Kennesaw State Universitys Multirotor Aircraft for 2017 IARC

Albert Cheng[1], Steffen Lim[1], Alec Graves[1], Owen Ortmann[1], Luke Appling[1], Hector Saldana[1], Thomas Smith[1], Thomas Fagan[1], Joshua Hunter[1], Kyle Pawlowski[1], and Robert Zenko[1]

[1]Kennesaw State University, Aerial Robotics Competition Team

Abstract

Kennesaw State Universitys Aerial Robotics Competition Team has developed a multirotor aerial vehicle to compete in the International Aerial Robotics Competition (IARC). The multirotor is designed to safely navigate through dynamic obstacles and interact with ground robots autonomously. The robust design allows the multirotor to safely withstand impacts such as ground robot interactions and small falling impacts. Additionally, the craft uses neural networking techniques to identify and track ground robots with more accuracy.

1 Introduction

The IARC mission 7A poses tasks that the craft is required to perform to complete the mission. These tasks include: accurately localizing the craft in an indoor environment without the use of GPS, identifying mobile ground robots, tracking the ground robots orientation, interacting with the ground robot using physical buttons, and avoiding dynamic obstacles within a constrained space and time. Solving these tasks would allow the team to successfully achieve mission 7A.

The competition can be broken down into five main tasks. Kennesaw State University's Aerial Robotics Competition Team has spent the past year developing a solution to each of these tasks. The first problem of localizing the craft requires the autonomous system to be able to track its position reliably over a long period of time. This is also constrained to the craft itself as external systems such as GPS are designed for outdoor use. The previous year's solution used a grid based detection algorithm which keeps tracks of the velocity of the grids and calculates the position of the craft over time. This system lacks the ability to recalibrate its position and tends to drift after some time. Using similar techniques, a semi-direct visual odometry (SVO) system tracks features that drift across a visual input to calculate its position in 3D space. By using SVO in conjunction with the grid detection system, the system is able to recalibrate itself during flight which allows it to accurately track its position for longer periods of time.

The second problem of identifying the ground robots has been achieved in previous years through traditional image recognition software. The software uses libraries such as OpenCV to do image manipulation such as color and shape detection to identify a ground robot. These systems, however, are unreliable in dynamic lighting conditions and different perspectives of the ground robot. A new solution using a Region-based Convolutional Neural Network (RCNN) is able to identify these ground robots much more reliably. The RCNN system creates a bounding box around a trained targeted object such as a ground robot. The system is able to detect multiple ground robots and different types of ground robots (green, red, or obstacles).

The next task of identifying the ground robots orientation is also achieved through neural networks. This uses a different neural network to solve. Its input will be a downward facing camera and it will output the orientation of the most centered ground robot with its range from the center of the image.

Interaction with the ground robot consists of two options: the front bumper and the top button. The craft will utilize the top button interaction since it will be faster to control from the air. The craft is designed with a large foam block underneath for a large surface area for interaction, contact, and landing.

The last hurdle involves avoiding obstacles. Using a horizontal sweeping LIDAR system, the craft is able to ascertain the distances of objects that are within close range. The LIDAR system, however, has a 120-degree blind spot. To remedy this, the craft will maneuver using pitch and yaw as opposed to pitch and roll, which only allows the craft to move in the direction of the visible angles. The RCNN ground robot identifier will also provide relative obstacle locations.

2 Structural and Propulsion

2.1 Frame

This year, Kennesaw State University has adopted a completely different design than last year, discontinuing the Hank series of multirotor. This was done in an attempt to correct several inherent design flaws common to all Hank models. For the current design, Kennesaw State University drew upon experience from several different projects the team has completed over the years. This years design will look like the model in Figure 1. In this design, the arms serve as both structural elements and propeller guards to prevent tipping and crashing when interacting with the ground vehicles. These arms are stabilized using the primary loading plates with bolts and double sided tape. This results in a lighter frame that is more durable than the previous 3d printed frames.

