ECE 445
Final Project Proposal

Collaborative Control of Ground and Aero Vehicles

Alvin Sun
Jialiang Zhang
Mingda Ma

TA: Andrew Chen
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Contents

1 Introduction **2**
1.1 Background . . . 2
1.2 Objective . . . 2
1.3 Physical Design . . . 2
1.4 High-Level Requirements . . . 4

2 Design **4**
2.1 Block Diagram . . . 4
2.2 Functional Overview . . . 4
2.3 Block Requirements . . . 5
2.3.1 Estimation Module . . . 5
2.3.2 Control Module . . . 6
2.3.3 Visualization Module . . . 6
2.4 Risk Analysis . . . 6
2.4.1 Low Level Control Delay . . . 6
2.4.2 COVID-19 Lab Access . . . 7

3 Ethics & Safety **7**

1 Introduction

1.1 Background

Autonomous delivery over drone networks has become one of the new trends which can save a tremendous amount of labor. However, it is very difficult to scale things up due to the increasing likelihood of collision between multi-rotor drones and ground vehicles, especially when carrying payload. In order to actually have it deployed in big cities, we could take advantage of the large ground vehicle network which already exists with rideshare companies like Uber and Lyft as well as public transportation networks such as buses and mailing / delivery services. The roof of an automobile has plenty of space to hold packages and a drone network can optimize for flight time and efficiency while having minimal interference with the automobile's route. While this can dramatically increase delivery coverage and efficiency, the problem of safely docking a drone onto ground vehicles in motion remains quite challenging.

1.2 Objective

We aim at a proof of the mentioned idea in the lab environment by implementing a decentralized multi-agent control system that automatically synchronize a drone with an in-motion ground vehicle when in close proximity. As this project is aiming towards a proof of concepts of a core challenge to the overall problem, we will make the assumptions that vehicle states (such as its position and orientation) can be accurately estimated. The infrastructure of the lab, drone and ground vehicle will be provided by our kind sponsor Professor Naira Hovakimyan. The synchronized motion will be achieved through a collaborative peer-to-peer control scheme. More specifically, the ground vehicle will estimate its own trajectory a couple of seconds into the future, and will periodically send the trajectory to the drone. Since the drone cannot acquire absolute position read from the motion capture system, the ground vehicle is also in charge of estimating the drone's poses (through motion capture). The drone will then optimize its current control to track this future trajectory.

1.3 Physical Design

As shown in Figure 1, we will design a collaborative control system so that the drone accurately tracks the predicted trajectory of the ground vehicle in real-time. After taking off from random initial conditions, the drone will fly towards the ground vehicle and stabilize into certain proximity range with respect to the ground vehicle. The problem of dynamic estimation is achieved through Vicon, an indoor motion capture system. In addition, we will also design a standalone alignment indicator that runs on board the ground vehicle. This is built with a custom-made LED matrix which can indicate the quality of the spatial alignment between the two vehicles. This hardware will display an overall color of green to indicate a good alignment, and red for a bad alignment. It also estimates the relative poses between the ground vehicle and the drone and display such relative displacement through LED patterns. As shown in Figure 2, the circle will be the position of the drone relative

