparison between the effects of a linear vs. nonlinear control algorithm.

$$\boldsymbol{\tau} = \mathbf{J}\dot{\boldsymbol{\omega}} + \boldsymbol{\omega} \times (\boldsymbol{J\omega} + J_r \Omega_r \boldsymbol{e_3}) \quad [1]^1$$

$$m_i \dot{\boldsymbol{v}}_i = \boldsymbol{R_i T_i} - m_i g \boldsymbol{e_3} \quad [2]^1$$

- $\boldsymbol{\tau}$: torque vector,
- $\boldsymbol{J}$: inertia tensor, & J_r: rotor inertia,
- $\boldsymbol{\omega}$: angular velocities
- Ω_r: rotor speed,
- $\boldsymbol{e_3} = [0\ 0\ 1]^T$: rotor orientation,
- $\boldsymbol{v}$: velocity vector,
- $\boldsymbol{R}$: rotation matrix,
- $\boldsymbol{T}$: forces.

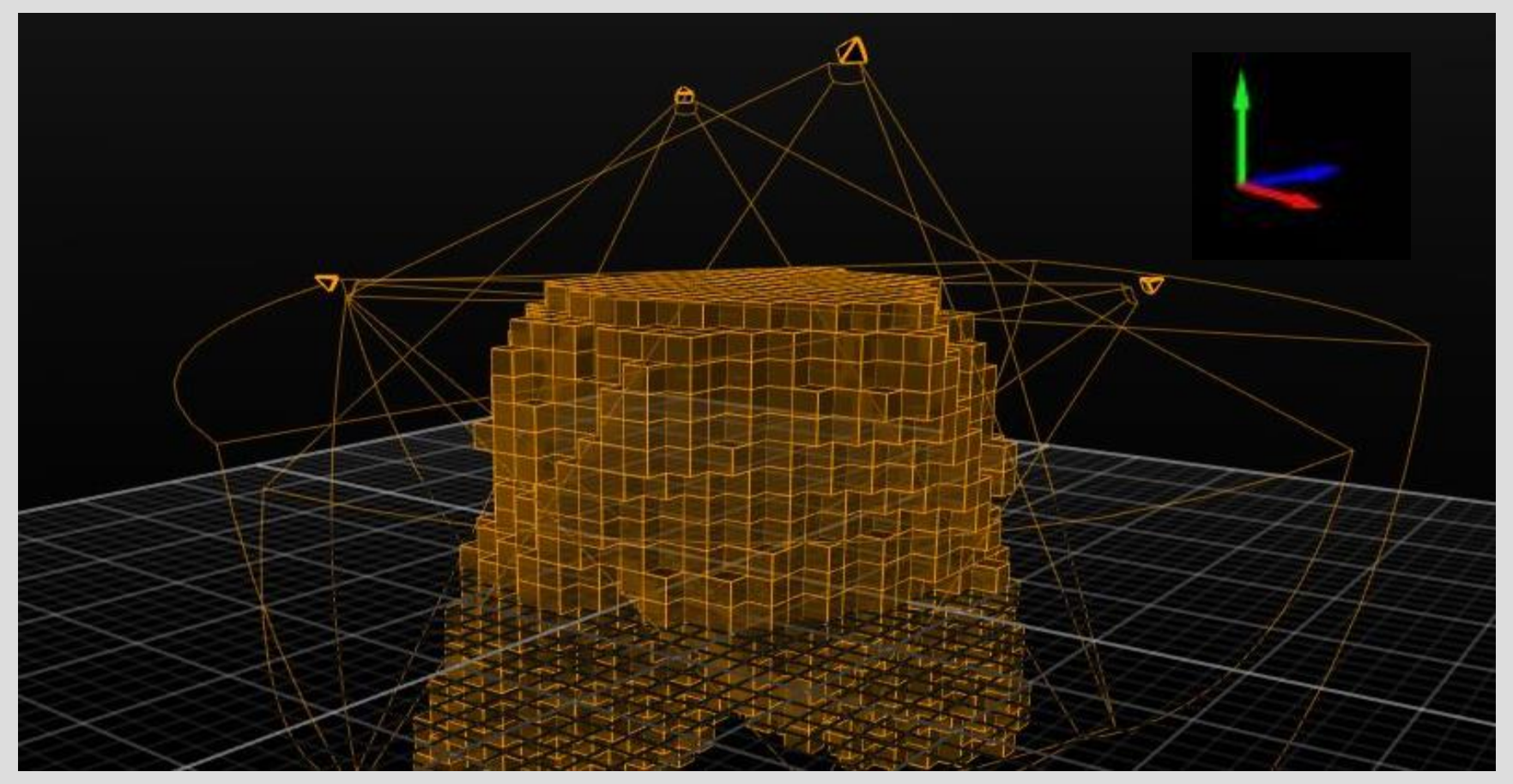


Figure 2: *Experimental capture volume using Motive software with 4 Flex 13 cameras.*