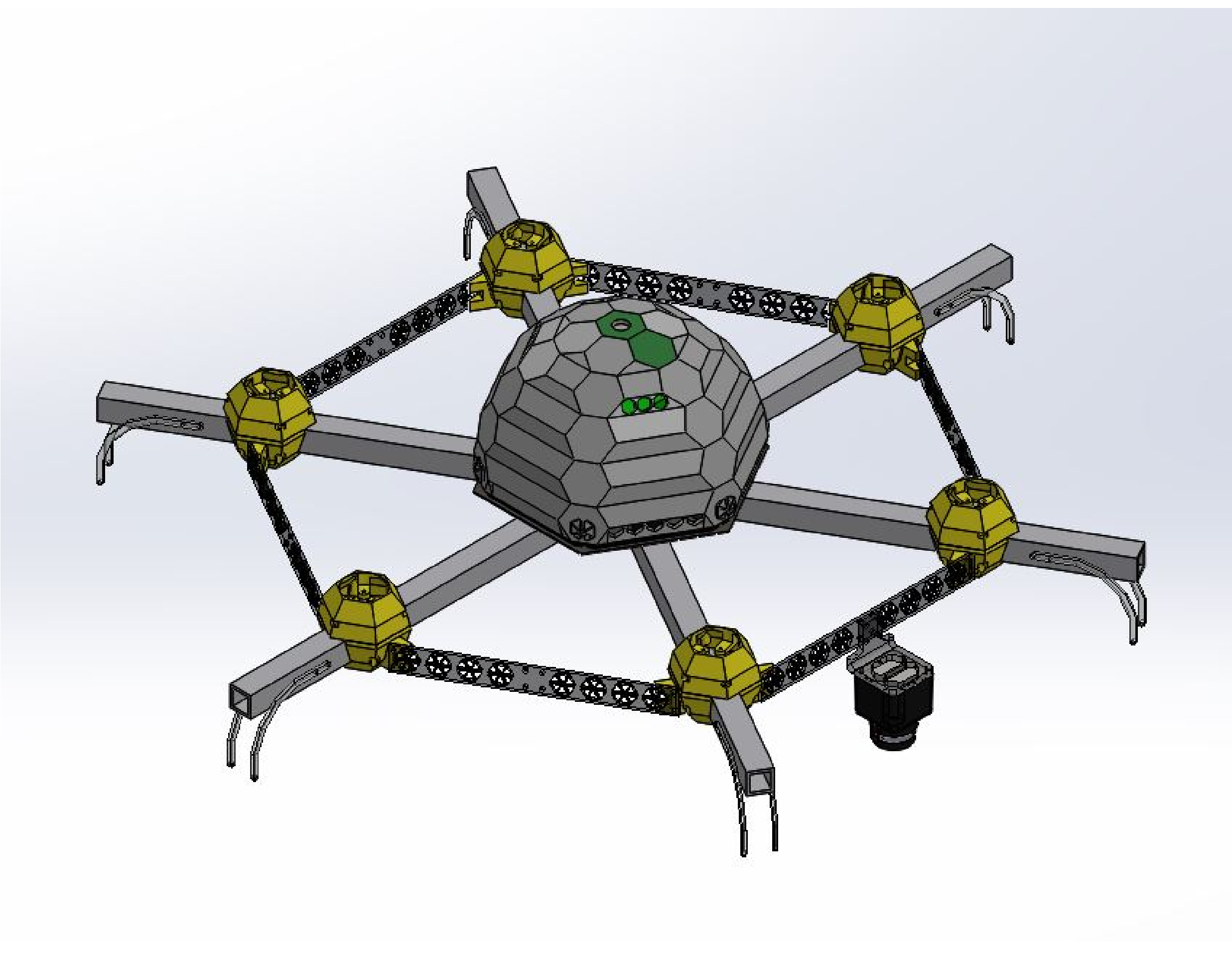

Figure 1: Multirotor Design Rendering

2.2 Foam Landing

The crafts primary method of interacting with the ground vehicles is to land on top of them, triggering the top touch sensor. The Aerial Robotics Competition Team decided that mechanical arms or detachable sections would unnecessarily complex, so a way was needed to safely land on the ground robots without damaging the craft. It was decided that a way was needed to soften the landing, which was achieved by using a foam pad attached to the bottom of the craft. Using a low-density polyurethane foam sheathed by a higher-density neoprene foam provided the necessary impact absorption with the neoprene shell protecting the softer polyurethane from sharp impacts.

2.3 Aesthetics

The arrangement of the arms on the frame produces a large, central, flat area on top of the structure plates. This causes all of the stress produced by the motors to be absorbed by the plates. Since the craft no longer had a recessed volume to store the electronics, a dome was designed to house and protect the electronics. Through the course of designing the craft, it was decided to incorporate a prismatic design with geometric patterning throughout the main dome. The theme was incorporated into the motor mountings by continuing the prismatic design.

