Technical Paper for the International Aerial Robotics Competition

Keefe Li, Mohammad Mohammad, Crista Mondragon Rivera
Chicago Engineering Design Team, University of Illinois at Chicago

ABSTRACT

Four autonomous quad-rotor air vehicles were developed for the purpose of collaborative human-machine interaction, fused sensory enhancement of a human operator by a fleet of aerial robots, swarm interaction, aerial target designation, and object interaction to compete in the International Aerial Robotics Competition: Mission 8. The air vehicles are built off of the Parrot AR Drone 2.0 with added improvements in program design, collision detection, and human-robot interaction. This paper will walk through the Chicago Engineering Design Team's thought process and technical implementation of the four aerial vehicles that are used for this competition.

INTRODUCTION

1.1 Problem Statement

As of late, hands-free interaction has become a forefront in our daily lives from smart home technology such as the Amazon Alexa and Google Home smart connected devices, to how humans travel with features such as autopilot being the next big boom in automotive technology. The integration of voice controlled commands and task assignment is crucial to Mission 8's success and is the focus of the Chicago Engineering Design Team's approach.

1.2 Conceptual Approach

The aerial vehicles were designed and implemented by students at the University of Illinois at Chicago through the Engineering Design Team (UIC - EDT). The initial design suggested was to build four air vehicles from scratch where features could be implemented and build upon in software and design. However, since this is Chicago EDT's first year entering IARC, pre-built aerial vehicles were considered since more time could be spent on developing new technologies rather than struggling with old ones. Moreover, Chicago EDT searched for pre-built air vehicles that had space for growth in the programming and design aspects. After a few weeks of research on various air vehicles found in the market, the Parrot AR Drone 2.0 was selected based on the safety features it implemented along with a vast network of other software engineers who had developed extensive libraries to use with the air vehicle. Once it was decided what pre-built air vehicles were to be used, the team focused on the technologies that needed to be added or developed.

The overall system architecture is composed of the Parrot AR Drone 2.0 mounted with ultrasonic sensors and a laser, along with a network where the air vehicles are connected to a central communication hub. This hub connects various devices such as the air vehicles, sensors, and the

WiFi mobile display device. At this offsite computer, all computations and commands are sent to the respective air vehicles for use in the arena. Scripts are executed from the offsite computer to dictate interconnectivity between each device on the network.
See Figure 1.2.1. Overall System Architecture

1.3 Yearly Project Milestones

The initial goal of the project was to develop the simplest air vehicle possible that met the requirements as mandated by IARC Mission 8. This included having the air vehicle fly autonomously, avoid obstacles, respond to verbal commands, use a laser on command, and send video feed to a display device.

The current design implementation is capable of human assisted autonomous flight, obstacle avoidance, and external video feed output with pending results on the verbal command technology and laser usage. The team's future plans include to focus on fully implementing verbal commands and laser usage, and continuously adding improvements to the current software that allows for autonomy, obstacle avoidance, and video transmission. Such improvements include updating or changing navigational algorithms and improving data analyzing for obstacle avoidance. In addition, future improvements include changing the physical components like the sensors to be more accurate. Currently, the air vehicles are using four ultrasonic sensors (HC SR04). However, these sensors offer limited feedback; the sensors may give erroneous results depending on the sound waves' surface impact, external noise, and rapid changes in position. For this reason, better sensors will be considered in the next iteration with the goal of providing more precise feedback compared to the current implementation found with the HC SR04.

AIR VEHICLE

The vehicles have been built upon the Parrot AR Drone 2.0 which has four "inrunner" type brushless motors with 14.5 Watts and 28,500 revolutions per minute, ARM Cortex A8 1 GHz 32-bit processor with digital signal processing video 800 MHz, and a Linux 2.6.32 operating system. For recording, the vehicle comes equipped with 720p 30fps HD camera with a wide-angle lens of 92 degrees and a vertical camera with QVGA 60fps that also measures the ground speed. For sensor input, the pre-built vehicle comes equipped with a three axle gyroscope with 2,000 degrees/ second accuracy, three axle accelerometer with an accuracy of +/- 50 milliG's, three axle magnetometer with six degree accuracy, and an altitude ultrasound sensor [1]. The team decided to build upon this vehicle because it already had many of the cameras and sensors that are needed to fulfill the tasks as illustrated by the International Aerial Robotics Competition Mission 8.