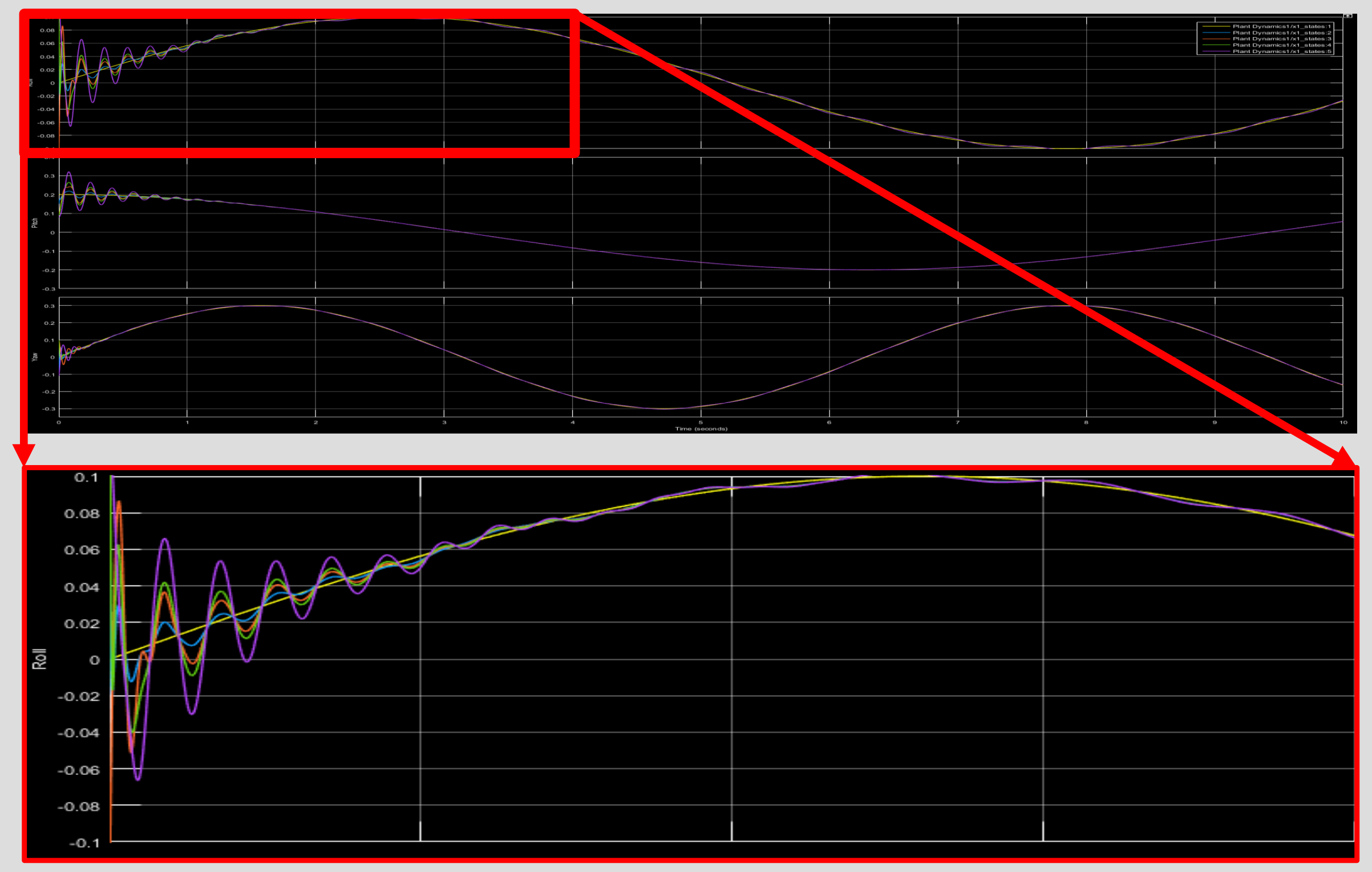
