Quadrotor Developed by Southern Polytechnic State University to Compete in the 2013 International Aerial Robotics Competition

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ABSTRACT

For the 2013 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 ODROID-U2, which communicates with a DigiSpark microcontroller and a ArduPilot Mega flight stabilization 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.

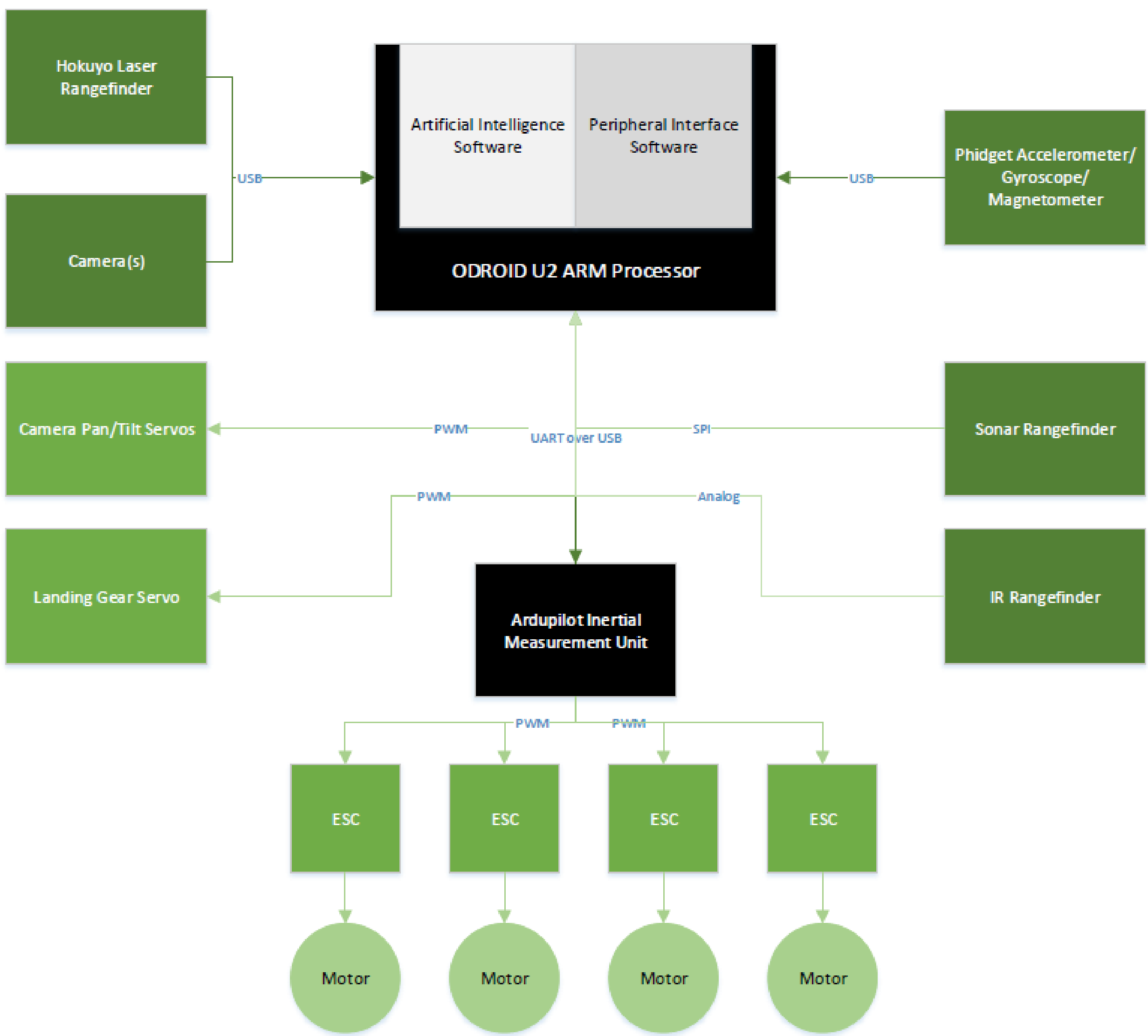

Figure 1. Control System Architecture.

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, identify the USB drive, retrieve the USB drive and drop off the decoy, and egress with the USB drive. Future years will include improvement of the navigation and detection algorithms.

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. Its three-axis gyros and accelerometers as well as it's modular and open-source nature made it the perfect choice of flight stabilization computer.

