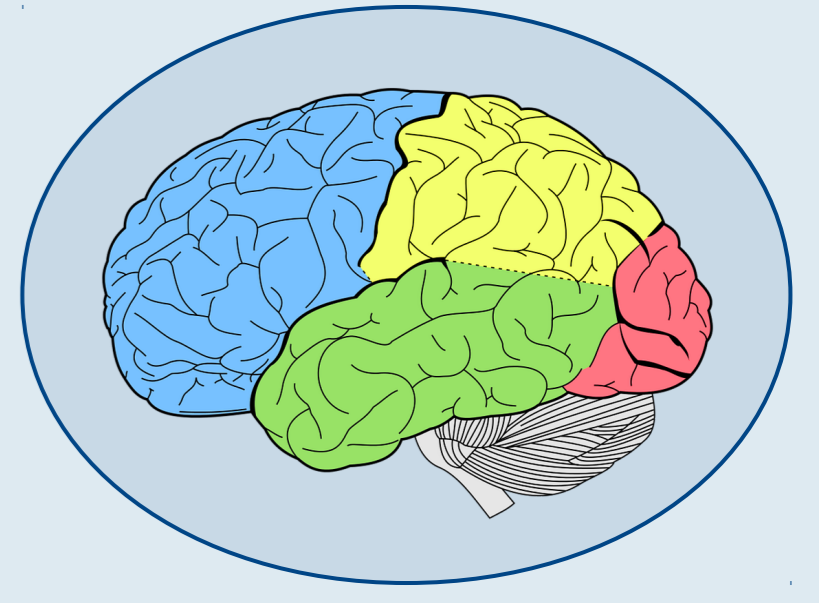




# The A-CLASS Method for Autonomous Quadcopter Formation Control



Shane Stebler, William MacKunis  
Embry-Riddle Aeronautical University  
Department of Physical Sciences

## ABSTRACT

Methodologies aimed at Advanced Control through Learning in Autonomous Swarm Systems (A-CLASS) utilize the tools of nonlinear control to develop and rigorously analyze new strategies of machine learning for formation control in collaborative autonomous multi-agent UAV groups. In A-CLASS, new algorithms for online, real-time machine learning can be achieved through the investigation of new automatic control policy improvement strategies, which optimize future control actions based on past experience. Recent advances in reinforcement learning methods have made significant progress in understanding and mimicking brain functionality at the level of the brainstem, basal ganglia, cerebellum, and cerebral cortex. In particular, neural network (NN)-based actor-critic structures, which utilize approximate dynamic programming (ADP), are promising techniques for simulating brain-like thinking in engineering systems. In this research project, new experience replay-based multi-agent control techniques will be investigated, which 'learn' from experience in real time the optimal control action in response to a given sensor stimulus. The end goal of this research project is experimental demonstration of new A-CLASS-based control methods on multi-agent groups of autonomous quadcopter UAVs using a motion capture arena.

## BACKGROUND

This research highlights two main topics: distributed control and collaboration of groups (*swarms*) and machine learning. The A-CLASS method aims to join these two areas.

### Distributed Control and Collaboration:

This facet of the A-CLASS method refers to the idea that individual agents work together as a group to accomplish a task. In such a system, control action is completed locally by each agent using relative/partial knowledge of the group and the environment. This results in a decentralized system that is much more robust to failure, increasing the likelihood of mission success.

Additionally, heterogeneous groups may be used, which largely increases the potential applications and achievable task complexity.

### Machine Learning:

Artificial Neural Networks (ANN's) are the learning mechanism of interest to this research. An ANN refers to a highly nonlinear mathematical construct, which allows a system to approximate time-varying dynamic uncertainty.

This technique is motivated by the brain. Furthermore, actor-critic techniques (to be used in A-CLASS methodology), mimic more than individual neurons and take on roles similar to the brainstem, basal ganglia, cerebellum, and cerebral cortex.