2.4 Propulsion

Six Turnigy Multistar 14 Pole Brushless 700 kV motors and 12 by 4.5 propellers provide lift for the multirotor. The total thrust generated is 2096g, with an efficiency of 6.44 g/W of thrust at maximum throttle output. At hover throttle, the craft has an efficiency of 8.80 g/W.

3 Power and Electronics

3.1 Power

A single four-cell 14.8V Lithium-ion Polymer (LiPo) battery is used to power both the brushless motors and the onboard 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 Thunder AC6 Smart LiPo balance charger.

3.2 Power Distribution and Kill Switch

A power distribution board (PDB) is used to distribute power to the motors, electronic speed controllers (ESCs), flight controller, and receiver. This year the team decided to create a new PDB assembled with only Surface-Mount Technology (SMT) components to reduce the size of the board as much as possible without sacrificing performance, as well as directly incorporate the kill switch onto it. The PDB will implement solid-state metal-oxide semiconductor field-effect transistors (MOSFETs) to control power flow to the components. The PDB will have a hexagonal shape to best fit in the center of the craft and provide equidistance of the motors from the PDB, which decreases the necessary length of ESC wires.

The main controller of the PDB will be an LTC4417 prioritized power-path controller. This gives the user the ability to switch between 3 different power sources. The current PDB is designed to take power from two sources: a LiPo battery or a USB power source, meaning that if a USB cable is connected from a computer to make adjustments to the flight controller settings, the power supplied by the LiPo battery will be cut off. The LiPo battery will be able to provide power again once the USB power source is disconnected. If time allows, the PDB can be slightly modified to accept power from another LiPo battery (the 3rd source) in case the first one fails or goes too low.

The safety kill switch will be incorporated in the circuit board as seen in Figure 2, to reduce the occupied space. The kill switch will be subjected to possible changes since it was observed last year that the components overheated during operation. A separate board for the kill switch will be used as an alternate solution if the built-in kill switch of the PDB fails.