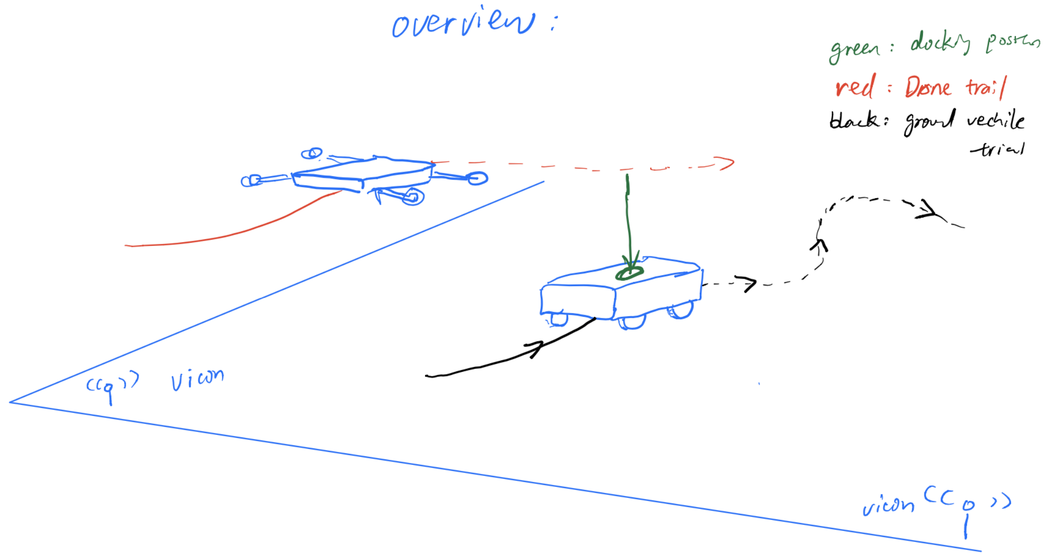
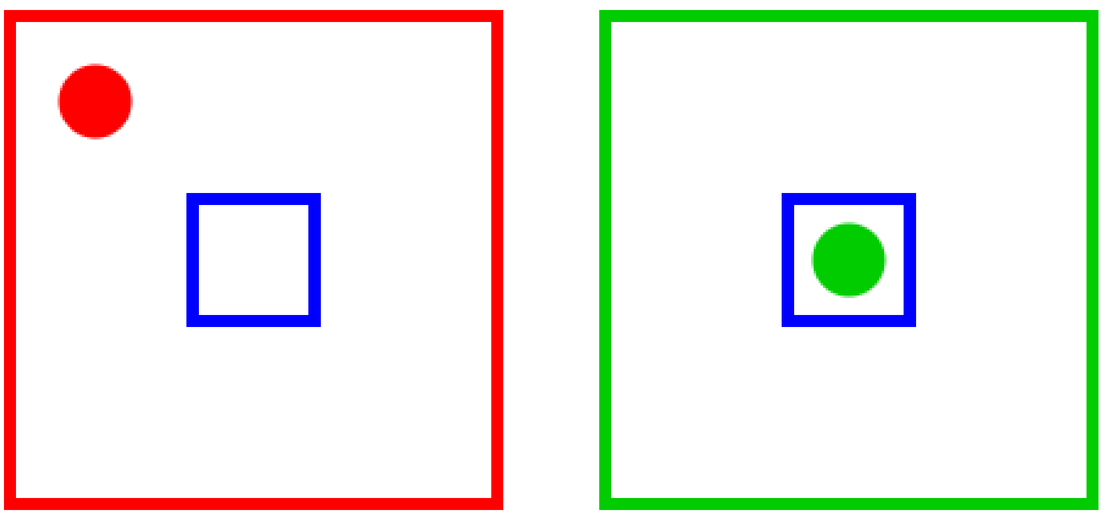


Figure 1: Overall Design Illustration

to the ground vehicle's heading. The overlapping between the circle and the center square indicates a good alignment situation.



(a) Bad Alignment (b) Good Alignment

Figure 2: Alignment Indicator Illustration

1.4 High-Level Requirements

The following requirements are all meant to be met under lab environment:

- The elapsed time between our Aerial Vehicle (AV) taking off and reaching the synchronous state (The drone could moving with the vehicle at the same speed. More details stated below) with our Ground Vehicle (GV) is no more than **20 seconds**.
- At synchronous state, the spacial proximity error between two vehicles is within a circle with **a radius of 30 centimeters**, centered at the spacial center of our GV.
- The LED indicator on our GV continuously reflects the spacial error between two vehicles with a delay of no more than **one second**.

2 Design

2.1 Block Diagram

See Figure 3.