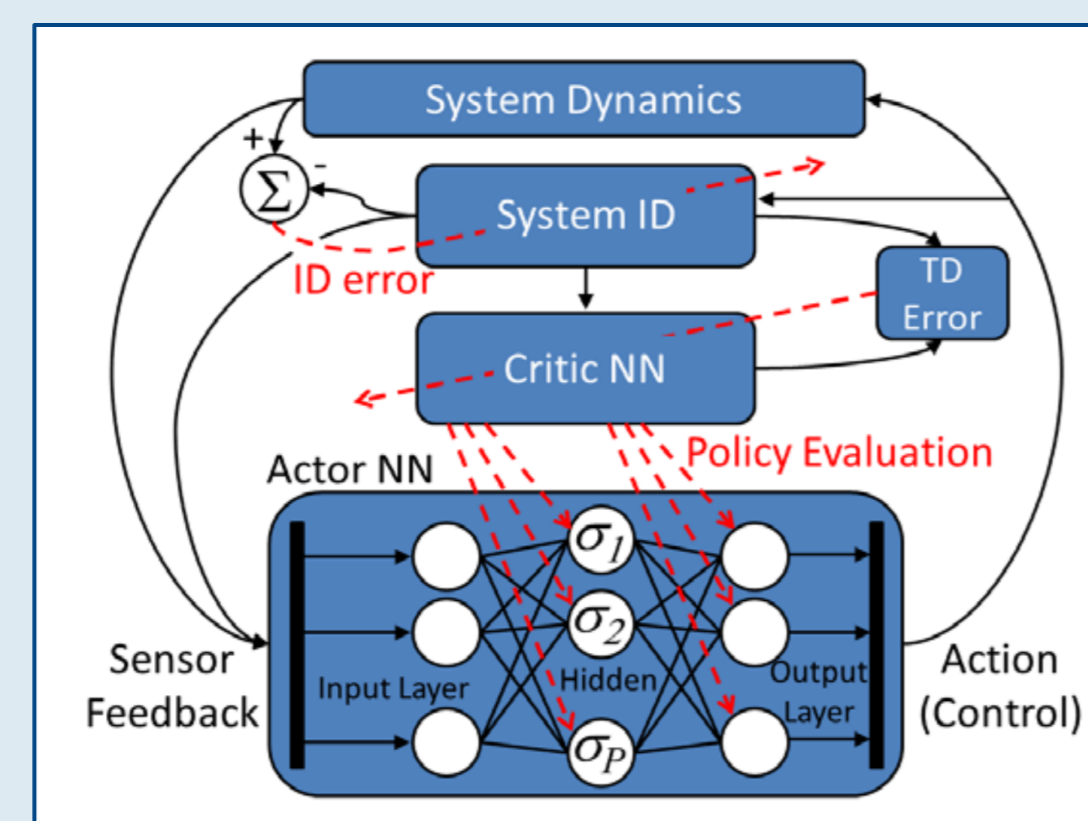


Figure: Actor-Critic Topology

## METHODOLOGY

### Experimentation:

A primary focus of the undergraduate contribution to the A-CLASS research was a testbed for experimental validation of theoretical advancements.

The testbed utilizes small, Crazyflie 2.0 quadrotors, weighing approximately 28 grams with a diagonal of approximately 12 cm. These vehicles each contain a number of infrared reflectors for tracking.

A system of four OptiTrack cameras tracks these markers and provided feedback to the on-board computers via RF transceivers

