Collaborative Control Design for a Drone Swarm

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PROBLEM DEFINITION

The aim of this project is to design a solution for the relative localization of drones in a swarm (two or more mobile robots) and the mapping of a target region with maximum dimensions of 15m x 5m x 8m. To avoid collisions, each drone should be able to detect the location of neighboring drones at up to 100cm and perform pose estimation with linear distance and angular orientation accuracy of 0.5cm and 2° respectively. The project should derive the real-time Voronoi tessellation of the target area with two drones flying at the same height to achieve optimal area coverage.

CONSTRAINTS

TECHNICAL CONSTRAINTS

- Network latency (40ms)
- Weight-bearing capacity of the drone: 0.5kg for Gaitech EDU Gapter drone
- Power consumption: drones should fly for 20 minutes on 1 battery pack

NON-TECHNICAL CONSTRAINTS

- Limited overall budget of $4,500
- Legal restrictions surrounding drone operation and data privacy
- Safety concerns related to drone operation

PROPOSED DESIGN

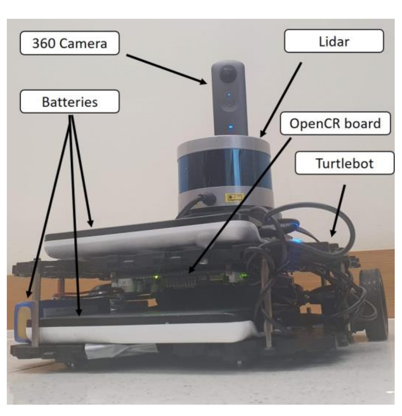


Figure 1A. Initial Turtlebot Design

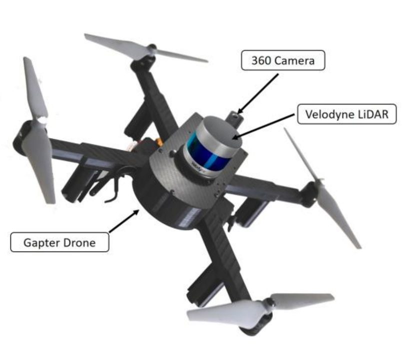


Figure 1B. Rendering of Initial Drone Design

The preliminary design was a 2D, ground-based approach using a Turtlebot Waffle Pi (Figure 1A), incorporating the Velodyne LiDAR and Ricoh-V spherical camera to refine trajectory planning, obstacle detection and mapping, with a proposed extension of the same concept in 3D with a Gaitech EDU Gapter drone (Figure 1B).

DESIGN DEVELOPMENT

To improve the design, we used several SLAM algorithms, and Hector SLAM (see Figure 2) was ultimately chosen for its superiority in mapping indoor environments in the absence of GPS and magnetometers: two constraints at our indoor lab space with high magnetic interference. The Velodyne LiDAR exceeded the weight-bearing limit of the drone, so the 2D RPLIDAR A1 was used instead.

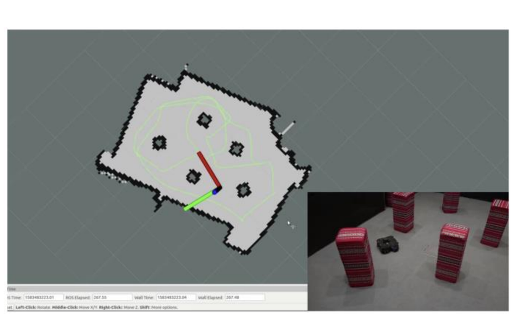


Figure 2. Obstacle Detection and SLAM navigation with Ground Vehicle

The spherical camera and LiDAR were positioned at the top of the drone for adequate viewing range. For pose exchange, an ad-hoc TCP/UDP communication was developed. For this setup, one TP-Link TL-WR802N Wireless N Nano Router was used on both drones. These routers produced an omnidirectional WiFi signal. The final design is shown below.