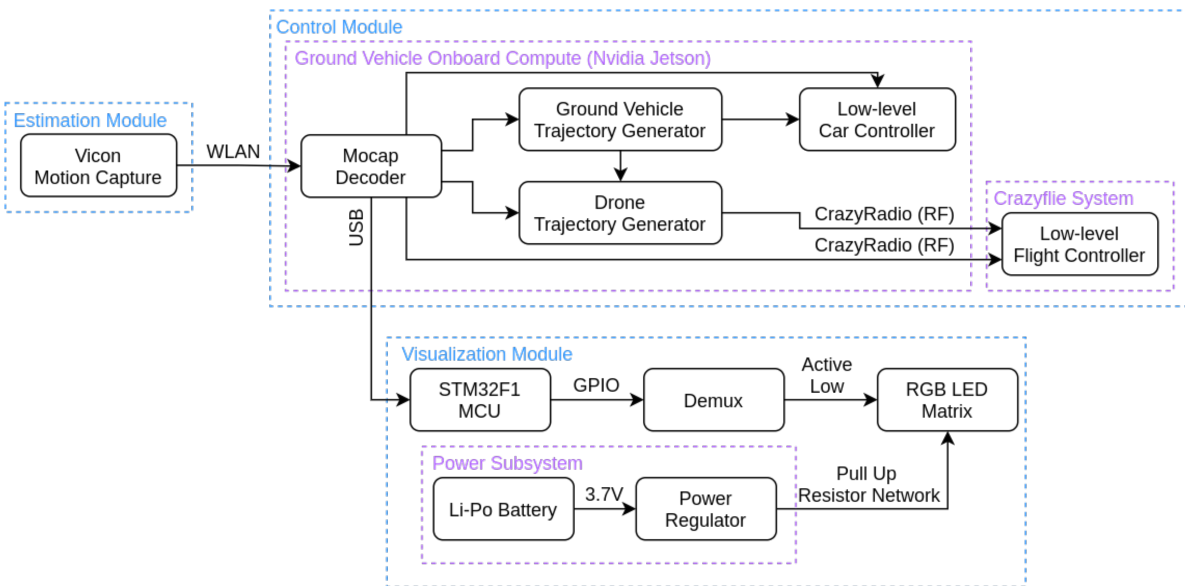


Figure 3: Block Diagram

2.2 Functional Overview

Vicon Motion Capture Vicon system uses high-speed cameras deployed around the lab to capture the motion of objects and collect the raw data.

Mocap Decoder Vicon decoder takes the raw data collected by motion capture and calculates the corresponding positions and orientations of the ground vehicle and the drone. It then broadcasts the calculated results to different subsystems through Wireless Local Area Network (WLAN).

Ground Vehicle Trajectory Generator (GVTG) GVTG generates a pre-programmed trajectory that will be passed on to the low-level car controller. GVTG will be deployed on the Nvidia Jetson microprocessor.

Low-level Car Controller Controls the movement of the ground vehicle and ensure its following of the trajectory.

Drone Trajectory Generator (DTG) Similar to GVTG, DTG generates a pre-programmed trajectory that will be passed on to the low-level flight controller on the drone's micro controller. However, due to the possible delays along the communication pipeline, DTG also needs to predict the ground vehicle's possible position and orientation within the next 2 seconds. DTG will also be deployed on Nvidia Jetson microprocessor.

Low-level Flight Controller Controls the movement of the drone and ensures its following of the trajectory.

STM32F1 Used as the interface with Mocap Decoder using USB port. It is also in charge of controlling the behaviors of the LED matrix.

Demux Used to decode the control signals sent by the MCU and convert them into signals that could be read by the matrix.

RGB LED Matrix Used to indicate the quality of the synchronization between the ground vehicle and the drone. The matrix will mainly display the position of the drone and landing position/range of the drone. The LED light box within the matrix will remain red when the synchronization has not been achieved. Once the synchronization has been achieved, the light box will turn to green.

Power Regulator Use correct resistors and capacitors to maintain the voltage of the power source to our designed value. Exact values of the resistors and capacitors remained to be decided.

Li-Po Battery One cell Li-Po batter used for power source.

2.3 Block Requirements

2.3.1 Estimation Module

The Vicon motion capture system is a commercialized indoor localization system that takes advantage of multi-view high speed imaging technologies. In order to configure it properly, we will need to install reflective markers to both ground and aero vehicles and calibrate their extrinsic poses before using the localization data coming from the system. The requirement for this module is to successfully capture the calibrated poses of the two robots with the Vicon system.

2.3.2 Control Module

This module is in charge of stabilizing both the ground vehicle and the drone. The overall requirement for this module is to achieve synchronous motion between the drone and the vehicle within certain proximity range.

Ground Vehicle Onboard Compute System This system is in charge for handling multiple software tasks including algorithms computation and message dispatching. It must accomplish the following tasks:

- Read in and decode the location and orientation of both robots coming from the motion capture system.
- Pre-plan a feasible and safe trajectory for the ground vehicle.
- Control the ground vehicle to follow the pre-generated trajectory.
- Generate feasible and safe trajectory for the drone based on the local ground vehicle trajectory.
- Send serialized messages including trajectory and mocap data to the drone.