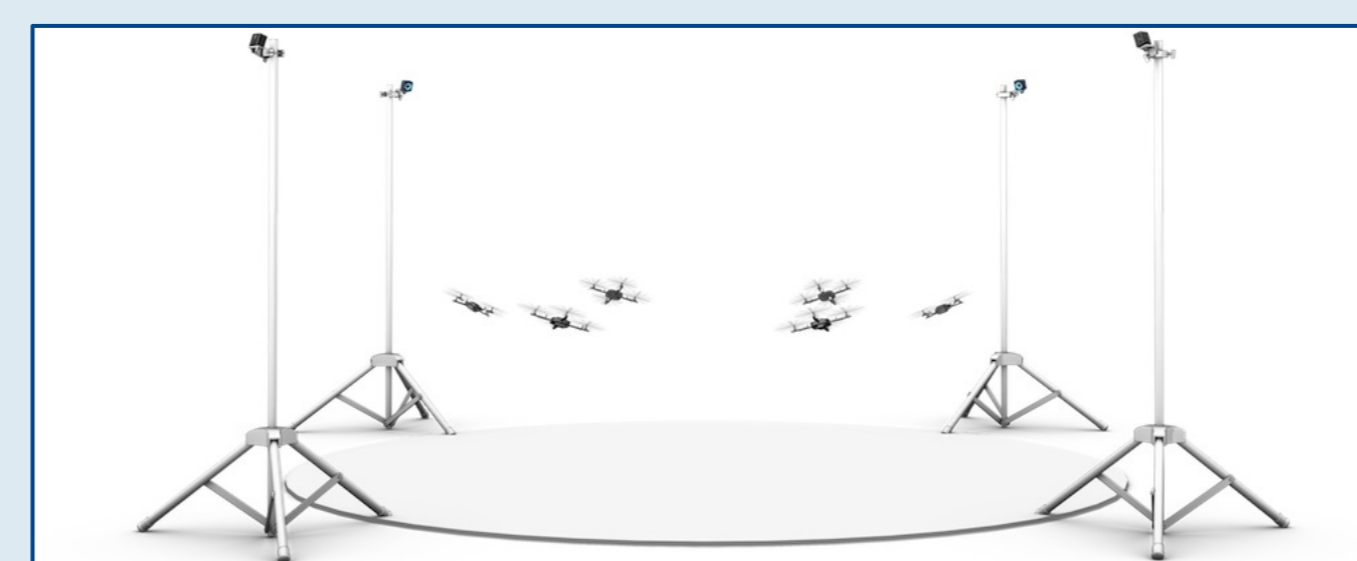


Figure: OptiTrack



Figure: Crazyflie 2.0 Agent

### Simulation:

In addition to experimental testing, simulations are used to preliminarily evaluate the performance of the A-CLASS method.

The simulation techniques are summarized by the control objective:

*Suppress deviations in the actual quadrotor displacement and orientation from a predefined reference.* This deviation (error) is written mathematically as,

$$e_i = \sum_{j \in \mathcal{N}_i} a_{ij} (x_j - x_i) + b_i (x_r - x_i), \quad r_i = \dot{e}_i + \alpha_i e_i$$

Where,  $e$  is the state error of each agent and  $r$  is the axillary error signal. Note that the  $a_{ij}$  term allows specific error between neighbors to be penalized and the  $b_i$  term allows error from the reference state to be penalized.

A baseline, robust feedback control scheme is selected as,

$$u_i = -g_i^{-1}(x_i) ((k_{s,i} + 1) e_i + \mu_i)$$

$$\dot{\mu}_i = (k_{s,i} + 1) \alpha_i e_i + \sum_{j \in \mathcal{N}_i} a_{ij} (\gamma_i \text{sgn}(e_i) - \gamma_j \text{sgn}(e_j)) + b_i \gamma_i \text{sgn}(e_i)$$

A final, significant facet of this research is the use of ANN's in the actor-critic configuration to approximate optimal control techniques for the swarm.