2.1 Propulsion and Lift System

Early on the team wanted to build upon a hexarotor design that was slated to compete in IARC Mission 7's competition, however, after looking at the maneuverability and actual use case of the air vehicle required for Mission 8, we settled on a quad-rotor design. The team chose the Parrot AR Drone 2.0 which offers many modification options due to its open source software development and choice of materials in regards to physical construction. The propulsion and lift system are powered by four brushless motors. The four 15 W motors, operate at 28,000 rpm during stabilized flight. However, when required for various turns and other maneuvers, the motors can fluctuate from 10,350 to 41,400 rpm. The AR Drone also comes with equipped with 10 inch propellers that are used for lift.

2.2 Guidance, Navigation, and Control

2.2.1 Stability Augmentation System

The air vehicle has four equally spaced rotors arranged in a cross-hair pattern about the center. The two rotors that directly oppose each other spin in the clockwise direction while the others spin in a counter-clockwise direction. The rotors create a downward force that allows them to propel themselves upward. The rotors must rotate in opposite directions to counterbalance the torque exerted by each rotor. In this way, the air vehicle can propel itself upward for flight. Stability is maintained by the Parrot AR Drone 2.0 by using its onboard flight controller unit that calculates rotor movement that counteracts external forces to remain at a stable hover.

2.2.2 Guidance and Navigation

The guidance and navigation system is based off of two main components: the Node AR Drone library designed by Felix Geisendörfer [2] and a speech input script that uses a speech API to process audio input taken from an external microphone found on the operator. This input will be relayed back to an offsite computer where it will process the phrase spoken and compare it to multiple valid inputs listed in our Node.js program. Based on the input, the scripting file will process acceptable movement and use the Node AR Drone library to send commands to the air vehicle.

The navigation algorithm is derived from two groups with each group having a slightly different algorithm. The first algorithm splits the air vehicles into two groups: air vehicles on the exterior perimeter and in the interior. The air vehicles on the outside will start on the edge of the arena. Each exterior vehicle will start on opposite sides of the arena and move forward until the they reach the opposite side. Next, the air vehicles will move a foot towards the interior of the arena and rotate 90 degrees then move forward a foot. It will keep repeating this loop until it detects part of the code on one of the bins. The next algorithm focuses on the interior air vehicles; the interior air vehicles will both start at the center of the edge of the arena. Both of them will move forward until they reach the opposite edge. The air vehicles will rotate 90 degrees: one rotating clockwise and the other counterclockwise. They will each move forward one foot after the rotation, and this loop will continue until they reach the opposite edge of the arena. Each air vehicle will keep repeating this loop until it detects a code from the bins. Even though we have developed our initial navigation, it will be continually updated in order to get the most efficient algorithm.

PAYLOAD

3.1 Sensor Suite

3.1.1 Sensors for Guidance, Navigation, and Control (GNC)

Guidance, navigation, and control are managed using a combination of navigational algorithms (as explained in 2.2), voice commands via an external microphone, and ultrasonic sensors for collision detection and threat avoidance. The order of precedence is as follows: speech commands, sensor input, and then navigational algorithms. Although the navigational algorithms are the primary source for navigation, speech commands and sensor input override this because of the external factors the air vehicles may face. Speech commands take precedence over sensor input, because the human has better judgement of the vehicle's surroundings.

The approach that will be taken is as follows: voice commands are managed by taking input via an external microphone. This input is then sent to an external computer on the same network the vehicle currently resides under and processed using a speech library. The speech API is used by script files to communicate with the air vehicles on what command was given and what to do next. Furthermore, the ultrasonic sensors aid in navigating through spaces and in collision detection.

3.1.1.1 Threat Avoidance

Collision detection and threat avoidance are managed by the sensor fusion of four ultrasonic sensors. The sensors communicate to the vehicle via an Arduino microcontroller which sends serial input values to an external computer that is connected to the network that the vehicle already resides on. The computer decides the best path for the vehicle to take based on previous running navigational algorithms and whether there is another object in the vehicle's range.

3.1.2 Mission Sensors

There are currently two video cameras that reside on the vehicle: the 720p 30fps HD camera with a wide-angle lens of 92 degrees located at the front of the vehicle and a vertical camera with 60fps located on the bottom of the vehicle. The front facing video camera is used for the human-robot interaction portion of the competition. These cameras are used for the video stream requirement. Input from the cameras is streamed to a WiFi mobile display device. In the case of the front facing camera, it allows the person in the competition to see what the aerial robots see; this facilitates human-robot interaction and lets the human develop better judgement on which vocal commands to give. Moreover, the down facing camera is used to identify anything under the aerial vehicle. In the case of IARC Mission 8, the operator will be using this to read the numbers located on top of each bin on the other side of the arena.