Crazyflie System Crazyflie is a commercialized product for nano-drone development. The requirement for this subsystem is to develop add-on firmware that can successfully decode the external measurement and trajectories data sent from the ground vehicle, and integrate those information into their already implemented low level controllers.

2.3.3 Visualization Module

Power Subsystem Power subsystem must be able to support a stable 3.6V voltage and 2A current

Overall The visualization module must be able to communicate with the Mocap system and correctly display the correctness and quality of the synchronization by displaying the position of the drone and its relative position to the target platform.

2.4 Risk Analysis

In our proposed project, we can foresee two greatest challenges that induce risk to the overall completion of the project.

2.4.1 Low Level Control Delay

The low level trajectory tracker uses a linearized feedback controller to minimize the error with respect to the trajectory to be tracked. However, due to model uncertainty and noises, there are an unknown amount of delay introduced by such control algorithm. There are two solutions to such challenge:

1. Since both the ground vehicle and the drone has different but relatively constant tracking delay, we can tune for a relative delay time between the ground vehicle and the

drone. If we model such delay explicitly, we can cancel out their relative tracking delay and have a equivalent synchronization between the two vehicles.

2. Another way of solving this problem is to implement more advanced nonlinear controller such as MPC (Model Predictive Control) algorithms to optimize for a finite future horizon. However, due to the complexity and time scope of the project, this feature is considered outside of the completion of the project. We will try to implement this if we have completed all the requirements with extra time left.

2.4.2 COVID-19 Lab Access

Since our proposed project is mainly based on lab facilities (such as Vicon) provided by our sponsor, it is essential for us to get access to the labs and run our experiments on site. However, due to the unforeseen COVID situation, there is a risk that if the COVID situation becomes worse, more restrictions will be implemented, and we will not be able to access the lab facilities. If such event happens, we will move the robotics component to a simulation based delivery, and the hardware indicator will gather robot information from the simulator instead of the Vicon motion capture system.

3 Ethics & Safety

Although our project by itself cast little to no ethics or safety concerns as a project in lab environment with comprehensive safety measures, as a proof of idea, it may raise the following issues:

- **Conflicts of Interests:** The successful deployment of such network may significantly reduce the needs for labors in relevant industries, taking jobs from workers, and causing conflicts between companies and workers / unions. Such consequences could go against #3 of the IEEE Code of Ethics "to avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist." [1] We currently do not have a solution for this and consider it far beyond our control.

- **Possible Unlawful Misuse:** Such a autonomous delivery system might offer more vacant for smuggling, whereas increasing the difficulty for tracking such crimes. Such consequences, together with the next two in the list, would go against #1 of the IEEE Code of Ethics "to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment." [1] To avoid such unlawful activities and minimize their damage, it would be very helpful to record every delivery specifications and detect for contraband before the package is sent into the autonomous system.

- **Potential Hazard to Public Safety:** Aerial vehicles might cause serious secondary injuries under potential misbehavior of the ground vehicles since the drone can cause heavy impact and consequent explosion under high-speed. UAV-related incidents are no strange to today's society as shown by [2]. These experiments [3] suggest the serious aftermaths. In response, we should advocate the drivers to drive safely or use reliable auto vehicle system to minimize the possibility of accidents as well as to build a emergent evasion response for the drones.

- **Privacy Concern:** In industries, the cyber-security measurement at ending terminals such as the drones could be overlooked. A breach can cause serious violation to public privacy. Potential misuse includes stalking and leaking private information. To protect the civic privacy, the whole system should be protected by reliable hardware / software security such that it is maintained and examined periodically.

With aforementioned concerns, some positive aspects are listed below:

- **Productivity:** Without doubt, autonomous delivery system could tremendously increase the productivity. This benefit, together with the next point, help to develop #1 of the IEEE Code of Ethics [1].

- **Service & User Experience:** Without human intervention, the delivery system would avoid much misbehavior of express and significantly improve the user experience.

- **Social Progress:** The wide-use of such a system could push the progress of our society in many aspects, such as productivity, economy, legislation, cyber-security, and so on. This complies #2 of the IEEE Code of Ethics "to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems." [1]

References

[1] IEEE, "Ieee code of ethics." https://www.ieee.org/about/corporate/governance/p7-8.html. Accessed: 2021-02-18.

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[3] E. Tegler, "What happens when a drone crashes into your face?." https://www.popularmechanics.com/flight/drones/a28774546/drone-head-collision/, Aug 2019. Accessed: 2021-02-18.