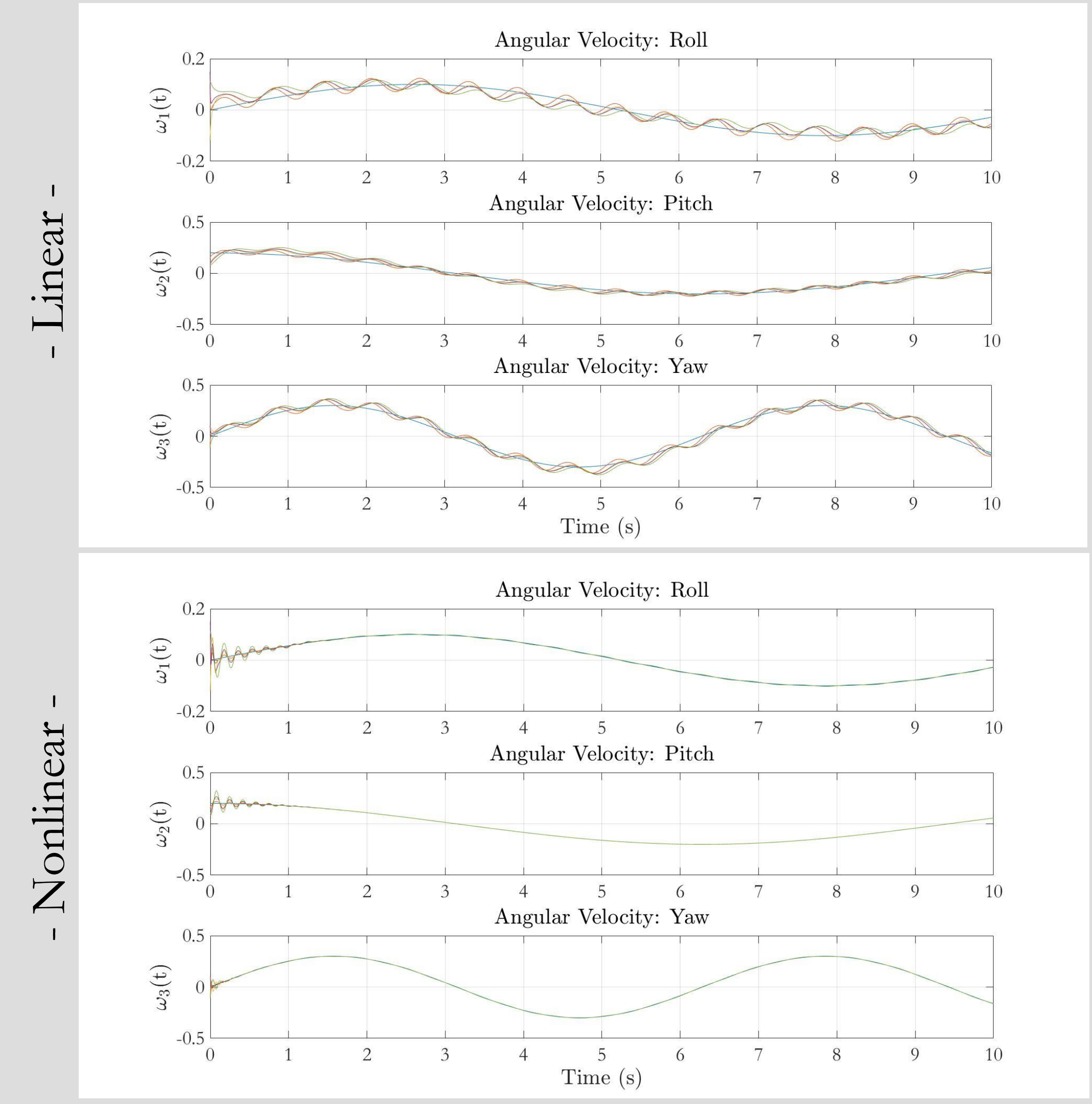