3.1.2.1 Target Identification

In order to complete the IARC Mission 8 competition, the air vehicles must be able to accurately identify potential targets in the mission. In this case, the targets at hand are the scrambled codes on top of each bin in the arena. Currently, the approach is to utilize the ground facing camera to constantly check if the camera finds something that resembles the codes. If so, the vehicle should stop and hover over the code so it can be read through the WiFi display connected to the camera (minor adjustments can be made to the vehicle's position via vocal commands). Further research is needed to develop an algorithm for processing the camera's image and to determine if the visual input resembles the codes. Furthermore, while the team researches this, the manual way to identify targets is to use the ground facing camera and to let the human recognize whether the target is present while observing through the WiFi mobile display. Through the manual mode, the human can give vocal commands to the aerial robot to halt and hover.

3.2 Communications

Communication is run through an offsite router creating an 802.11n network in a star network design for the air vehicles' connections. Once the air vehicles have all been connected to the router, there are two files that are executed: the first is a workspace for the actual command execution feed from the air vehicles, and the second file is for the video feed of the air vehicles. The video feed webpage is backed by the Node-DroneStream library created by Bernhard Weisshuhn [3]. Here the live video streams coming from the air vehicles are set to a specific port on their respective IP addresses and then transmitted to a WiFi mobile display device. The user has the ability to cycle through the feeds from each specific air vehicle. Additionally, the user can change the camera orientation from front facing to downward facing. In addition to having the air vehicles connected to the network, there is an external microphone and cloud service that connects to the network. The human running through Mission 8 will be fitted with an external microphone for voice command which will be powered by a cloud based speech recognition system.

See Figure 3.2.1. Communications Architecture

3.3 Power Management System

The pre-built vehicle uses a high density, three-cell lithium-polymer battery with a capacity of 1500mAh at 11.1V. In addition to this battery, the vehicles also need at least an additional 5V for the ultrasonic sensors mounted onto the vehicle. Further research is needed for power management for the laser that needs to be mounted for IARC Mission 8.

OPERATIONS

4.1 Flight Preparations

4.1.1 Checklists

Upon initial confirmed connection with the battery, each one of the air vehicle's propellers will turn approximately 30 degrees to check the motors ability to operate. There are four LEDs underneath each motor that will illuminate red on startup and once the check has completed, all four LEDS will illuminate green. Once the air vehicle has been powered on and has gone through its respective mechanical checks, network checks are performed. The central router will emit an 802.11b/g/n network for connection with the air vehicles, sensors, Internet, WiFi mobile display device, and an offsite computer. The offsite computer will telenet to the air vehicle via the router and output connection information for each air vehicle connected to the network, the sensors on the air vehicles, the WiFi mobile display device, and an Internet connection. This information states connection activity for each device on the network and passed/failed network connections. After the network checks have been performed, the last checks are performed on the human-machine interface. These checks include turning on and operating the WiFi mobile display device, examining running video feed from the air vehicles, and external microphone checks. The WiFi mobile display device should be running the air vehicle video feed interface, and the external microphone should have clear audio input. After all these checks are performed, the operator can use the air vehicles and begin Mission 8.

4.2 Human/Machine Interface

The operator has three interfaces in which he or she can communicate with the vehicle. The three interfaces are the external microphone, an offsite computer on the same network as the vehicles, and a WiFi mobile display device. The microphone is used as the main communication device between the human and robots inside the IARC Mission 8 arena. The microphone will be used for vocal commands to instruct air vehicles (see 3.1.1). In addition to the microphone, the vehicle can be controlled by an offsite computer. However, the computer's main purpose is to run underlying calculations and script files. The offsite computer should only be used during Mission 8 if the air vehicle fails to turn off via vocal command and must use the kill switch script on the computer. In addition to the computer and microphone, the operator may use a WiFi mobile display device to monitor the activity of the air vehicle via the two cameras (see 3.1.2). Although the operator may choose which air vehicle they are viewing on the device, any commands coming from the device are strictly restricted according to the official IARC Mission 8 rules.