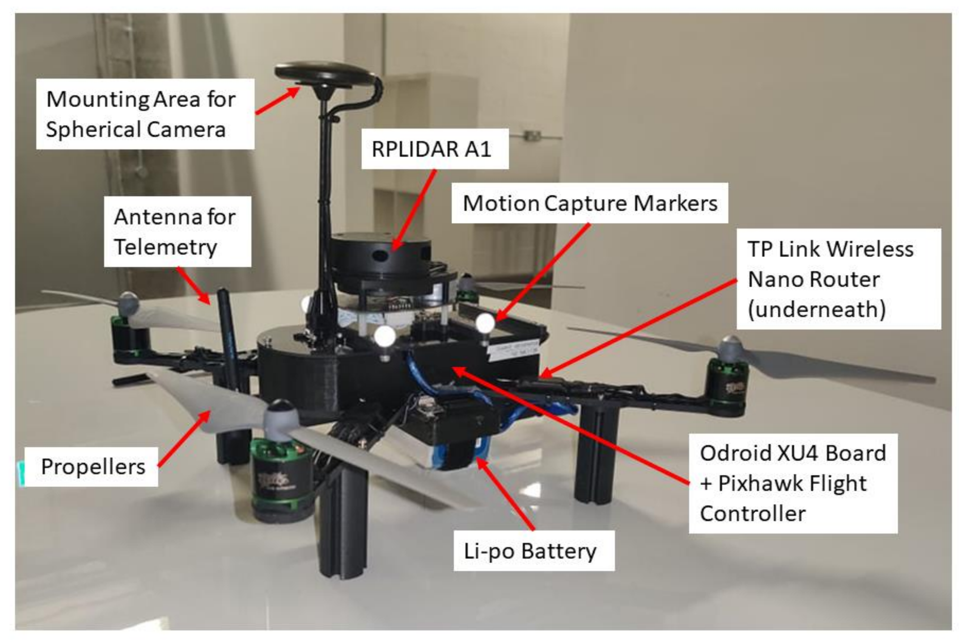


Figure 3. Final Drone Design with Labeled Components

IMPACT OF COVID-19 ON THE PROJECT

Although our overall goals for the project remained the same, intermittent lab closures due to Covid-19 led us to abbreviate the testing process with fewer experimental trials. Our final area coverage test was converted to a simulation because of lab access restrictions. We have chosen to forego some further research and testing that we had hoped to complete.

TESTING CRITERIA

The Vicon motion capture system (Figure 4) is a network of cameras that allows us to verify the position

- Whether the pose estimation is accurate to 0.5cm linear distance and 2° angular orientation and the map of the target area is accurate to within 3cm
- Whether the shaking of the drone is damped by 0.05g to reduce sensor noise
- Whether the pose exchange rate is sufficient to avoid collisions (maximum 303ms latency)
- Whether safety hazards are successfully mitigated

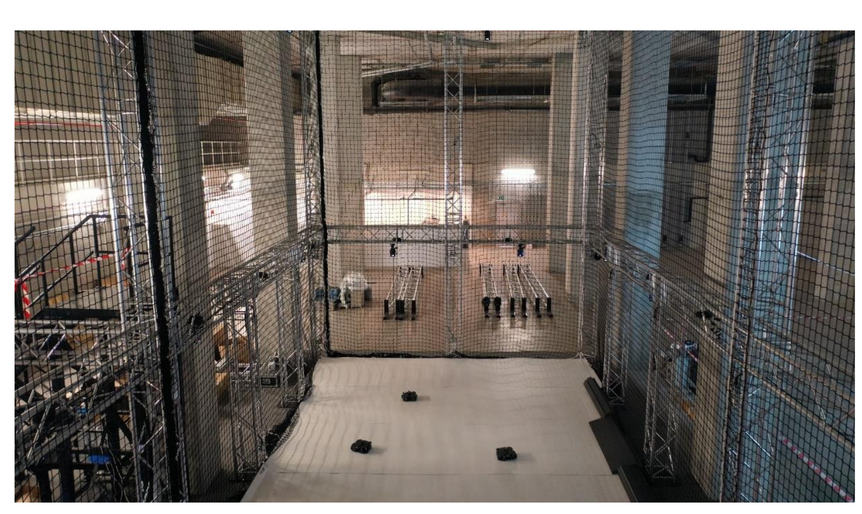


Figure 4. Vicon Motion Capture System at the Kinesis Lab

RESULTS & TEST DATA

The following tests were conducted to validate SLAM. A map of NYU Abu Dhabi's A1 building was obtained (Figure 5A) and neighboring drone were identified using visual servoing (Figure 5B) with accuracies within the range of the testing criteria.

