University of Central Florida Entry for the 2013 AUVSI Foundation's International Aerial Robotics Competition

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ABSTRACT

This paper details the development and construction of a quadrotored unmanned aerial vehicle that is capable of navigating and mapping indoor environments when there is little available information about the contents of the structure. The University of Central Florida's autonomous vehicle APUS was designed to compete in the International Aerial Robotics Competition's 6th Mission. APUS utilizes computer vision, optical character recognition, and state-based programming to navigate an unknown compound fully autonomously.

INTRODUCTION

In recent years, the use of unmanned aerial vehicles has become more widespread in many fields. Yet UAVs have become known for their military applications since they excel in reconnaissance, and the pilot of the aerial vehicle does not get hurt if the aerial vehicle is shot down. Other applications of UAVs include scientific research, search and rescue missions, and border patrol.

Quadrotors are a design of UAV that are becoming more popular since they are very accessible to consumers through remote controlled aerial vehicles. Quadrotors are designed with a cross like frame with a rotor on each end of the frame like shown in Figure 1. To control pitch and yaw, the quadrotor needs only to vary the speed of certain rotors depending on how it wants to move.

This paper will show how our unmanned aerial vehicle will accomplish Mission 6, using cameras and ultrasonic sensors to map out the indoor environment, locate the USB flash drive, and replace the flash drive with an identical decoy.

Problem Statement

The objective of the 2013 IARC 6th Mission is to successfully and stealthily infiltrate a secure structure, autonomously navigate unknown terrain, retrieve a small payload and return, undetected, to starting position in ten or fewer minutes. Remaining undetected constitutes a "clean" mission.

The designed vehicle must meet the following criterion:

a. The vehicle's weight must not exceed 1.5 kg
b. The dimensions must not exceed 1 meter in any direction
c. Must have a built in "kill switch" that immediately terminates flight
d. The vehicle must be fully autonomous.

In the event of detection, an alarm sounds and the mission is reclassified as a "dirty" mission. In this instance, the time allotted for flight is reduced to five minutes.

Conceptual Solution to Solve the Problem

We chose to use to Parrot AR Drone 2.0 as our initial platform due to its flight stability, low weight, and pre-existing optical flow analysis programming. Additional components were carefully considered based on necessity, weight, and input type.

The design utilizes two main cameras: one front-facing and one downward facing. Computer vision and optical character recognition will be used alongside the front-facing camera to determine if the blue LED is on, interpret any signs that might be encountered, and avoid any obstacles in the path of the vehicle. The downward facing camera will be used once the target inbox is located in order to quickly retrieve the flash drive and deploy the decoy.

A total of six ultrasonic sensors will be used to determine the surroundings of the vehicle. Data received from the sensors will be transmitted wirelessly through an onboard microcomputer and wireless adaptor to an off-board computer for processing. The off-board computer will use this information to generate a map of the area and calculate the most efficient exit route from the compound.

Yearly Milestones

As this year's entry marked the University of Central Florida's first attempt at the International Aerial Robotics Competition 6th Mission, many milestones were met during the course of the project.

During the course of the project, the University of Central Florida team developed several feasible designs for the autonomous vehicle and weighed the benefits and disadvantages of each design in order to settle on the best possible design for the challenge.

AIR VEHICLE

The Autonomously Programmed Unmanned System (APUS) weighs approximately 650 grams and has dimensions of 517 mm by 517 mm. APUS stands at a height of approximately 165 mm.

Propulsion and Lift System

The vehicle is propelled by four 15W brushless motors outfitted with speed controllers. The motors are configured in an "X" frame design and rotate in alternating directions to generate lift as shown in Figure 1. Direction control is made possible by controlling the speed of the rotation of the various motors.

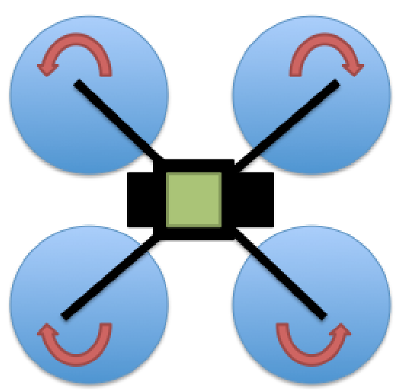

Figure 1, Motor Configuration of the Vehicle

Guidance, Navigation, and Control

Guidance and Navigation

A basic navigation program is pre-programmed into the vehicle, to ensure some movement, but the guidance is predominantly handled by an off-board processor. Figure 2, pictured below, details the process of communication between various components of the vehicle.

