# Multi-rotor aircraft developed by Southern Polytechnic State University to Compete in the 2014 International Aerial Robotics Competition

David Haffner

Mechanical Engineering Technology student, Southern Polytechnic State University

Michael Doherty

Computer Science student, Southern Polytechnic State University

Nick Schulz

Mechatronics Engineering student, Southern Polytechnic State University

Brandon Hopewell

Computer Science student, Southern Polytechnic State University

ABSTRACT

For Mission 7 of the International Aerial Robotics Competition, the Southern Polytechnic State University Aerial Robotics Team has developed a multi-rotor aerial vehicle capable of stable interest-based autonomous flight. Using its onboard sensor array, the multi-rotor can locate and interact with other robotic vehicles in order to accomplish the objective. Additionally, the robust 3D-printed design allows the multirotor to safely withstand collisions with obstacles and other aerial vehicles encountered during the mission.

## 1. INTRODUCTION

### 1.1 Problem Statement

IARC Mission 7 requires teams to have an autonomous aerial vehicle that can demonstrate the ability to interact with moving objects, navigate in a sterile environment with no external navigation aids, and interact with other autonomous air vehicles. These factors are assessed by the team's ability to successfully guide 10 randomly moving ground robots through one side of an arena while simultaneously avoiding obstacles in its path.

### 1.2 Conceptual Solution

To successfully complete the mission, we will use a multirotor designed for autonomous flight in a GPS restricted environment. Our strategy consists of using a defensive flight pattern to patrol the arena perimeter to guide the ground robots toward the goal line. This flight pattern will allow the vehicle to constantly monitor the ground robots while simultaneously monitoring the arena's perimeter. The aircraft will detect and identify the current trajectories of ground robots using the RGBD camera and the downward facing camera.

Due to the pseudo-random behavior of the ground robots and the limited observability of the arena, we've determined the most effective way to achieve the task is by restricting flight to defensive patterns. This allows the ground robots to casually interact with each other and the aerial robot will only interact with ground robots that have been identified as having a high probability of exiting through an incorrect side of the arena.

The vehicle will decide how to interact with the ground robots based on prioritized goals.

A basic list of goals in priority from high to low are as follows:

0. Takeoff and Localize the multirotor to the arena.

1. Maintain a defensive flight pattern by following the arena perimeter dynamically while avoiding other obstacles.

2. Detect and localize the ground robots in the arena.

3. Target a ground robot for “herding” (i.e. modifying the robot’s trajectory to guide it toward the green line of the arena) if it is detected within a specific distance from the multirotor.

4. Calculate the trajectory of the currently targeted ground robot.

5. Herd the ground robot by either landing in front of the robot to engage the bumper sensor, or by interacting with the Hall-effect sensor.

6. Return to the autonomous defensive flight pattern.

### 1.3 Yearly Milestones

For the first year of Mission 7, we plan on having an aircraft that can autonomously take off and land, follow the perimeter of the arena, and detect and interact with ground robots. In the following years we will plan to:

1. Continuously evolve the aerial vehicle’s structural elements to achieve a wide range of platforms, allowing different performance and efficiencies to be used in a variety of situations.
2. Continuously integrate electronics, components, and sensors more seamlessly.
3. Improve optical flow technology to be able to move freely around the arena without having to repeatedly visit the origin to counteract drift.
4. Improve obstacle detection, classification, and avoidance.
5. Improve detection of ground robots by being able to detect robot orientation.