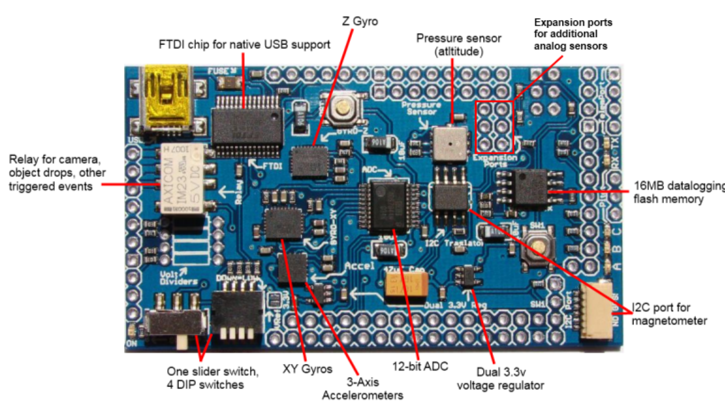

Figure 2. ArduPilot Mega 2 Hardware Diagram.[1]

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.

Localization is done using a ROS package called Hector Mapping that relies only on data from the Hokuyo for SLAM, combined with adjustments due to pitch and roll of the quadrotor. This package essentially implements a kind of visual SLAM through what the Hokuyo can "see". This reduces a lot of overhead that would occur if various other SLAM methods like odometry, reckoning, and triangulation from ground stations were used.

To determine where to go next, the quadrotor uses a frontier exploration algorithm that also attempts to scan the entire map area so that the visual recognition camera has a chance to see the USB drive. Once an area is mapped, it will move on to the nearest unmapped area. This process will give it destinations to visit.

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 through a UART over USB connection to the flight stabilization computer. This flight stabilization computer then generates pulse-width modulation (PWM) signals to the rotor speed controllers to generate the desired thrust. The flight stabilization computer also uses it's built-in accelerometers and gyroscopes to ensure the quadrotor remains unaffected by the hazardous downwash of outside sources, such as air conditioning vents. 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 while also avoiding the camera during egress.

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.

[1] http://wiki.ardupilot-mega.googlecode.com/git/images/ArduPilotMegaImages/APM-IMU.png

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 multiple sensors: a Hokuyo URG-04LX-UG01 laser, two MAXSonar-EZ1's, a Sharp IR range finder, and a PhidgetSpatial Precision 3/3/3. 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. Two of these are used to counteract error originating from noise, and also to distinguish between changes in terrain (e.g., a table), and changes in absolute altitude. The Sharp IR range finder is used to detect sudden, immediate threats to the quadrotor (e.g., office chairs and desks level with the vehicle) and has a resolution of 0.3 in. Lastly, the PhidgetSpatial Precision 3/3/3 is a high resolution all-in-one accelerometer/gyroscope/magnetometer that provides valuable data to our navigation algorithms. The onboard software on the quadrotor reads in the data from this wide variety of sensors and uses it to determine how to navigate in the arena.

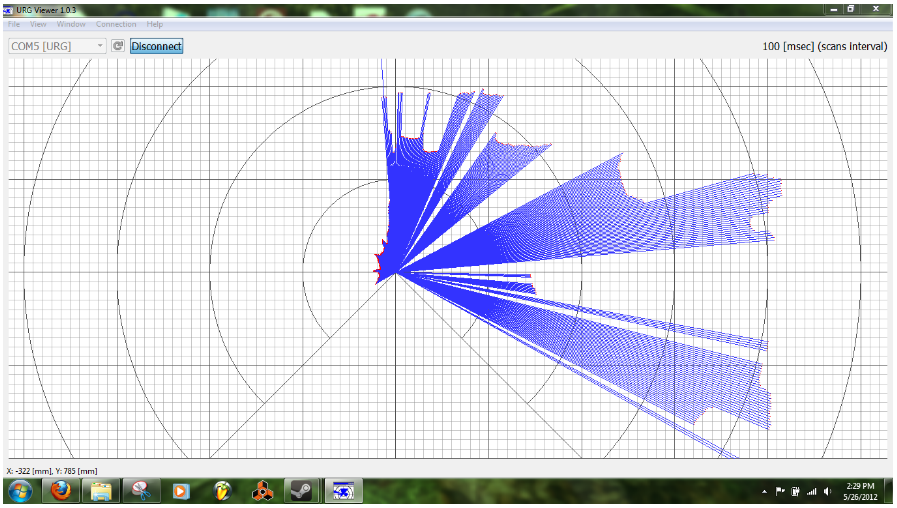

Figure 3. URG-04LX-UG01 Mapping Data

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 USB cameras attached to the Odroid-U2.

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 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.

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, at least two team members

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

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 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 Interface

A ground station located outside the arena displays vitals such as the quadrotor's current position, velocity and acceleration. Images from the quadrotor'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 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 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. The landing gear is a combination of rigid parts with fiberglass poles tying them together with spring shock absorbers to dampen landing impact.

