Autonomous Vehicle Infinite Air Time Apparatus (AVIATA) Proposal Document

1 Overview

We plan to develop a system that can achieve indefinite flight time, capable of hovering and transporting a payload autonomously. This system will be known as the Autonomous Vehicle Infinite Air Time Apparatus (AVIATA). The system will consist of a central structure lifted by 8 multirotor vehicles (drones), each of which will detach before its battery is drained. Freshly-charged replacement drones will autonomously dock to the structure. Control and communication techniques will be used to ensure that the structure can keep itself airborne and respond to navigational commands based on the status and number of available drones.

Our team – Unmanned Aerial Systems at UCLA (UAS@UCLA), `https://uasatucla.org/` – includes members skilled in airframe design (Bhrugu Mallajosyula, Willy Teav, David Thorne, James Tseng, Eric Wong), software engineering (Axel Malahieude, Ryan Nemiroff, Ziyi Peng, Yuchen Yao), and business (Lisa Foo). We have access to a workshop with required tools during the school year, and can begin work on the mechanical and software aspects of this project simultaneously once approved.

1.1 Relevance to ARMD Strategic Thrust

This project addresses Strategic Thrust 6: Assured Autonomy for Aviation Transformation. AVIATA's swarm of unmanned aerial vehicles advances both function and mission-level autonomy in civil aviation.

At the function level, AVIATA automates individual drones' coordination within the swarm such that the entire swarm can be thought of as a single unit: individual drones will automatically fly from the home station to the correct position within the swarm and dock with the payload. This abstracts away the concept of individual drones by entrusting them with increased responsibility, simplifying operation and increasing redundancy and reliability. Should an individual drone fail, the remaining drones will be sufficient to share the extra workload until a replacement is made available.

At the mission level, AVIATA provides more flexibility in the range of tasks drones can perform. Provided that enough drones are deployed, the swarm approach enables the transportation of large payloads over arbitrarily long distances. In addition, this design renders the relatively low flight time of drones irrelevant, as it allows for fully-charged drones to take the place of dying ones. Due to these benefits, potential missions are effectively no longer constrained by flight time.

1.2 Project Objectives

Our objective is to develop a proof-of-concept system for AVIATA in order to demonstrate its viability and potential applications. As such, our goal as a team is to build a prototype capable of lifting a 10 lb payload and swapping in replacement drones using the approach proposed in the following sections. In theory, it would then suffice to replace our drones with larger (and more expensive) drones to increase the maximum payload possible.

2 Approach

2.1 Airframe Design

From a mechanical perspective, the system will consist of several independent drones and a separate octagonal frame to which the payload is attached (Figure 2.2). An octagonal frame was selected to reduce the bending moment each frame member is subjected to while providing locations for up to 8 hexacopter drones to attach. Since the objective is to prove the system rather than individual drones, our design uses off-the-shelf drones capable of up to 10 lbs of thrust each. The frame consists of eight carbon fiber tubes of equal length connected at each corner by a 135° tube joint. At each joint is a docking mechanism to allow for one of the independent drones to align itself and attach to the frame; the docking mechanism itself is described in Section 2.2. Below each joint is a hook to which the central payload will be attached.

2.2 Docking - Mechanical Design

Docking will be one of the more intricate processes in this system. Drones will be swapping in and out of the swarm according to their level of charge, and the docking mechanism must allow drones to rigidly attach themselves to the frame such that each drone acts as a series of "propellers" for the multivehicular structure. The docking mechanism will consist of two coordinating substructures: (1) permanent magnets and electromagnets to ensure alignment, and (2) solenoid-based locks that will hold the drones in place once aligned.

As a drone approaches the frame, it roughly aligns itself with a docking point using the software described in Section 2.3. Two electromagnets of opposite polarities on the drone align with corresponding permanent magnets at the docking point to finalize the orientation of the drone relative to the frame. Once aligned, two solenoids mounted underneath the drone extend their shafts into keyways built into the frame's corner joints (Figure 2.1). When the drone needs to undock, the solenoids will unlock and the drone will be able to slide out of the docking mechanism.