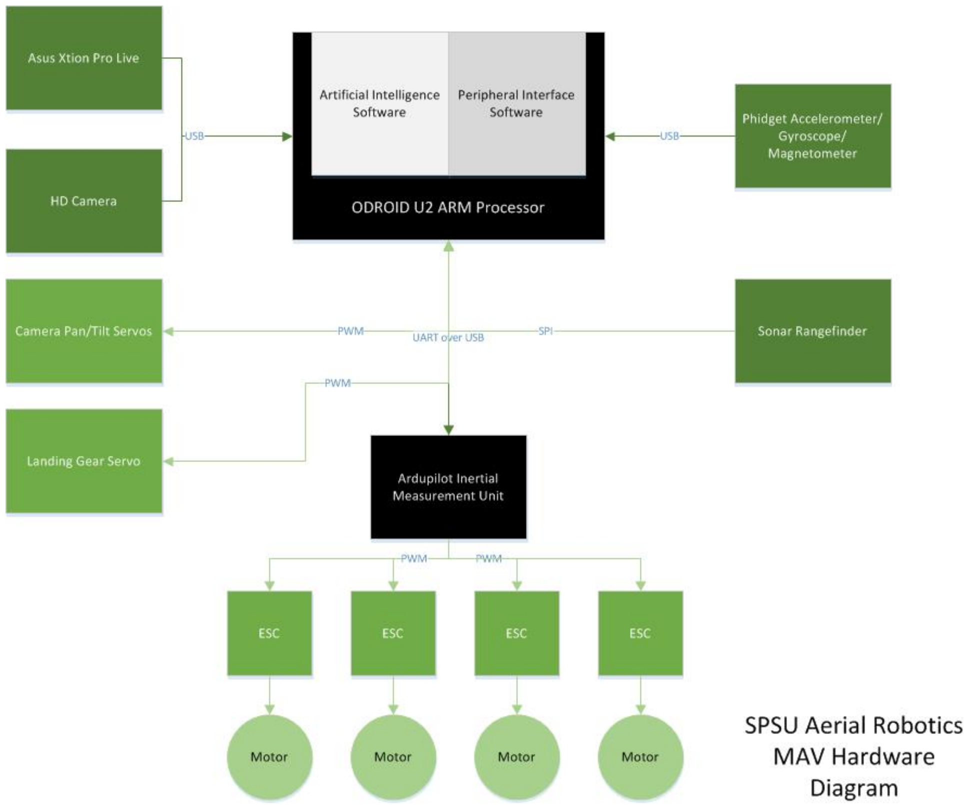



Figure 1.0 – SPSU Aerial Robotics MAV Hardware Diagram

## 2. AIR VEHICLE

The airframe design is a 3D-printed structure. 3D printing the arms allows for rapid design changes and more design freedom with the contours of the arms. The arms have a low drag profile to aid in thrust efficiency. The arms were designed with a ten degree tilt to direct propeller wash outward, increasing the stability of the airframe. The core of the structure is made up of a series of G10 plates. The plates were manufactured using CNC machines. G10 is a rigid material and also lightweight. This material can handle large impacts. These internal plates center the flight controller board within the structure of the airframe.

### 2.1 Propulsion and Lift System

We are using six Scorpion 1280 kv motors paired with ten amp electronic speed controllers along with an eight by four inch propellers. The total thrust generated is over thirty six hundred grams. The thrust efficiency is 6.22 grams of thrust per watt.

### 2.2 Guidance, Navigation, and Control

#### 2.2.1 Stability Augmentation system

For flight stabilization, we chose to use the Pixhawk autopilot designed by the PX4 open-hardware project. We utilize the 3-axis accelerometer and gyro to obtain stable flight.

### 2.2.2 Navigation

One of the biggest challenge of Mission 7 is being able to accurately navigate in a sterile environment without external navigation aids. By establishing a point of reference (e.g the the top left corner of the arena) and accurately measuring displacement, the aircraft will always know its position within the arena. The multirotor is equipped with a PX4 Flow embedded optical flow camera capable of calculating flow vectors at 120 Hz in low light conditions. In addition, a downward facing HD webcam is used to calculate optical flow on high resolution features at about 20 Hz.  A 3-axis Phidget accelerometer is used as an IMU sensor as well.

The combination of optical flow and IMU sensors as well as the use Kalman filtering gives us a reasonably accurate estimate of displacement. If the multirotor detects that it is experiencing a large amount of drift, it will return to its point of reference to zero out the displacement.

The aircraft is equipped with the Asus Xtion Pro Live RGBD sensor.  As the craft navigates in the arena, the RGBD sensor points in the same direction as the craft to identify possible obstacles. If an obstacle is detected, an evasive maneuver is added to the top of the navigation queue.

### 2.3 Flight Termination System

In the event that the aerial vehicle suddenly experiences undesired behavior, pressing a switch located at the ground station will kill all power to the motors. In addition, the aerial vehicle has a manual override, allowing a human pilot to take over in the presence of a less serious event.

## 3. PAYLOAD

### 3.1 Sensor Suite

#### 3.1.1 GNC Sensors

The onboard 3-axis gyroscope/accelerometer, barometer, and sonar sensors are used by the flight computer to maintain stable flight.