See Figure 4.2.1. Tentative GUI Setup on WiFi Mobile Display

RISK REDUCTION

5.1 Vehicle Status

5.1.1 Shock/Vibration Isolation

Major risks for the air vehicles include electrical system malfunctions and instability caused by motor vibration. To protect against both situations during flight, the vehicle is to be encased in a styrofoam housing. Additionally, a plastic 3D printed polylactic acid (PLA) outer covering is used. The styrofoam housing will keep the electrical system organized and protected. Likewise, the outer plastic casing keeps the air vehicles safe and adds mass to them. As a result of the added mass, the vibration from the motors becomes less significant to the overall structure which reduces the impact and potential damage.

5.1.2 EMI/RFI Solutions

Our portable router will be creating a 802.11n WPA encrypted network to prevent unwanted connections and interference. Each of our air vehicles will also have a unique password attached to each of them, further preventing accidents and unwanted connections from happening.

5.2 Safety

Early on in the pre-built air vehicle selection process, safety was one of our main concerns. The AR Drone 2.0 comes with an expanded polypropylene hull with propeller guards. Along with the aforementioned safety measures, the air vehicle comes fitted with an ultrasonic sensor and a three-axis gyroscope that can cut off all motor power if the air vehicle generates more than a 90 degree angular tilt relative to the ground. Additionally, the aerial vehicle has readily available libraries from the manufacturer with kill switches and other safety landing procedures. In the event of an emergency, the team has implemented these libraries on an offsite computer to be called for the air vehicle.

5.3 Modeling and Simulation

Simulation of navigational algorithms were made using the Unity game development engine which uses a combination of Javascript and C# scripts to simulate environments. The team chose to do the algorithmic testing using this software because the team already had more experience using Unity than any other simulation software. Unity allows for users to create 3D objects and use its physics engine. The team used the Unity physics engine to test physical components of the air vehicles. In addition, the team was able to simulate the IARC Mission 8 arena with the basketball court sized arena, bins, cover walls, and enemy air vehicles. In the future, the team would like to move away from Unity because its main purpose is not for simulation of robotic vehicles. However, for this year, it proved to be very useful in developing and testing algorithms for navigation.