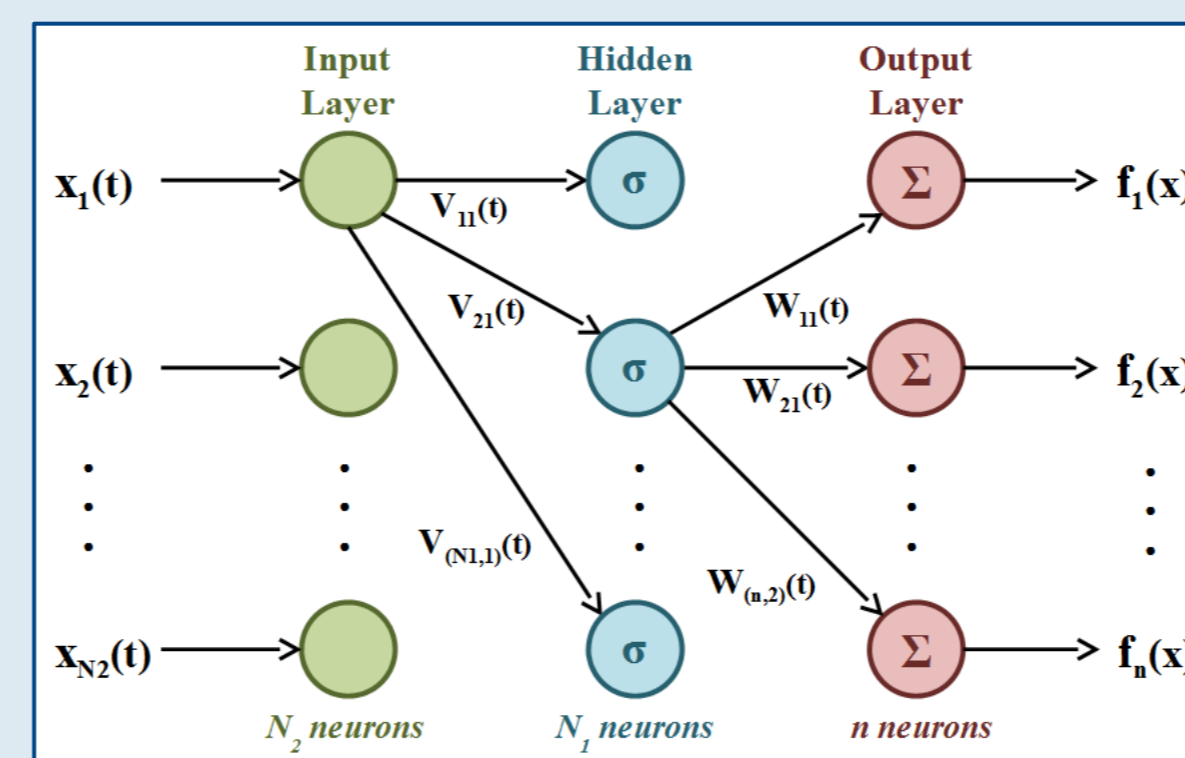


Figure: NN Architecture

## RESULTS

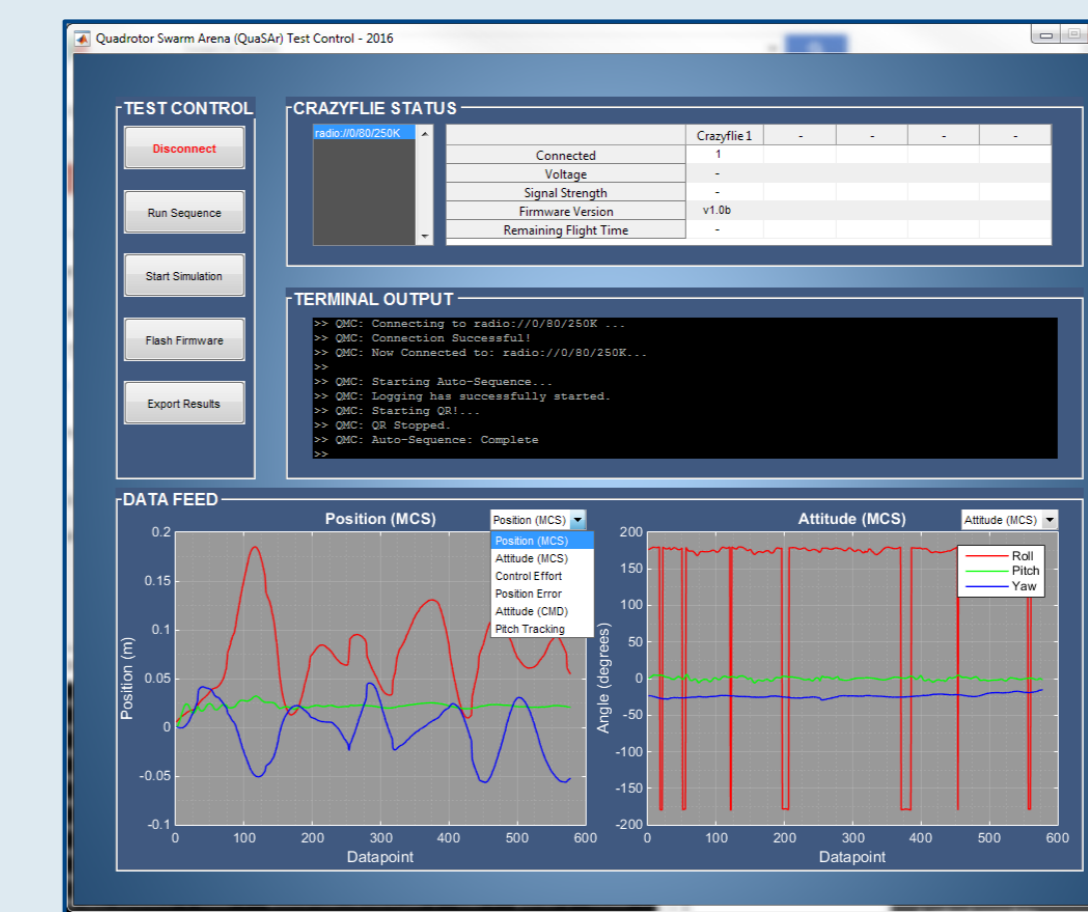


Figure: Preliminary Experiment Data

The initial construction of the swarm control testbed is complete for experimental validation of the specified techniques. Sample experimental data shows that the testbed successfully delivers the necessary signals for future experimental validation of A-CLASS methods.