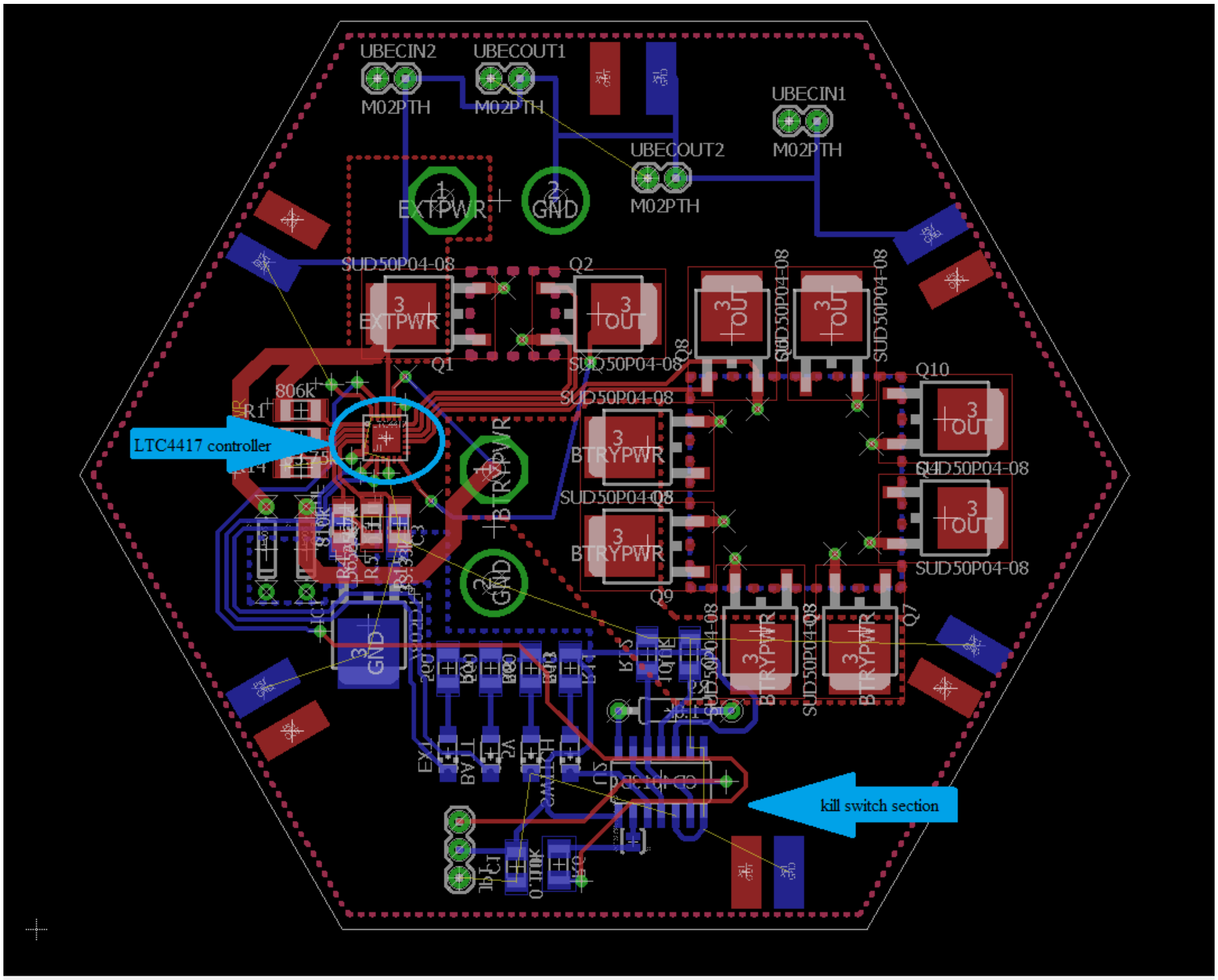

Figure 2: Power Distribution Board

3.3 Sensors

The sensor array consists of two visual USB cameras, a point LIDAR, a sweeping Hokuyo LIDAR, and an internal IMU from the Pixhawk flight computer. All the sensors communicate through Robot Operating System (ROS). The Odroid XU4 ARM processor is used to control the craft and host ROS and other software.

The craft uses two elp-USB500w02m-l21 type USB cameras with 90-degree viewing angles. One camera is facing forward with a slight tilt downward to get ground robot positions and SVO viewing perspective. The other camera is pointing downwards for the ground robot targeting and orientation regressor network and grid detection systems. The point LIDAR is the TeraRanger One with a 0.2 to 14 meter range for the altitude measurement. It will be mounted on the rear of the craft and elevated to keep it above its minimum range while the craft is landed to maintain accurate readings. The Hokuyo URG-04LX-UG01 is used to track obstacles. It will be mounted in the forward arc of the craft. The sensor is mounted where the foam landing pad will incase the 120-degree blind spot of the Hokuyo. The craft uses a Pixhawk Ardupilot flight computer to control the ESC motor controllers and provide accelerometer and gyroscopic information. The flight computer will provide stability and low-level control to the craft.