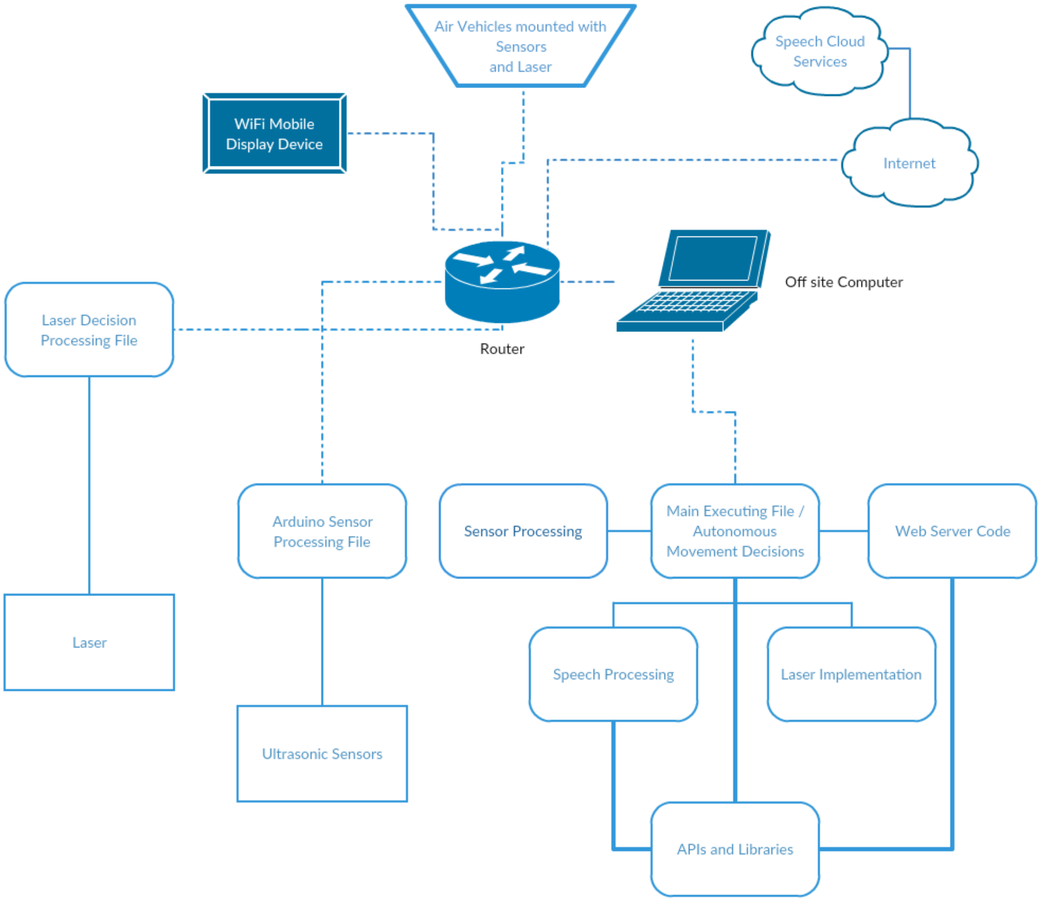
5.4 Testing

The majority of testing was completed in the Chicago Engineering Design Team's garage. Given the closed environment, components were tested individually. For initial testing, the team started off by creating a simple "Read Evaluate Print Loop" (REPL) for one air vehicle to test commands to make sure there was a proper connection to the WiFi network created by the onboard communications module. After the connection was confirmed, the team started to work on an autonomous script that would do the same commands without any input into the command line as in previous testing instances. After this, the team changed the testing environment to an HTML webpage. The webpage held a picture stream in the center along with multiple buttons on the right hand side that sent commands to the air vehicle. The commands included takeoff, land, calibrate and a camera orientation swap. The webpage was used for both input to the air vehicle along with a place for testing further development such as the video feed component and the switching of the camera. From there the team transitioned more from a debug phase to actual application with the ultrasonic sensors inplace. The team went on to test for various cases such as obstacle(s) in one, two, three, or all directions to account for instances that could happen in the arena with opposing air vehicles.

CONCLUSION

Our vehicles have been designed and rigorously tested to meet competition and safety goals. In designing our vehicles, the team used Unity to simulate and model the course, which helped tremendously in breaking down goals and design choices. Using a modified commercially available air vehicle means that the team can buy replacement parts or backup vehicles rapidly if needed. A prebuilt air vehicle also provides some guarantee that the hardware will work as intended and is less likely to suffer from defects. The Parrot AR Drone 2.0 also comes with the Parrot HDK (Hardware Developers Kit), which allows the team to send commands to the AR Drone. Further research has led the team to Node JS, the Node AR Drone library, and the Node-DroneStream library, allowing the team to connect to the vehicles and write the necessary programs for the vehicles to perform competition goals. The team’s selection of ultrasonic sensors aids in the rapid detection and avoidance of both dynamic and static obstacles. The team’s prioritization of voice command over gesture command and use of a microphone eliminates the need for line of sight, advanced image recognition algorithms, and certain competition unknowns such as field orientation, noise, and lighting. Our use of a REPL helped with troubleshooting and redundancy within our programs. Issues with possible EMI/RFI were addressed with WPA passwords for the team router and unique ones for each individual vehicle. To prevent electrical system malfunctions and instability caused by motor vibrations, each vehicle will be protected with an inner housing made of styrofoam and a 3D printed outer casing made of PLA. A polypropylene hull with propeller guards was used for every instance of testing to prevent harm to the vehicle and people in its path. In case of emergencies, a built-in shut off is included in every vehicle, which can be activated at any time by tilting the vehicle 90° degrees towards any side. Our largest and by far most effective safety measure is the inclusion of a preflight checklist, which details how to connect to each vehicle, what should happen upon connection, how to activate and test each program, safety measures that should be on, and how to activate the emergency shut off. We believe our vehicles are designed and ready for the competition, as well as, any challenges that may appear.

FIGURES



Solid lines - Connected directly with each other (through code)
Dashed lines - Connected wirelessly

