Quadrotor Developed by Southern Polytechnic State University to Compete in the 2012 International Aerial Robotics Competition

David Haffner
Mechanical Engineering Technology student, Southern Polytechnic State University

Sean O'Callaghan
Mechatronics Engineering student, Southern Polytechnic State University

Charles Pagano
Computer Science student, Southern Polytechnic State University

Nick Schulz
Mechatronics Engineering student, Southern Polytechnic State University

ABSTRACT

For the 2012 International Aerial Robotics Competition, the Southern Polytechnic State University Aerial Robotics Team has developed a quadrotor aerial vehicle capable of fast and efficient navigation through an indoor environment barred from GPS access. The custom-manufactured quadrotor uses sonar, lasers, and visual recognition to collect data about its environment and uses this information to build a map of the area.

1. INTRODUCTION

1.1. Problem Statement

The main task for this mission is to have an autonomous aerial vehicle that can search through an unexplored facility, obtain a USB flash drive, drop off a duplicate USB flash drive at the same location, and exit the facility within the given time frame. The vehicle must remain in the air and undetected for the entirety of the mission.

1.2. Conceptual Solution

To successfully complete the mission we will use a quadrotor designed for autonomous flight in an unexplored environment. The vehicle is equipped with a large array of sensors designed for aiding it in navigation. The majority of the software is run on a Android RAZR which communicates with a C8051F151 Microcontroller and a ArduPilot Mega 2 Flight Computer to make up the central processing unit (CPU) of the quadrotor. The CPU of the quadrotor collects data from the sensors and transmits that data and other calculated vitals (e.g. the velocity of the quadrotor) to a laptop at the ground station.

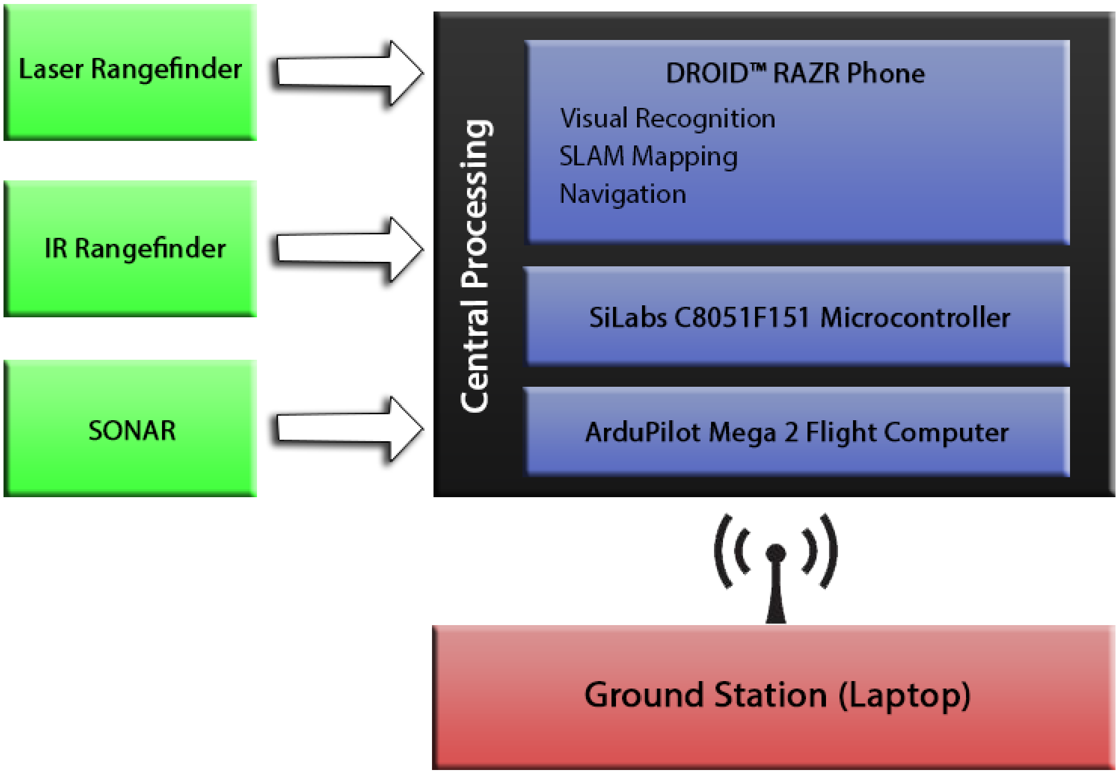

Figure 1. Control System Architecture.