In addition, simulations of theoretical A-CLASS methodology show that formation flight is successfully achieved.

One leader and four followers were found to successfully track reference trajectories using ANN estimation techniques for optimal control input solutions.

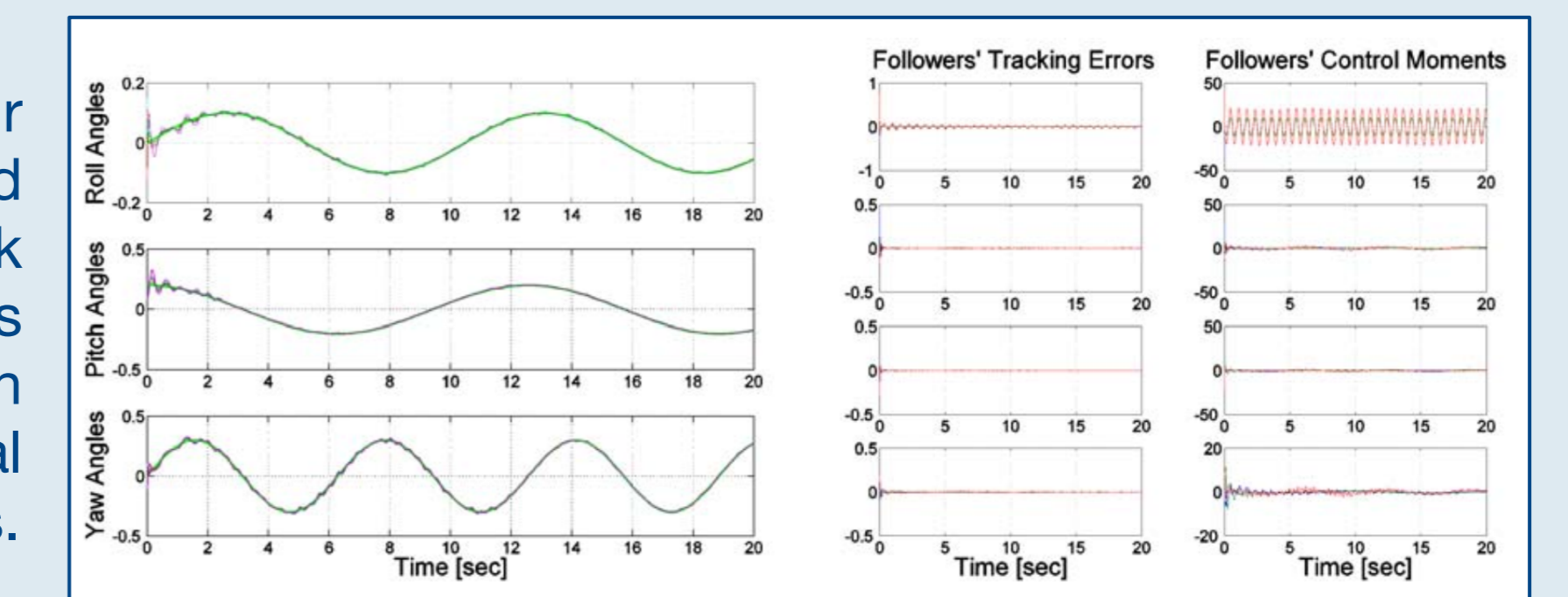


Figure: Preliminary Simulation Results

## CONCLUSIONS

Significant progress has been made toward the implementation of A-CLASS methods on autonomous quadrotor systems. Mainly, theoretical advancements have been made in the area of state estimation using an external motion capture system. One such advancement resulted in the publication by the authors detailing the implementation of a neural network to achieve online learning. This online construct was coined the *dynamic neural network*. In addition, the authors have also published results which use nonlinear estimation techniques for quadrotor agent control using the output feedback specifically found on the developed swarm control testbed.

## REFERENCES

- [1] S. Stebler, M. Campobasso, K. Kidambi, and W. MacKunis, "Dynamic Neural Network Based Sliding Mode Estimation of Quadrotor Systems," ACC, Pending Acceptance 2017.
- [2] S. Stebler, W. MacKunis, and M. Reyhanoglu, "Nonlinear Output Feedback Tracking Control of a Quadrotor UAV in the Presence of Uncertainty," ICARCV, Accepted for Publication - Pending 2017.

## ACKNOWLEDGEMENTS

The authors would like to thank the Physical Sciences Department for supporting this research as well as Embry-Riddle Aeronautical University for its contributions in the procurement of experimental materials.