Figure 1.2.1. Overall System Architecture

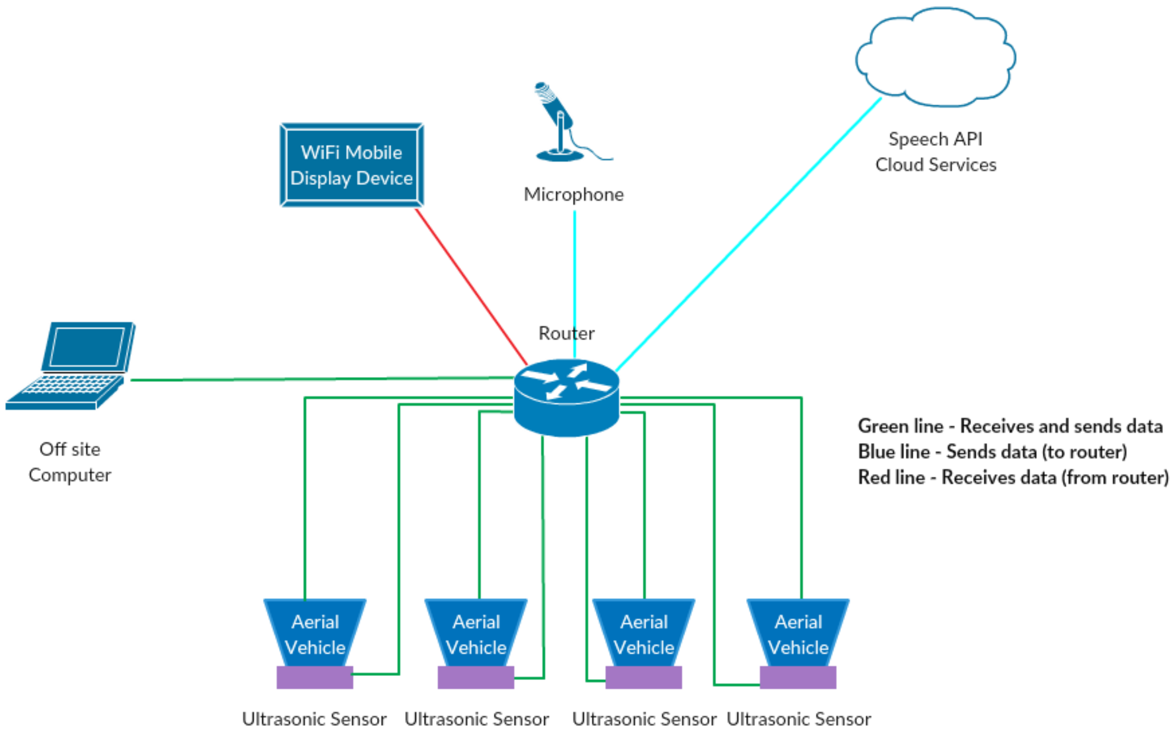


Figure 3.2.1. Communications Architecture

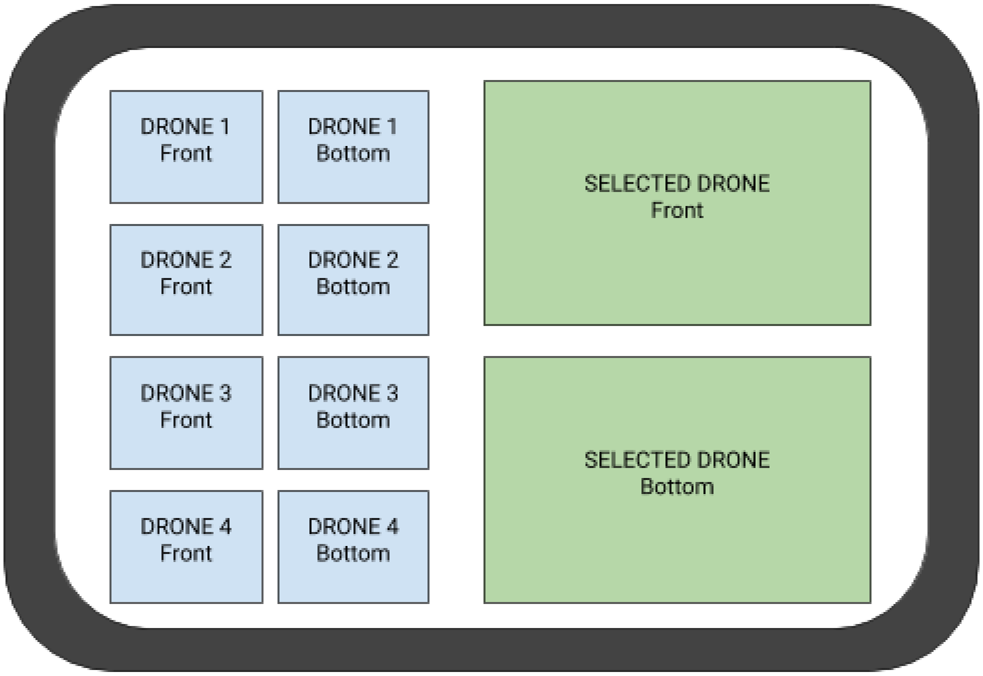


Figure 4.2.1. Tentative GUI Setup on WiFi Mobile Display

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