4 Software

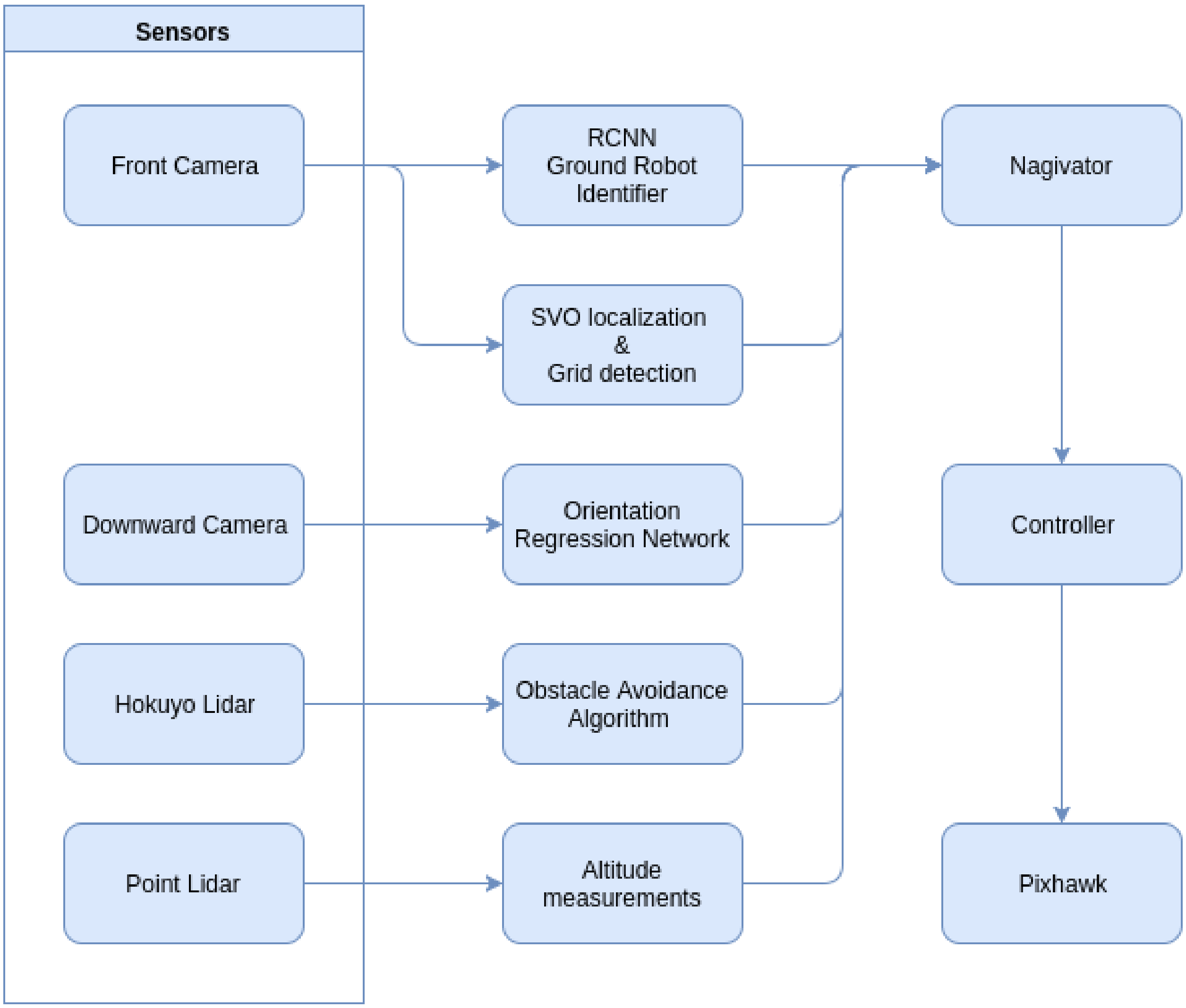

Figure 3: Multirotor Design Rendering

The system uses various sensors to interpret information about the environment. In Figure 3, the algorithm architecture describes the flow of information from the sensors to the flight computer. The communications system is hosted through ROS on the Odroid.

4.1 Robot Operating System (ROS)

The core of the system relies on ROS Kinetic Kame. ROS allows different systems aboard the craft to communicate with each other. In the current implementation of the drone, the sensors feed into the Odroid forming one node in which preprocessing is performed to create useful input. There are also nodes that use the sensory information to calculate further information about the drones surroundings. One input identifies ground robots from a distance, another evaluates a robots position when the drone is hovering above, and a third tracks the drones position in space. A navigation node receives information from these other nodes and calculates the optimal actions for the craft to take. Finally, a control node uses the input from the navigation node to communicate directly to the Pixhawk using the ROS library MAVROS.

4.2 Neural Networks

There are two types of neural networks that will be used in the competition: the RCNN and the orientation regressor. The RCNN uses pretrained networks such as YOLOv2 to set up a precalibrated set of weights to train on the competition. The network will be trained to identify the bounding boxes of green and red ground robots as well as the obstacle robots. Training the network requires a minimum of 500 labeled images of the targets. Computation time is a large concern for running this system. Possible off-board processing might be implemented if the onboard computer cannot handle the computational requirement.

The orientation regressor network will require less computation compared to the RCNN ground robot detector. The regressor will only need a low-resolution image input with a distance and orientation vector output. The network is trained to provide the distance to the closest ground robot and its orientation. This will be used with the crafts downward facing camera to facilitate its interaction with the ground robots. Knowing a ground robots location and direction allows the navigator to intercept it as it is moving.

Both networks are trained using images gathered from the Kennesaw State Universitys gym environment. The ground robots were created based on the iRobot Create 2 specified by the official IARC website. Images are taken in different lighting conditions and multiple perspectives on many backgrounds for generalizability.

4.3 Localization

Localization is a vital component of the control system detailed in this report. Localization entails tracking the position of the craft on the field. As part of this competition, this must be accomplished using only onboard sensors. The problem of localization is solved through the use of an efficient visual odometry algorithm that runs directly on the onboard computer. The algorithm employed, Semidirect Visual Odometry, is capable of operating in real-time on limited hardware such as the 20 Watt ARM-based computer used in this project.