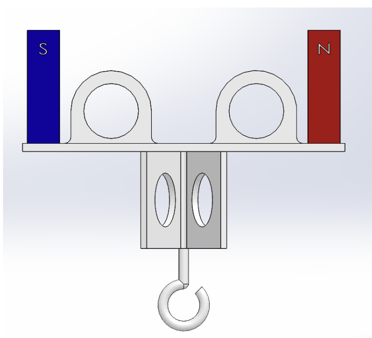

Figure 2.1: Docking component located at each vertex of the octagonal frame

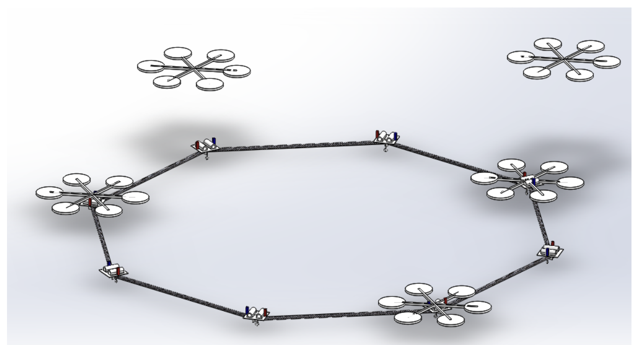

Figure 2.2: Octagonal frame with three hexacopters attached

2.3 Docking - Software Design

There are two stages to docking a drone: (1) approaching the swarm using GPS, and (2) docking using computer vision. Since GPS cannot achieve the centimeter-level precision that docking requires, the drone will switch over to a vision-based targeting system once within a distance of 2 m, using its camera to identify the target indicating the proper docking location. The switch-over distance was chosen based on experimentation: proof-of-concept testing with the OpenCV computer vision library (`https://opencv.org/`) indicate that shape and color detection can be reliably accomplished at a vertical distance of 2 meters. (Since the target must be within the field of view of the drone for detection to occur, approaching from the top offers the best range of detection.)

The vision targets will consist of pairs of different colors in order to enable the drone to identify the orientation of the target as well as its location. In addition, to ensure a drone does not mistake one vision target for another, we select distinct pairs of colors for each target such that only one target matches the drone's destination. Once identified, this information can then be passed to a PID controller for real-time adjustments.

2.4 Cooperative Control

The control system for the multi-vehicle structure will be implemented by modifying open-source flight control software. Because the AVIATA structure is rigid, it can be thought of as a single vehicle with a specific propeller configuration. In this configuration, the distance from the structure's X and Y (roll and pitch) axes to any given propeller varies significantly; therefore, each rotor will contribute a different torque based on its distance from the axis of rotation. Utilizing previous research (e.g. `https://www.lehigh.edu/~das819/pdf/icra18-modquad.pdf`), we will initially select a solution that minimizes motor saturation by offsetting the control input of each motor by the same amount, increasing or decreasing so that the direction of torque is correct. If motor saturation is not an issue, we may instead prioritize the adjustment of motors farther from the axis of rotation, since they have the highest ratio of torque to control input.

As drones dock and detach, the configuration of available propellers changes. Therefore, we improve stability by updating the controller in real-time to reflect the current state. Additional logic will determine which drones are allowed to detach to ensure that those remaining are sufficient to maintain control. The minimum number of allowed drones can be configured based on the payload size.

In order to coordinate between the drones, one vehicle is designated as the master, which executes standard control software using GPS to produce a thrust and attitude target and continuously broadcasts it to all other vehicles. Based on this target, each vehicle will independently determine control outputs according to its location within the structure. (Because the vehicles are rigidly attached, they are all expected to measure the same orientation.)

2.5 Inter-Drone Communication

We plan to use a mesh network to enable inter-drone communication, since it avoids overloading the ground station's WiFi router and adds more redundancy and flexibility to the network. We have selected an open source framework, LibreMesh (`https://libremesh.org/`), that provides basic functionality such as hash mechanisms and session management; however, we will be modifying its data transfer and dynamic routing strategies. The network will use a combination of limited flooding and greedy forwarding to minimize the latency for transferring data between the ground station and each drone. For dynamic routing, link-quality estimation will be used to determine whether each drone should connect to its neighboring node or increase the number of connection points to ensure connection quality.

3 Impact

The AVIATA system offers a set of features that have never before been simultaneously available. It achieves infinite flight time and a large payload capacity while still being small enough to ship easily. We believe AVIATA has promise in advancing capabilities in emergency communications, environmental monitoring, and supply transportation, but there may be many other applications not touched on here.

First, AVIATA can be quickly deployed with a communications device to provide 24/7 low-latency network access in a local area, which can benefit first responders and the public in natural disasters where standard communication infrastructure may become unavailable. Second, AVIATA can augment environmental monitoring by continuously gathering data from the air (e.g. air particulate presence). Third, AVIATA provides a solution to transportation tasks where vertical takeoff and landing is required, the journey is too long for a single drone, and charging hubs can be stationed along the path. Finally, this project paves the way for further research incorporating cooperative drone behavior and docking between airborne vehicles.

4 Logistics

4.1 Project Timeline

We plan to finish the project within 9 months from September to June. On the mechanical side, the drone-payload attachment frame should take approximately 4 weeks to finalize and 8 weeks to construct using the UAS@UCLA laboratory's workshop. On the software side, we plan to allot 8 weeks to implement the vision and control systems required for docking, which include identifying a vision target and using PID control to align and approach. The final 8+ weeks to completion involves incremental testing, adding in target identification, physical docking, automatic drone replacement, and collective navigation in sequence.

4.2 Crowdfunding Strategy

We plan to conduct our crowdfunding campaign through the UCLA Spark platform. We previously succeeded in raising $10,000 in 30 days for an annual drone competition we participate in (`https://spark.ucla.edu/project/18937`), and we are confident in being able to repeat a similar campaign for the USRC. Donation sources included alumni, particularly those with UAS@UCLA affiliations, official company sponsors of UCLA Engineering, and contacts through networks developed with faculty.