#### 3.1.2 Mission Sensors

Asus Xtion RGBD camera is used for computer vision and determining the position of objects in space, such as the ground robots.  A second downward facing camera provides optical flow data, detects robots directly below the drone, and detects if the drone would leave the arena.

### 3.2 Communications

The aerial vehicle relays vitals and other data to a ground station using the wireless 802.11n and ZigBee 802.15.4 standards. Additionally, the manual override employs the use of a radio frequency transmitter operating in the 2.4 GHz range.

### 3.3 Power Management System

To conserve weight, a single three-cell 11.1 volt Lithium-ion Polymer (Li-Po) battery is used to power both the brushless motors and the on-board electronics. A power distribution board with built-in circuit protection and voltage regulation is used to ensure the electrical system is safely powered. Batteries are charged safely and expeditiously using a DuraTrax IntelliPeak ICE charger.

## 4. OPERATIONS

### 4.1 Flight Preparations

Before each flight, steps are taken to ensure the flight is both safe and successful. First, the batteries are checked to see if they are fully charged. Partially charged batteries can cause undesired flight behavior that may result in damage to the aerial vehicle. Next, at least two team members inspect the aerial vehicle and confirm that all hardware is properly connected and secured to the frame. When everything is cleared of any problems, the ground station and manual override transmitter are powered up and checked. Afterwards, the aerial vehicle is powered on and a launch program activates all of the software and peripherals and establishes a connection to the ground station. A table-top test is performed to confirm that vitals are correctly being relayed to the ground station and that the manual override and kill switch inputs are being acknowledged by the aerial vehicle. Only after these steps are performed can the aerial vehicle be safely flown.

TABLE 1. FLIGHT PREPARATIONS CHECKLIST

▢ Batteries are fully charged

▢ FIRST INSPECTION: All wires and hardware secured in the right place

▢ SECOND INSPECTION: All wires and hardware secured in the right place

▢ Ground station and manual override transmitter powered on

▢ TABLE-TOP TEST 1: Acknowledgement of manual override

▢ TABLE-TOP TEST 2: Acknowledgement of kill switch

▢ Manual override pilot on standby

▢ Takeoff

### 4.2 Human/Man-Machine Interface

A ground station located outside the arena displays vitals such as the multirotor's current position, velocity and acceleration. Images from the multirotor's onboard cameras can also be viewed. The kill switch and manual override transmitter are both located at the ground station as well.

# 5. RISK REDUCTION

## 5.1 Vehicle Status

### 5.1.1 Shock/Vibration Isolation

The multirotor uses a combination of structural design and vibration dampening materials to counteract shock and vibration. The vibration dampening material is a form of acrylic rubber and visco-rubber materials that is placed strategically throughout the vehicle. All circuit and control boards are equipped with the visco rubber washers to act as vibration dampeners. The flight computer is attached to a mount plate using vibration dampening foam tape. In case of vertical and horizontal shock to the multirotor, the landing gear is a combination of a ball-screw geared servo retract system with carbon fiber tubes. The length and angle of the rods add flexibility creating a natural suspension system.

### 5.1.2

### Electromagnetic Interference (EMI) & Radio Frequency Interference (RFI) Solutions

To prevent back EMF or power spikes caused by the switching motor coils, protection circuitry is used on all computer hardware. An inductor is placed inline with the power supply to prevent current spikes and help maintain the voltage in the following capacitor, while the capacitor is placed in parallel to the power rails to filter voltage spikes. Additionally, all wires are shielded to protect from

