EECS/MechE 206A

Autonomous Drone Racing (Research Project)

Alejandro Municio, Ben Finch, Michael Howo, Rohin Shanker

Fall 2025

1 Team Information

Name	Background
Alejandro Municio	Alejandro is a Mechanical Engineer in the MEng program interested in control systems and autonomous aerial vehicles. He has a Bachelor's in Aerospace Engineering from San Jose State University. He is currently studying model predictive control and doing his capstone project in Autonomous UAV Bridge Inspection in the HiPeR Lab.
Ben Finch	Ben is an ME - Robotics MEng student who studied General Engineering at the University of Warwick for his undergrad. His interests are in applied fluid mechanics, EV powertrains - particular battery design, and robotics. On the robotics side, controls and autonomy, particularly for UAVs. His capstone project is on UAV solar panel inspection and cleaning, also with the HiPeR Lab.
Michael Howo	Michael is pursuing his MEng degree in Mechanical Enginnering with a concentration in robotics. His bachelors was also in Mechanical Engineering from UC Santa Barbara. He is currently doing his capstone in Autonomous UAV Bridge Inspection as part of the HiPeR Lab and has prior experience working with mechatronics.
Rohin Shanker	Rohin is an EECS and BioE major interested in biohybrid systems and computational biology. He has been coding for over a decade and has worked with 10+ languages.

2 Abstract

Drone Racing research project:
This project aims to develop a modular UAV control and localization framework capable of executing agile, high-speed navigation through obstacle-constrained environments, with a focus on autonomous drone racing. In this context, the drone must navigate through a sequence of checkpoint-defined regions, which can include narrow passages, tunnels, or box-shaped volumes representing obstacles. The control system is responsible for ensuring the drone passes safely through these regions, avoiding collisions while maintaining smooth and efficient trajectories.

Backup project:
If are not accepted to the Autonomous Drone Racing research project, we will still try to achieve a similar goal of developing a control and localization framework for our drone to navigate a smaller subset of the obstacles.

3 Project Description

Project Goals
Drone Racing research project:
The goal of this project is to develop a software pipeline enabling a racing drone to perceive its environment, localize itself, and plan efficient trajectories for agile and obstacle-aware flight. Overall, this project aims to deliver a control and localization system specifically designed for navigating constrained obstacle courses at

high speeds, while providing a platform suitable for future reinforcement learning-based improvements.

Backup project:
The goal of our backup project is to do the same localization and path planning just on a different drone.

System Architecture
Drone Racing research project:
The control system will be designed using optimal control theory. The underlying cost function will be carefully structured to guide the drone's behavior through these constrained spaces. The function will assign higher penalties for positions closer to the boundaries of each checkpoint, encouraging the drone to fly through the centermost portion of the region. Additional terms in the cost function will discourage excessive trajectory changes and unnecessary accelerations, promoting smooth, high-speed flight. Hard constraints will enforce that the drone remains within the navigable region, preventing it from straying outside the bounds or colliding with obstacles. The resulting optimal trajectory will therefore balance speed, precision, and efficiency, allowing the drone to fly through the centermost path of each checkpoint while minimizing deviations or abrupt maneuvers.
A critical aspect of this project is robust localization, as the drone will operate with only a single onboard camera. To reliably navigate these constrained environments, the project will develop a visual-inertial fusion pipeline capable of accurately estimating the drone's position, orientation, and surrounding environment in real time. This localization system is essential for ensuring that the optimal control trajectories can be executed safely, particularly when flying through narrow passages or tunnels where even small positional errors could result in collisions.
While the primary focus is on developing a high-performance control and localization framework, the project will be formulated to support future reinforcement learning integration. By structuring the simulation environment, cost function, and control outputs appropriately, the system will allow reinforcement learning agents to later refine control policies, optimize trajectory execution, or improve environment perception under previously unseen conditions. This design ensures that the project not only advances the immediate goals of autonomous racing but also provides a foundation for data-driven, adaptive flight strategies in future work.

Backup project:
Similar to the research project we will need to implement a control system algorithm for for autonomous path planning and use a simulator to test and refine our trajectories. Our localization system will leverage dual cameras (rather than the single camera the race regulations require) to provide stereo vision, enabling more accurate depth perception and improved navigation through obstacles.

Sensing, Planning and Actuation
Drone Racing research project:
Sensing: single camera (per race regulations) and IMU sensor
Planning: path planning and localization algorithms
Actuation: executing the planned path

Backup project:
Sensing: stereo vision camera and IMU sensor
Planning: path planning and localization algorithms
Actuation: executing the planned path

Testing and Evaluation
Drone Racing research project:
Testing will involve flying the drone autonomously through a mock racing course. The project will be deemed successful if the drone can navigate at least a portion of the course without manual control. Our primary goal is reliable obstacle detection and avoidance, with a reach goal of optimizing flight trajectories for faster and smoother navigation.