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.

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. A bumper made from a rigid yet thin fiberglass material behaving like a flat spring surrounds the perimeter of the quadrotor to protect people and property from the propellers. They additionally protect the quadrotor itself in case of accidental contact.

5.3. Modeling and Simulation

The simulator we're using is a package named Rviz which is from the Robotic Operating System (ROS) made by Willow Garage. The Rviz simulator's main use is for displaying map, laser, IMU, and other sensor data for testing in preparation of the IARC mission. This may also be used to display the real-time state and sensor data of the quadrotor during the IARC mission.

Rviz makes the testing of guidance, navigation, and control algorithms for the quadrotor simple & efficient. 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.

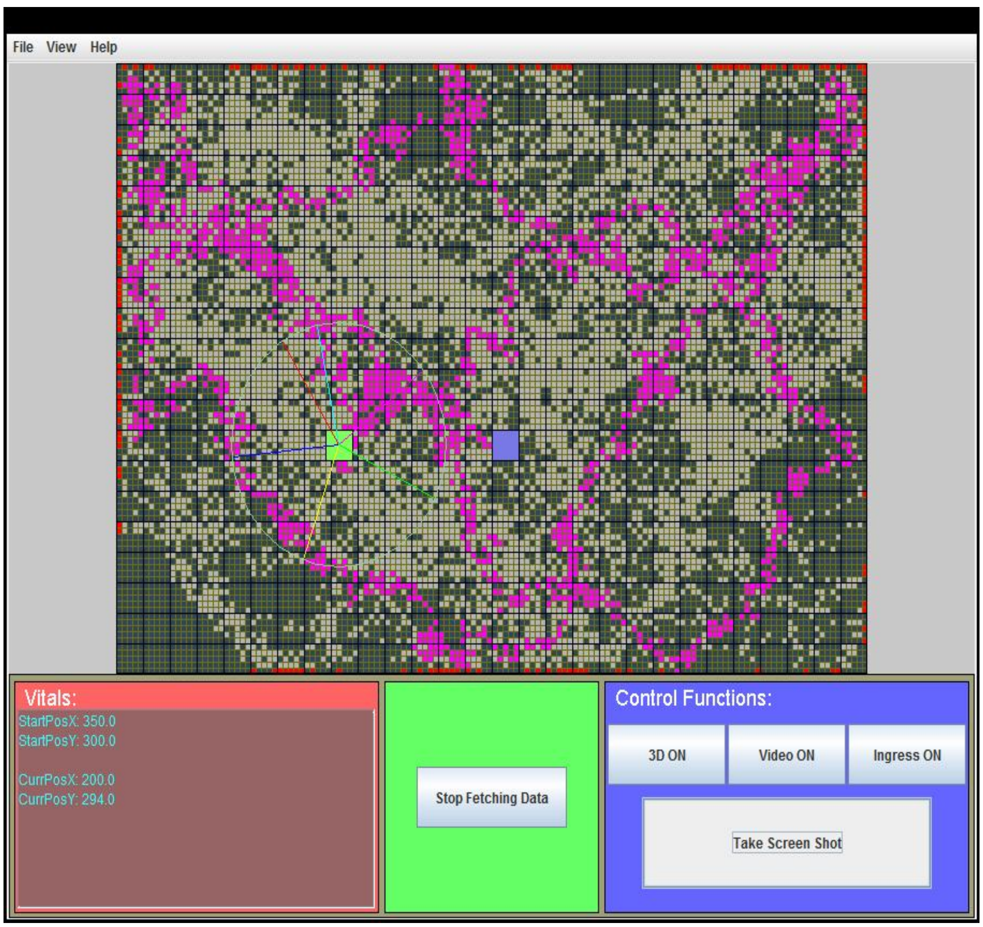

Figure 4. Quadrotor Simulator Diagram.

5.4. Testing

We unit tested several parts of the system; laser data acquisition, OpenCV image processing, distributed processing of data, USB pickup and decoy drop off system, and system integrity. We also tested the drone in a course which simulates the scenario that will be encountered in the competition.

6. CONCLUSION

The quadrotor we have 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. The skills learned and technology developed in trying to complete the goals of this competition have wide-reaching applications that extend outside the scenario presented here. Technology which allows this quadrotor to navigate its environment autonomously can be used in other form factors, such as rovers and submarines. It's ability to accomplish a complicated, multi-step task without the need for constant human guidance allows machines to perform tasks that ordinarily would have required human intervention, thus freeing people to work on other objectives. Also, using autonomous drones allows people to stay out of harm's way whether it be in a battlefield, a hazardous industrial situation, in space, or a burning building.