4/29/2011

IPRO312 FINAL PROJECT REPORT

Executive Summary

The aim of this IPRO is to develop a low cost, electric powered, unmanned aerial system (UAS) that consists of an unmanned aerial vehicle (UAV) that is capable of autonomous flight and autonomous target recognition which is controlled from a ground station. The project will be built towards the rules stated in the AUVSI UAV Student Competition (See Appendix). The first semester of this project focused on developing the system. To develop this system the IPRO team was split into three sub-teams: one team developed the autopilot system, one team developed the target recognition system, and the last team built the ground station where the autopilot and target recognition system will be integrated.

Currently, this IPRO just finished its second semester. This semester, the team was split in a similar manner as the first semester, but integration of the three sub teams was emphasized. The autopilot and vision system was further developed and integrated into the ground station. The system consists of a UAV and a ground station. The UAV is controlled by the ground station by entering way points (GPS coordinates) into the ground station. Additionally a camera mounted onto the airplane captures images of the ground which is sent to the ground station. The ground station processes the images from the UAV and also monitors the condition of the UAV while in flight.

Purpose and Objectives

The use of Unmanned Aerial Systems (UAS) for intelligence, surveillance, reconnaissance as well as in search and rescue is rapidly expanding in both civilian and military applications at an unprecedented rate which was not foreseen a decade ago. Accordingly, there are significant job opportunities in this field and it is expected that this will continue to grow in the next decade. However, the design of UAS is truly an interdisciplinary task as it requires an excellent team work with expertise in diverse areas ranging from aircraft design to autonomous flight, video and data transmission to visual object recognition, the operation of ground station such as real time data analysis and antenna tracking as well as legal/policy aspects of UAS flight operations.

In this IPRO project, we have developed an electric powered low cost, light weight, UAS solution that will utilize complete autonomy.

The overall goal of this IPRO was to design and build a small scale UAS that is capable of:

1. Autonomous flight and navigation through way points within a mission zone of 2 km radius with fail safe functions such as "return to home" and "flight termination" in case of radio and/or video transmission loss
2. Target recognition through real time video and telemetry transmission and data analysis. This is to be done by using image processing algorithms coupled with position determination from GPS receivers and other onboard sensors. The data acquired would then be transmitted to a ground station for post processing and prioritization.

The design of the UAS would require the selection or construction of a stable airframe with the flight characteristics required for high quality images and video as well as a decent endurance and range for the surveillance of large areas. Furthermore signal transmission, reception and processing methods will need to be developed to ensure functionality at a multitude of ranges and conditions, with provisions being made for overlapping signal coverage. The focus of this IPRO was system integration of the autopilot system and image processing into the ground station.

Organization and Approach

As mentioned previously the IPRO 312 team was divided into three subsystems: Autopilot Team, Vision Team and the Ground Station Team. Each had a unique approach and team goals.

i. Autopilot Team

The heart of the autopilot system is a modified Arduino Mega (ATMega1280). The ArduPilot Mega is connected to a RC receiver to handle manual control for pitch, roll, yaw, throttle, and mode changes.A separate 900MHz XBee radio is used to transmit data to the ground control station via the MavLink protocol. GPS, airspeed, and magnetometer sensors also feed data to the ArduPilot Mega. Several servo outputs control attitude control and throttle to an electronic speed controller (ESC). The ESC provides output to the motor as well as power to the ArduPilot Mega.

A ten channel radio controller is used to manually control the aircraft and change autopilot modes. Four channels are used for attitude (pitch, roll, and yaw) and throttle control. An additional two channels are devoted to toggling between the six modes of the aircraft, Manual (Hardware), Manual (Software), Return to Launch, Autopilot, Fly-By-Wire A, and Fly-By-Wire B.The autopilot system navigates by a series of waypoints fed into the EEPROM (electronically erasable programmable memory) on board the ArduPilot Mega. These can be set before flying or in flight. A UBlox GPS module locks onto the position and constantly updates throughout the flight. Coupled with a magnetometer, the autopilot system is able to navigate to the different waypoints.

Since the autopilot system is open source and is adaptable to any airframe, project specific variables are setup in an external configuration file. Protocols for GPS, ground control station are setup here as well as limits for sensors. The configuration file also gives the flexibility to tune the PID loops so that the airplane can stabilize itself.

Before uploading the autopilot code to the UAS, the code was tested in X-Plane. X-Plane is a flight simulator that allows users to simulate flight from an array of different aircrafts. It helps simulate realistic weather conditions, where one can control wind, turbulence, and all forms of precipitation. In X-plane, the plane was not behaving as expected or as commanded. This resulted in a series of diagnostic tests. The tests were performed to make sure the code includes all six flight modes needed. At first, most of the flight modes were not recognized by the radio controller. The six modes had to be selected in a diagnostic test individually.

Once all six modes were recognized, the fail-safe feature was tested. The fail-safe feature essentially goes into Return to Launch flight mode when the UAV loses radio control. In order to test this feature, radio control was turned off and the flight mode of the UAV was checked for RTL. However, the UAV continued to stay in the flight mode it was originally set to. After further diagnostic tests, it was discovered that the fail-safe feature was not included in the original ArduPilot Mega software code. The autopilot code had to be upgraded to the most recent version of ArduPilot Mega in order to include the fail-safe feature.