1.3. Yearly Milestones

For Southern Polytechnic's first year of competing in IARC Mission 6, the quadrotor will be able to navigate autonomously within the arena, avoiding detection by the security camera at the perimeter. Mission-critical goals will be met in future years, such as USB drive retrieval and laser barrier deactivation.

2. AIR VEHICLE

2.1. Propulsion and Lift System

Quadrotors generate thrust using two pairs of counteracting rotors. Yaw, pitch, and roll can be achieved by varying the speeds of each of the rotors. Quadrotors are naturally unstable, so an inertial measurement unit (IMU) is needed to adjust the inputs accordingly.

2.2. Guidance, Navigation, and Control

2.2.1. Stability Augmentation System

For flight stabilization, we chose to use DIY Drones' ArduPilot Mega 2. Its three-axis gyros and accelerometers, as well as Google Maps integration and XBee communication, make it the perfect choice of flight computer.

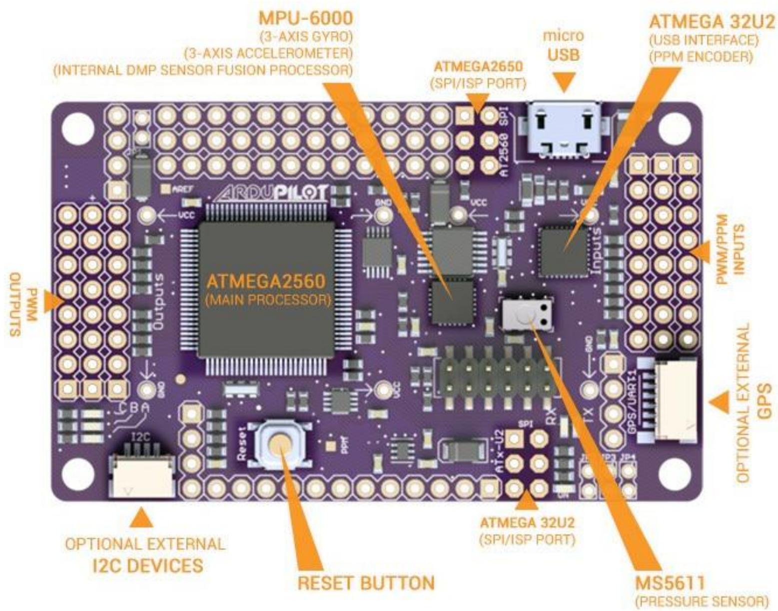

Figure 2. ArduPilot Mega 2 Hardware Diagram.[1]

2.2.2. Navigation

In order to tackle the problem of navigation, it needs to be broken down into smaller tasks. These tasks are: 1) localizing the quadrotor, 2) determining the next location that the quadrotor will move to, and 3) moving the quadrotor to the selected location.

To localize the quadrotor, we used an adaptation of the Extended Kalman Filter, which helps eliminate drift. This Kalman Filter becomes increasingly more inaccurate as time progresses because it has to predict the current location of the quadrotor based on an increasing number of past and future predictions. For this reason, we have also developed an algorithm that determines the location of the quadrotor based on its distance relative to stationary routers located outside of the facility. The Android-powered DROID RAZR™ phone mounted on the quadrotor detects the signal strength of these routers and converts that signal strength into an approximate distance from each router.

In addition to determining its current location, the aerial vehicle also calculates its best possible next move. In order to do this, the quadrotor assigns a

[1] http://code.google.com/p/arducopter/wiki/APM2board

weight to all regions in space within a certain distance from the quadrotor (i.e. assign a weight for all regions within fifteen feet of the quadrotor). The weighted values are based on sensor data interpreted by our filtering programs. Region weight, distance, and mission status (e.g., mission time and USB drive status) are the key factors used to determine the vehicle's next destination.

Once the quadrotor has determined its location and destination, It must determine how to move to that location. This process is done using simple commands (e.g., throttle up, throttle down) sent to a Silicon Labs C8051F121 microcontroller that processes and in turn generates pulse-width modulation (PWM) control signals as a result. These PWM signals are appended by a flight computer to ensure the aerial vehicle remains stable in the air, and then processed by the rotor speed controllers to generate the desired thrust.

The process is repeated until the quadrotor obtains the USB drive. On obtaining the flash drive the vehicle uses the A* searching method to find the quickest route out of the building using its current generated map.