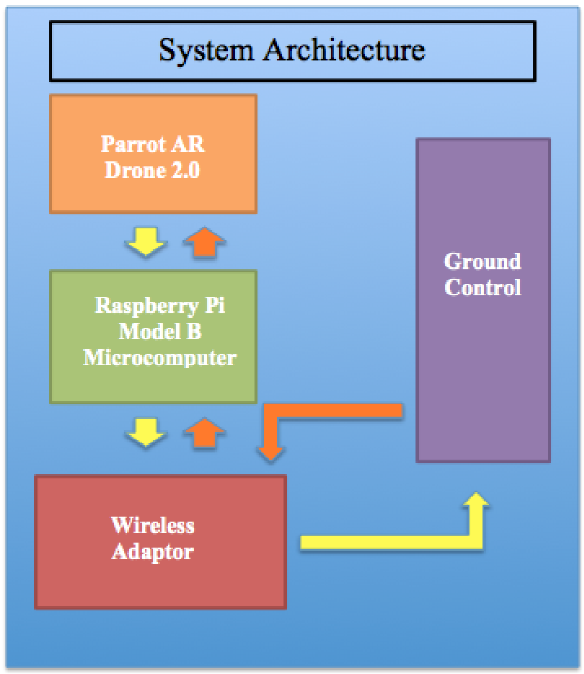

Figure 2, System Architecture of APUS

1. The first phase of guidance is a simple forward command. This is to ensure that the vehicle will exhibit some motion during flight. This command is handled by the processor of the Parrot AR Drone 2.0.

2. The second phase of guidance relates to the additional sensor inputs. Ultrasonic sensors determine the surroundings of the vehicle and the vehicle will execute one of a number of predefined responses to the interpreted data.

Priority is assigned to each programmed response based on the importance of the task. The selection of response is based on a number of factors including distance to the nearest obstacle, visibility of higher priority objects, and time remaining until flight termination.

Control

APUS operates using state-based autonomy. There are a total of eight programmed states:

1) Window search, in which APUS uses its many sensors and cameras to locate and utilize the entry point,

2) Hallway scan, in which APUS scans its immediate surroundings and for objects or obstacles further into its peripheral. This state catalogs obstacles and their distances and prioritizes necessary procedures by their relative distance from the system.

3) Barrier deactivation, in which APUS executes all steps necessary to deactivate the laser barrier.

4) Obstacle avoidance, in which APUS uses its cameras and sensors to locate possible obstacles and plan flight routes around them. APUS stores the location of all encountered obstacles in order to shorten flight paths upon retrieval of the target item.

5) Visual input interpretation, in which APUS uses computer vision and optical character recognition to receive and interpret information gathered from the onboard cameras and responds accordingly.

6) Search and Retrieve, in which APUS uses its cameras and sensors to enter and scan the rooms for target objects and initiates a retrieval process if the specified criteria are met.

7) Extraction, in which APUS uses gathered data to map and execute a route out of the building.

8) Disposal. APUS disposes of the retrieved object by dropping it outside of the 3m-security perimeter or returning to its starting position for manual recovery by the handler.

Stability Augmentation System

In order to maintain a stable hovering position, APUS alternates the amount of power being sent to each motor. Roll, pitch, yaw, and depth are monitored using an onboard gyroscope and controlled using the known vehicle properties with the excess weight of additional components factored into any calculations.

In addition to the state-based programming, there is a background optical flow analysis program operating at all times to ensure that the vehicle is flying in a stable pattern.

Flight Termination System

In the event of loss of communication with the vehicle, there are several emergency termination systems in place. The first of which is accessible from the mobile override station. There are two main landing functions of the mobile override station: landing, which allows for a controlled landing and emergency stop which immediately cuts power to all motors.

In addition to the mobile override station, the ground control has an additional emergency stop that serves as a backup in the event of a mobile override station failure. This will immediately stop the power flowing to all motors.

PAYLOAD

Sensor Suite

In addition to the ultrasonic sensors on the bottom of the vehicle that are used to determine altitude and position in the Z direction, there are four additional sensors added and configured to detect any obstacles in the XY coordinate system. The four additional sensors are "daisy-chained" and alternately generate signals of 4Hz. This allows the vehicle to identify any possible obstacles in its immediate surroundings. The location of any potential obstacles or barriers is sent to an off-board computer that will generate a map of the area in order to reduce the time needed to exit the compound.