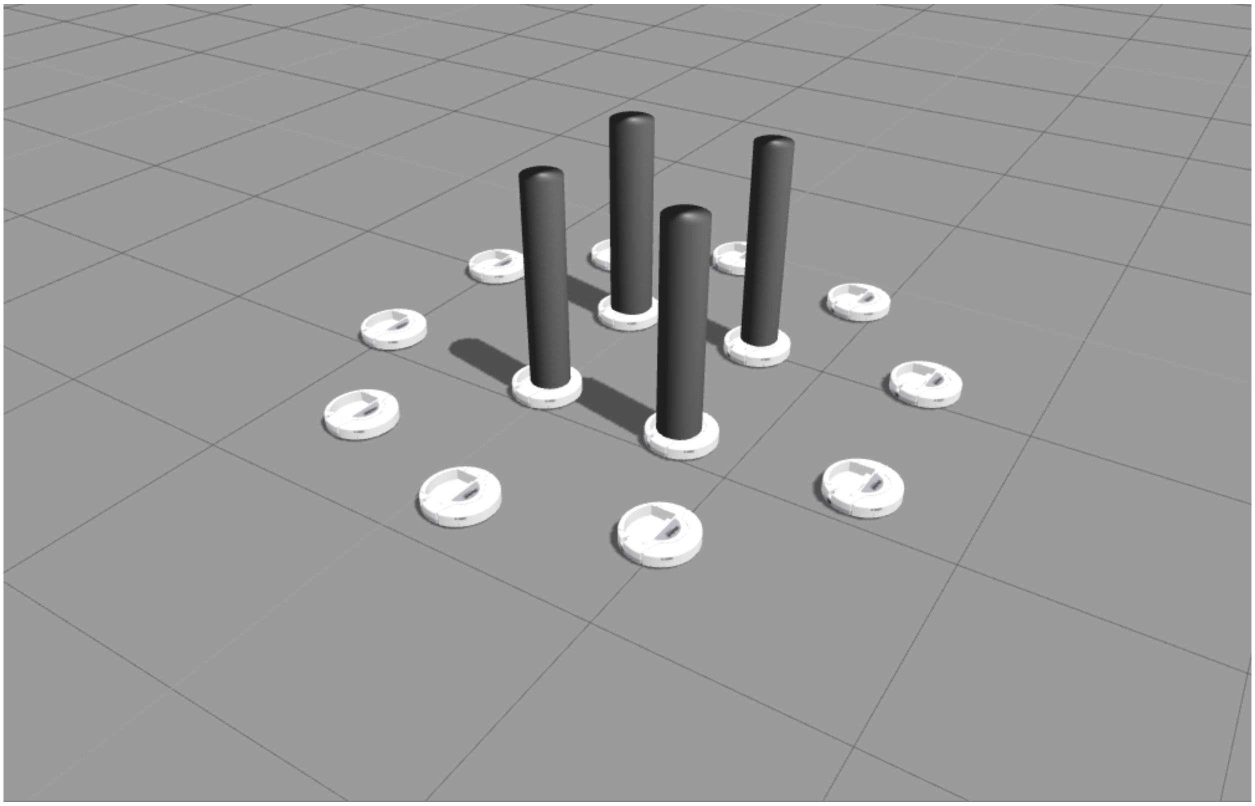
## 5.2 Safety

To prevent injury, numerous protections have been put in place. In the event that the aerial vehicle suddenly experiences undesired behavior, pressing a switch located at the ground station will kill all power to the motors. In addition, the aerial vehicle has a manual override allowing a human pilot to take over in the presence of a less serious event. The landing gear is retracted during flight and doubles as the vehicle's propeller guards.

## 5.3 Modeling and Simulation

In order to test behaviors of our multirotor in the Mission 7 environment; we utilize RVIZ, a 3D visualization tool from ROS and Gazebo, another 3D simulation tool that also has a physics engine. With use of these programs we can effectively test our algorithms. This not only saves time, but it is also cost-effective. Instead of purchasing several iRobots we can simply test them in our virtual environment.

The simulation allows us to observe how the random behavior of the robots will cause them interact with each other, and ultimately allows us to determine the best way to interact with them. The simulations can also log data that we analyze in order to create an effective approach to the mission.



**5.4 Testing**

Initial testing of the aircraft involved placing it on a test stand and ensuring the flight control systems worked as expected. Tests of autonomous takeoff and landing functionality were performed. Once the aircraft was able to autonomously ascend and descend safely, we tested the ability follow a line. Tests of the vehicles ability to detect and track the ground robots while adjusting the vehicles heading for an intercept course were also done. Drifting during flight is minimized using optical flow. The final test is landing over a ground robot and causing it to change direction.

## 6. CONCLUSION

In conclusion the multirotor is going to consist of many features such as an ARM based computing system, G10 body and other important features that will allow it to efficiently herd the ground robots. More features are planned for the future to further improve the functionality of the multirotor aerial vehicle. We are continuing to test the aerial vehicle through physical and virtual means in order to better assess its functionality and improve on it. Our goal throughout the whole process will be to create a autonomous aerial vehicle that can robustly herd the ground robots towards the green line.