4.4 Obstacle Detection and Avoidance

The craft avoids obstacles detected by an onboard Hokuyo LIDAR sensor. The sensor gives an array of distances from objects all around it. With some preprocessing, the other programs are given the direction to and the distance from the closest object. The navigator makes constants checks throughout the running of its main functionality to ensure the drone does not come too close to any obstacles. If the sensor detects an object within the determined safe distance, an emergency function is activated that directs the craft to steer away from the threat.

4.5 Navigation Node

Implementation of a simple algorithm for ground robot interaction would consist of a greedy method, where the craft will attempt to interact with the closest ground robot and attempt to guide it through the goal. Rather than attempting to guide multiple robots at any given time, the craft will guide a single robot in sequence until the time runs out or a manual override engagement is activated. The moment the craft autonomously takes off, the craft will identify the nearest ground robot to target using RCNN and the forward-facing camera. Once a ground robot is within the field of view of the downward facing camera, the craft infers its orientation and interacts with the ground robot as necessary.

4.6 Controller Node

The controller regulates the communication between the Odroid and the Pixhawk. It manages the proportional integral derivative (PID) controller and MAVROS communication library to the Pixhawk. The PID controllers are based on the position of the craft and the targeted position calculated by the navigator.

5 Operations

5.1 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 multirotor. Next, at least two team members must inspect the multirotor 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. Afterward, the aerial vehicle is powered on and a launch script activates all necessary software and peripherals. After a connection to the ground station has been established, a table-top test is performed to confirm that data is being correctly relayed and the manual override and kill switch inputs are being acknowledged by the multirotor. Once all the preceding steps have been performed, the multirotor may be safely flown.

- ☐ Batteries are fully charged.
- ☐ FIRST INSPECTION: All connectors and hardware secured in the right place.
- ☐ SECOND INSPECTION: All connectors 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!

5.2 Human-Machine Interface

A ground station located outside the arena displays vitals such as the craft's current position and behavior and images from the craft's onboard cameras. The vehicle is equipped with a radio-controlled kill switch. This kill switch remotely disconnects the power to the vehicle in the event of an emergency. The ground station also has a software manual override that can be triggered simply by pressing the designated key on the keyboard. When the software manual override is engaged, the vehicle stops all actions and lands at a preset descent rate.

6 Risk Reduction

6.1 Vehicle Status

6.1.1 Shock/Vibration Isolation

The multirotor is designed using materials that exhibit an acceptable amount of elasticity to prevent unnecessary vibration from the high RPM motors. Vibration originating from the motors is absorbed and dampened by the structure of the multirotor. Metal structural components have the characteristic trait of transferring vibrations to all attached components. This has been prevented by manufacturing the vehicle using ABS plastics, nylon hardware, and G10 fiberglass. The elastic nature of the craft's structure and assembly hardware reduces the need for additional shock/vibration protection. These features enable the multirotor to obtain stable images from the onboard cameras without the added weight of additional shock protection.

6.1.2 Electromagnetic Interference (EMI) and 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. Low-pass filters and shielded cables are used whenever possible to counteract high-frequency noise caused by EMI. Communications antennas are placed as far away from motors and other antennas as possible. Additionally, multiple radio frequency bands are used to minimize RFI between them, as well as RFI from outside sources at the venue.

6.2 Safety

In the event that the multi-rotor suddenly experiences undesired behavior that poses an immediate threat to people or the environment, pressing a switch located at the ground station will kill all power to the motors. Alternatively, a signal can be sent to safely land the multirotor or allow manual override of the controls in the presence of a less serious event.

6.3 Testing

Initial testing of the multirotor 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 multirotor was able to autonomously ascend and descend safely, the ability to travel along a given flight trajectory was tested. Tests of the multirotor's ability to detect and track the ground robots were also performed. The multirotor was tested in the Kennesaw State University gym using components similar to those used in the competition. The final tests involved successfully landing in front of a ground robot while avoiding static obstacles placed in its flight path.

7 Conclusion

The Kennesaw State University Aerial Robotics Competition Team has developed an autonomous multirotor aerial vehicle capable of solving several problems posed by Mission 7A of the International Aerial Robotics Competition. Using its onboard sensor array, the multirotor can locate and interact with other robotic vehicles in order to accomplish objectives. The structure of the multirotor is able to safely withstand collisions with obstacles encountered during the mission. With the completion of Mission 7 likely to happen sometime in the next few years, the IARC will once again have pushed the envelope in state of the art of aerial robotic flight behavior.