Backup project:
Same testing and evaluation method perhaps on a slightly different course.

4 Tasks

1. **Drone Hardware** In the event that our group is not selected to work within the Drone Racing Research Project, our group will build a similarly equipped drone that will utilize the same array of sensors. This will include an integrated 3 axis accelerometer/gyroscope, pressure sensor, and single camera. In the event single camera localization proves to be too challenging to implement in simulation, stereo vision cameras will likely be used to improve the drone's localization capabilities.

    (a) **Formalize Available Hardware.** In the event that our group is not selected for the research project, we will need to formalize what hardware we are going to use for the project. This will involve determining what is needed to feasibly run a model predictive control system, assessing how important stereo vision is for localization. This decision will largely be determined by what hardware from the class is available to us. Currently the Tello Drone seems like it has the best array of sensors. The Crazyflie drones might be too small to hold more than one camera and its microprocessor will likely struggle to run a model predictive control system. In the event that it is chosen, appropriate changes will need to be made to the project scope. We are also considering buying a more expensive drone, such as a BetaFPV. [by 10/29]

2. **Simulating the Drone Environment:** We will be setting up a virtual environment, using Isaac Sim and ROS, to test the drone's dynamics and control system. This will allow us to avoid damaging the actual drone hardware early on, as we develop and test the drone's software pipeline.

    (a) **Getting Up to Speed** Assuming we are selected for the research project, we will want to become familiar with the current software stack and any additional software tools that are being used for the project. This would also include, setting up Isaac Sim and becoming familiar with its functionality [by 10/29]

    (b) **Simulating/Modeling Drone Dynamics** Selecting a suitable dynamics model for the drone and implementing it into the simulation. The model will closely consider any hardware limitations and/or unique capabilities. [by 10/30]

    (c) **Simulating/Modeling Race Environments** Modeling different obstacles that would be expected on the race course in the sim. This would include waypoint boxes, tunnels, simple obstructions, etc [by 10/31]

3. **Localization** A considerable section of the code pipeline will be focused on designing a robust means of localization [by 11/03]

    (a) **Sensor Fusion** Developing a framework that can effectively integrate sensor measurements to attain as accurate of a state estimation as possible [by 11/05]

    (b) **Obstacle Detection.** Developing a module that identifies the location of incoming obstacles through the drone camera data [by 11/07]

4. **Model Predictive Control System Development** This section will be the focus of our Model Predictive Controls Project for our MechEng C231a class.

    (a) **Control System Design** Deciding an appropriate control model, control constraints, local trajectory horizon [by 11/07]

    (b) **Optimization Formulation/Research** Formulating a convex optimization method that will penalize slow flight, proximity to obstacles, and changes in trajectory. Additionally it will constrain the drone's flight to fall within race course boundaries and any other needed boundaries/limitations. [by 11/09]

5. **Flight Testing** We will test the robot in a controlled environment, featuring real-life obstacles that match our simulation test conditions.

    (a) **Basic flight Functionality.** For our backup project, our drone should be capable of rudimentary controlled flight early on. [by 11/07]

(b) **Sensor Functionality.** For our backup project, our sensors should be proven functional early on [by 11/09]

(c) **Test Setup.** If our group is selected, testing will take place in Cory 391. In the event that our group is not selected, we will assemble a simple racecourse that outlines a simple racetrack and will feature similar obstacles to the ones modeled in the simulation [by 11/24]

(d) **Drone Flight Testinng.** Drone flight testing will be conducted during Thanksgiving week. [by 11/28]

6. **Reporting Results.**

(a) **Formalizing Project Presentation** We will have full results [by 12/11]

(b) **Completing Website Report** A report outlining the project premise, our approach to solving the problem, and our final results [by 12/19]

Backup project:
The timeline for our backup project would be very similar. Instead of getting up to speed with the lab we would be testing our own drone and hardware components.

5 Bill of Materials

5.1 Use of Lab Resources

If our application to the autonomous racing drone project is successful, it is assumed that the majority of standard equipment such as gates or access to the motion capture room will be available to us.

Item	Quantity
Tello drone (Backup project)	1
Motion capture room (Backup project)	1

5.2 Other Robotic Platforms

Item	Quantity	Owner/Location
A2rl custom built racing drone	1	C.K. Wolfe

5.3 Other Purchases

Item	Quantity	Justification
Printed Aruco tag (Backup project)	8	For validating and potentially locating gates in initial tests
Foam rings - DIY (Backup project)	1	To construct gates, or borrow Sastry group equipment
Additional lightweight camera (Backup project)	1	Potential option for stereo vision
Fasteners and mounting (Backup project)	1	Inexpensive but included for rigor