2.3. Flight Termination System

In the event that the aerial vehicle suddenly experiences undesired behavior, pressing a switch located at the base 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

In order to localize itself and navigate within the environment, the aerial vehicle utilizes three sensors: a Hokuyo URG-04LX-UG01 laser, a MAXSonar-EZ1, and a Sharp IR range finder. The URG-04LX-UG01 is the quadrotor's main navigational sensor, has a 240 degree field of view and can detect objects up to 5.6 m at a resolution of 1 mm. The MAXSonar-EZ1 is the quadrotor's altimeter and has a resolution of 1 in. Lastly, the Sharp IR range finder is used to detect sudden, immediate threats to the quadrotor (e.g., office chairs and desks) and has a resolution of 0.3 in. The onboard software on the quadrotor reads in the data from these sensors and uses it to determine how to navigate in the arena.

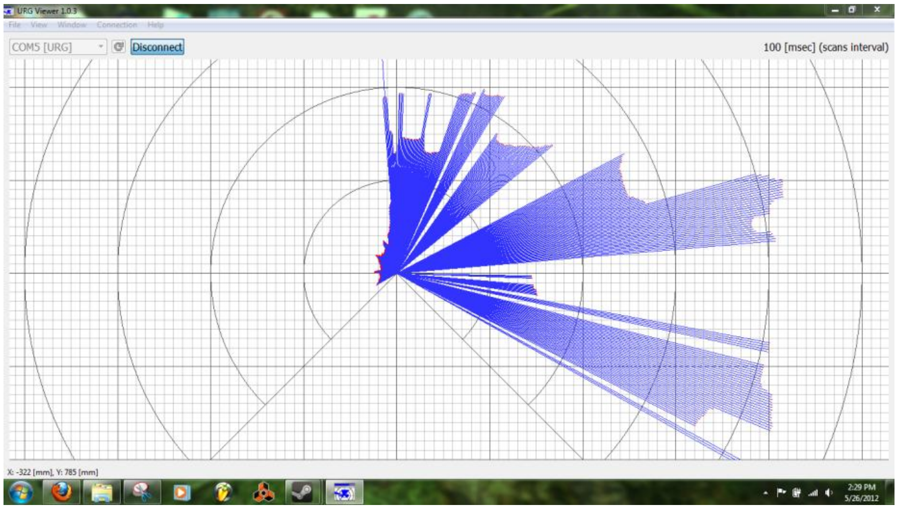

Figure 3.   URG-04LX-UG01 Mapping Data

3.1.2. Mission Sensors

There is a mission timer on the quadrotor that is used to determine if there is enough time remaining in the current run to complete the mission. If the mission time is ten seconds away from the max time it takes to complete the mission then the quadrotor will self destruct. The max time it takes to complete the mission changes depending on whether the quadrotor has been detected or not.

The computer vision software we've developed utilizes the OpenCV Library[2] for the purpose of object recognition, object tracking, and color detection. For all of these tasks the software uses images taken from the camera of the on board Android RAZR.

3.2. Communications

The aerial vehicle relays vitals and other data to a base station using the wireless 802.11n and XBee 802.15.4 standards. Additionally, the manual override employs the use of a radio frequency transmitter operating in the 72 MHz 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 fuse protection is used to ensure current gets to where it is needed. Batteries are charged safely and expeditiously using a DuraTrax IntelliPeak ICE charger.

[2] http://opencv.willowgarage.com/wiki/

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 to capacity. Partially charged batteries can cause undesired flight behavior that may result in damage to the aerial vehicle. Next, the aerial vehicle is inspected by at least two different people to make sure all wires and hardware are connected and secured in the right places. When everything is cleared of any problems, the base station and manual override transmitter are powered up and checked. Afterwards, the aerial vehicle is powered on and a table-top test is performed to confirm that vitals are correctly being relayed to the base station and that 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
- ▢ Base 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. Man/Machine Interface

A base station located outside the arena displays vitals such as the quadrotor's current position, velocity and acceleration. Additionally, a simulation of the quadrotor's mapping can be viewed in either 2D or 3D. A video stream from the quadrotor's onboard camera can also be viewed. The kill switch and manual override transmitter are both located at the base station as well.

5. RISK REDUCTION

5.1. Vehicle Status

5.1.1. Shock/Vibration Isolation

The quadrotor uses a combination of structural design and vibration dampening materials to counteract shock and vibration. The vibration dampening material is a form of visco-rubber material that is placed in between the frame and flight computer board. All circuit and control boards are also equipped with the visco rubber material as well. In the case of vertical and horizontal shock to the quadrotor, the landing gear is equipped with a suspension to absorb vertical impacts. Propeller guards protect against rollovers and horizontal impacts. The propeller guards are made from a rigid yet thin fiberglass material that behaves like a flat spring. The landing gear is also a combination of rigid parts with fiberglass poles tying them together.