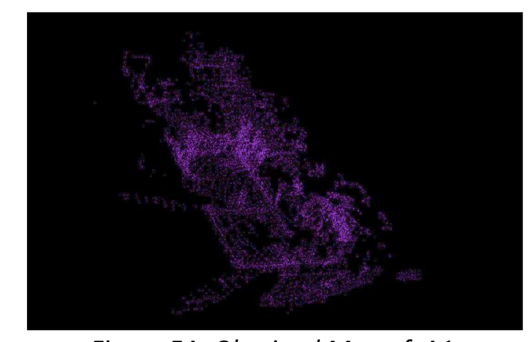


Figure 5A. Obtained Map of A1

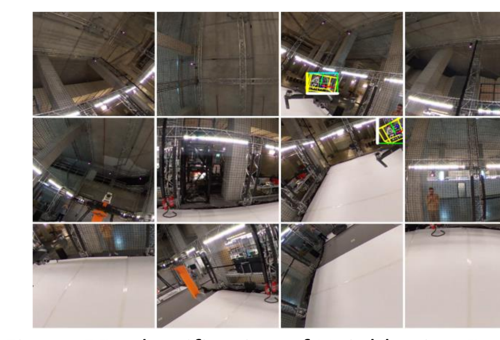
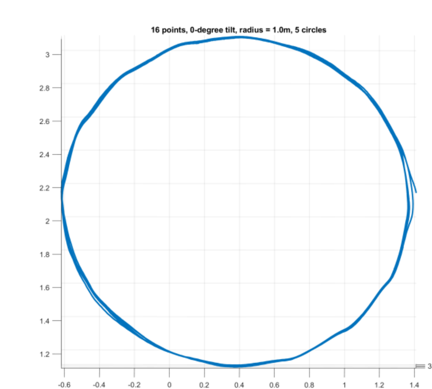


Figure 5B. Identification of Neighboring Drones

Trajectory planning was validated by programming a Gapter drone to rotate in five circles with sixteen waypoints per circle and recorded through the Vicon motion capture system cameras (Figure 6). Timestamp and translation was obtained for both Vicon and Ad-hoc network designs (Figure 7) to discern the optimum mode of data transmission.



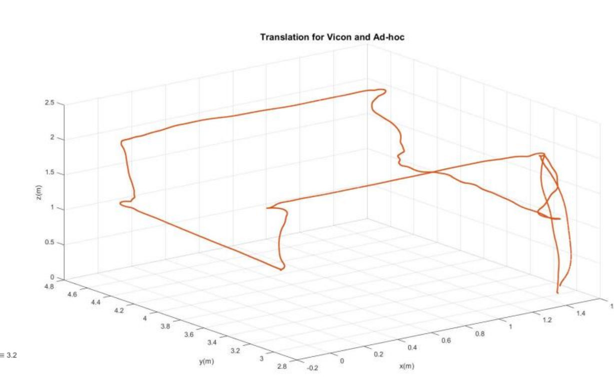


Figure 6. Implemented Circular Trajectory; Figure 7. Testing of Different Network Designs

A virtual simulation of the area coverage algorithm with Voronoi partitioning was simulating using *Processing* and Java (Figure 8).

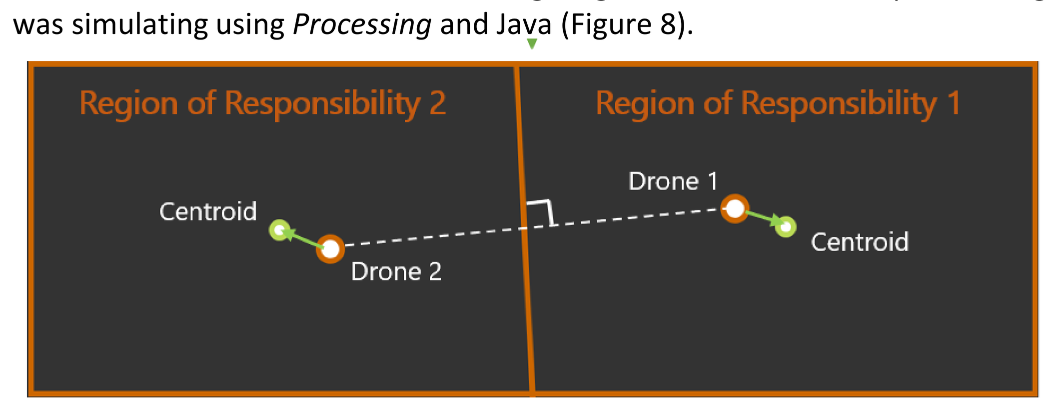


Figure 8. Virtual simulation of Area Coverage Algorithm

DISCUSSION

A variety of tasks related to collaborative control of a drone swarm, including trajectory planning, SLAM navigation using LiDAR sensing, identification of environmental markers via rectified spherical images, pose exchange via ad hoc networks, and area coverage, were successfully implemented and validated through simulations and lab testing. The components selected for the drone design successfully fulfilled the evaluation criteria and complied with relevant design constraints.

ACKNOWLEDGEMENTS

We would like to express our sincere appreciation and gratitude to our advisors Dr. Anthony Tzes and Dr. Jeremy Teo, as well as our lab supervisor Dr. Nikolaos Evangeliou. Additional thanks to Dr. Pradeep George and Dr. Ramesh Jagannathan for their mentorship throughout the capstone process.

AY:2019-2020, Senior Design Capstone Project I & II, Capstone Coordinators: Dr. Ramesh Jagannathan and Dr. Pradeep George, Capstone Advisors: Dr. Anthony Tzes, Dr. Jeremy Teo