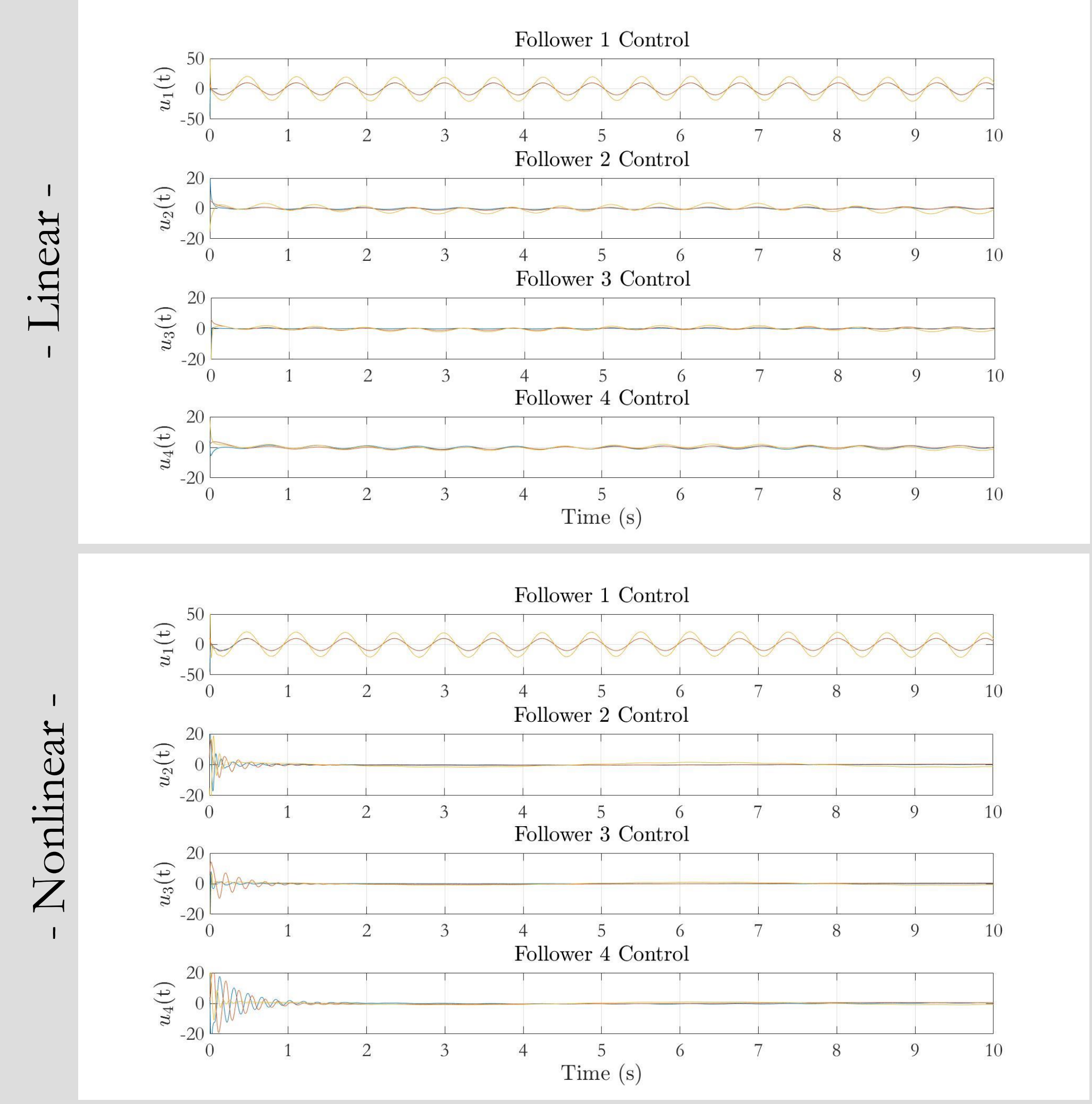
Figure 3: *Preliminary angular roll velocity response using a nonlinear adaptive control method.*

RESULTS

ANGULAR VELOCITY RESPONSE



CONTROL TORQUE COMMANDS



REFERENCES

[1] Macnab, C.J.B., Nicol, C., Ramirez-Serrano, A.; "Robust Neural Network Control of a Quadrotor Helicopter," in *IEEE Conf.* 2008, Schulich School of Engineering, University of Calgary.
[2] Motive: Tracker; *NaturalPoint, Inc. OptiTrack*. 2017.
[3] 550mm RTF Quadcopter UAV; RB-Sho-03, *Robot Shop*, 2016. RC Hobby.