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. After the inductor/capacitor filter, a TVS (transient voltage suppression) diode is put in parallel with the power rails to add a final overvoltage protection by shunting current if the voltage exceeds 6 volts. Software RF addressing is used to prevent RF interference and conflicting signals from other RF sources on the same frequency band.

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 base 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. Propeller guards have also been placed over each of the four rotors to prevent damage to the arena and the rotors themselves.

5.3. Modeling and Simulation

The quadrotor simulator we've developed fetches map, laser, and image data and displays them in real-time to the user. The main display is in 2D top-down view but the user has the option of displaying the data in 3D for a more realistic simulation. The user may also view a live video feed from the camera on board the quadrotor.

The simulator is designed mainly for the testing of guidance, navigation, and control algorithms. The user has the ability to build custom maps of any size, fill it with obstacles, and place the quadrotor at any location in the map. After building a custom map the user can either test navigation algorithms they are developing or fetch live sample data that the sensors of the quadrotor are collecting.

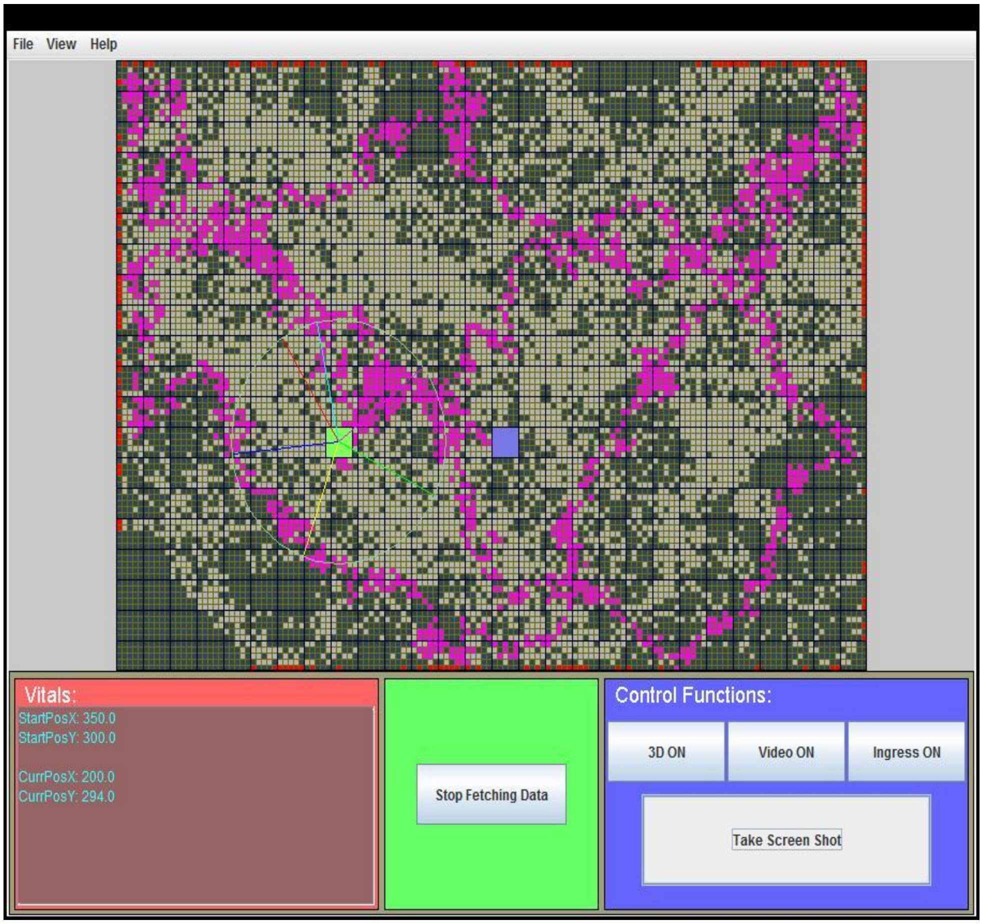

Figure 4. Quadrotor Simulator Diagram.

5.4. Testing

A portion of our localization algorithm, that dealt with collecting received signal strength indicator (RSSI) data from two routers, was tested in our school gym. We made a grid of strings in the gym that we traversed in a snake like pattern collecting RSSI data at each grid block. The data was then graphed to find a correlation between the RSSI values and the location they were collected at relative to the routers.

6. CONCLUSION

The quadrotor we've developed is capable of autonomously navigating an unexplored area without detection. It is equipped with an array of sensors to aid it in determining its location, building a map of its environment, detecting objects, and performing many other mission critical tasks.