Also included onboard is a gyroscope that is intended to prevent the vehicle from unintended tilting as well as an accelerometer to send information about vehicle speed.

There are two primary cameras in use by the vehicle. The front-facing cameras has a resolution of 720p and a frame rate of 30fps, this allows for the image quality needed to properly execute the computer vision and optical character recognition programs. The downward-facing QVGA camera has a frame rate of 60 fps in order to assist in determining the speed of the vehicle. The downward facing camera has more limited computer vision capability, however the current level is sufficient to identify the target thumb drive.

Communication

Communication with the vehicle is handled by an onboard WiFi module built-in to the Parrot AR Drone 2.0. In order to process the autonomous programming wirelessly, data from the ultrasonic sensors is sent to a ground station for processing via microcomputer and wireless adaptor. The information is interpreted off-board and relevant commands are transmitted from the ground station back to the drone via the microcomputer.

Power Management System

The vehicle is powered using a single three cell Lithium-Polymer battery with a capacity of 1000mAh. This allows for a total flight time of approximately eleven minutes utilizing all systems. Batteries are charged using a Li-Po battery charger that is fitted with a timer to prevent overcharging.

OPERATIONS

As with any project, there are a number of concerns about the safety of the design. In order to reduce the risk presented to team members and bystanders, a number of safety features were put in place.

Prior to any scheduled flight, there are a number of precautions taken to ensure the safety of the team, bystanders, and the vehicle.

During flight, discretion of whether the vehicle's flight is jeopardizing the safety of nearby persons or the vehicle itself is left to the mobile override station operator and the ground control station operator. However, there are several means to override the autonomous programming of the vehicle in the event of unforeseen complications.

Below is a checklist of the steps deemed necessary prior to, during, and following a flight to ensure the continued safety of all persons.

Pre-Flight	Check: ● Fully charge primary battery ● Fully charge backup batteries ● Check all connections ● Ensure link with mobile override station ● Ensure link with ground control station
During Flight	Check: ● Monitor vehicle status via ground control station ● Monitor vehicle to determine if override is necessary ● Terminate flight
Post-Flight	Check: ● Review recorded flight for any areas of concern ● Check all connections ● Check battery status

Vehicle Status

Vehicle status is monitored from the ground control station. Information about the status of the vehicle and its current flight is recorded and later analysed. As an additional safety measure, all flights are recorded to an internal USB drive for additional processing. Data stored on the USB drive is accessible from the mobile override station.

The mobile override station is an additional safety feature put in place. It provides a realtime, first-person view from the perspective of the primary front-facing camera. In the event of unforeseen complication, the station can be used to manually override and pilot the vehicle.

Man/Machine Interface

Though mainly designed as an autonomous system, it is possible to manually override the autonomous functioning of the vehicle and regain control of the vehicle via the paired mobile override station. The mobile station is paired to the wireless connection APUS. This will override the priority of any autonomous actions and divert all control of the vehicle to the mobile override station operator.

Safety

Each of the four propellers is surrounded by a foam frame that is intended to prevent foreign objects from being caught in the moving blades.

APUS is equipped with an emergency stop feature which immediately stops the motors powering the vehicle. This feature is accessible from both the ground control station and the mobile override station.

Modeling and Simulation

Custom parts were all designed using Solidworks 2013 and manufactured in-house. This allows for rapid production of replacement parts in the event of a system failure that results in broken parts.

Simulations were run using Gostai Lab on an Ubuntu platform. The modular nature of the program allows for rapid updates and for monitoring of all relevant vehicle systems during simulation.

Testing

Testing was done on-site at the University of Central Florida in an outdoor replica of the competition field. In order to minimize the effect of the wind on the flight stability of the vehicle, the challenge testing location was chosen to be a spacious annex on university grounds that is buffered from the wind.

General systems tests are performed intermittently to ensure the continued functioning of all system as well as the functionality of the mobile override station. These tests are performed on an outdoor field with low traffic.

CONCLUSION

In conclusion, the University of Central Florida has designed a small, lightweight vehicle that is capable of navigating unknown terrain fully autonomously. This design is currently undergoing testing in both a physical and virtual environment. At this point in the design process, the vehicle is capable of a basic level of autonomy. Higher levels of autonomous function are expected to be developed in the coming weeks.

Acknowledgements

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