Presently, the autopilot team plans to test the autopilot flight mode in the next test flight. In autopilot mode, the UAV should be able to autonomously takeoff, navigate through different waypoints, and autonomously land. In the same test flight, the autopilot team plans to test the fail-safe feature and determine whether the UAV goes into RTL mode when radio control is turned off. The results of the next test flight will determine the parameters that need to be modified in the current code.

ii. <u>Vision Team</u>

The visual system of the UAS is designed to detect and identify targets of basic geometric shapes and colors, with an alphanumeric painted on it, as shown in Fig. (1). The dimension of the target is between 4 feet and 8 feet, and the alphanumeric is fit within the size of the target.

Figure 1: An example of the target.

The objective of the visual system is to report the shape of the target and its color, as well as the alphanumeric and its color.

The visual system is designed to work by two steps, detection and identification. In the first step, detection, the UAS flies at a relative high altitude, scans the searching area, takes pictures of large areas of the ground at some constant rate, and sends them back to the ground station.

In the current plan, the UAS flies at a height of approximately 230ft, at a speed of approximately 30mi/h. A wide-angel (approximately 130deg.) video camera (GoPro HD Motorsports HERO Camera) is mounted between the front landing gears, taking high definition (1920pix * 1080pix) pictures of the ground of an area of 1000ft * 560ft, at a rate of approximately one frame per every 5 second. Note that at this rate, every point on the ground is covered by two adjacent pictures, so that no point on the ground is missed by the searching. The searching path is shown in Fig. (2), where *d*=1000ft and *L*=560ft are the dimensions of the area covered by each picture.

As the camera takes the pictures, an Eye-Fi SD card plugged in the camera transmit the pictures wirelessly to a beagle board on the UAS. The beagle board makes some preliminary processing (e.g. compression) of the pictures and sends them back to the ground for further processing.

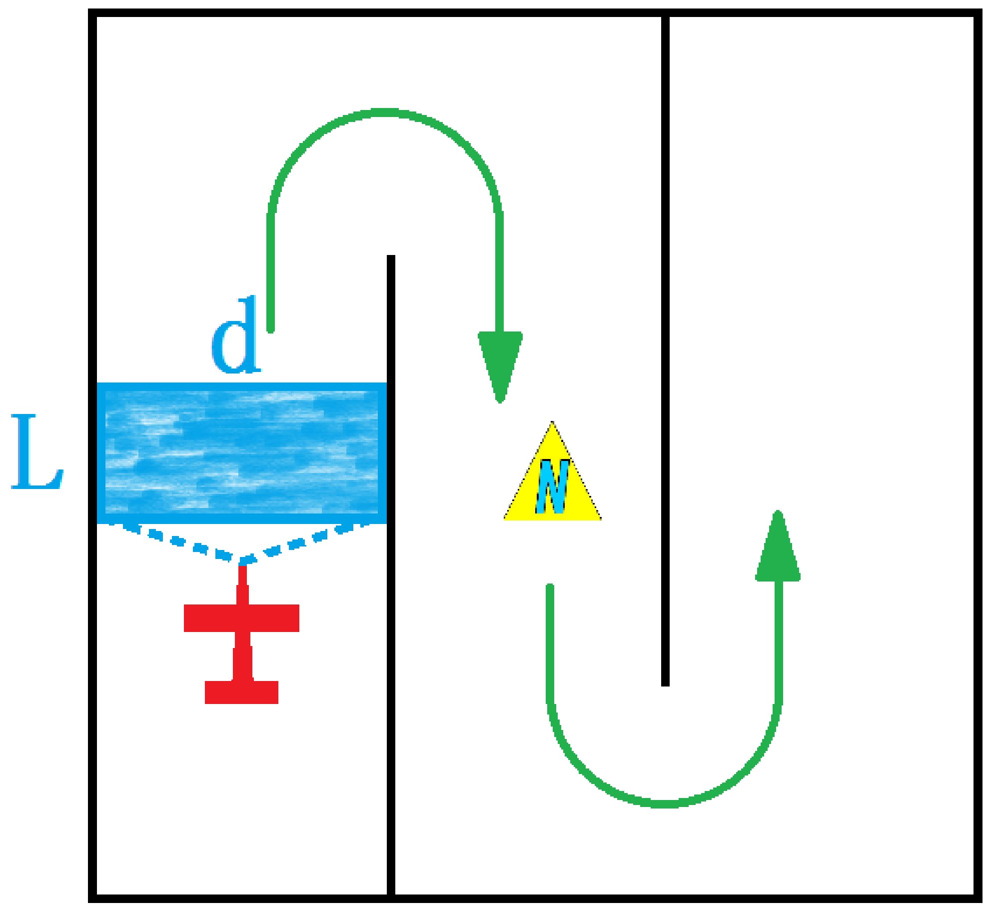


Figure 2: Searching path of the UAS, not to scale.

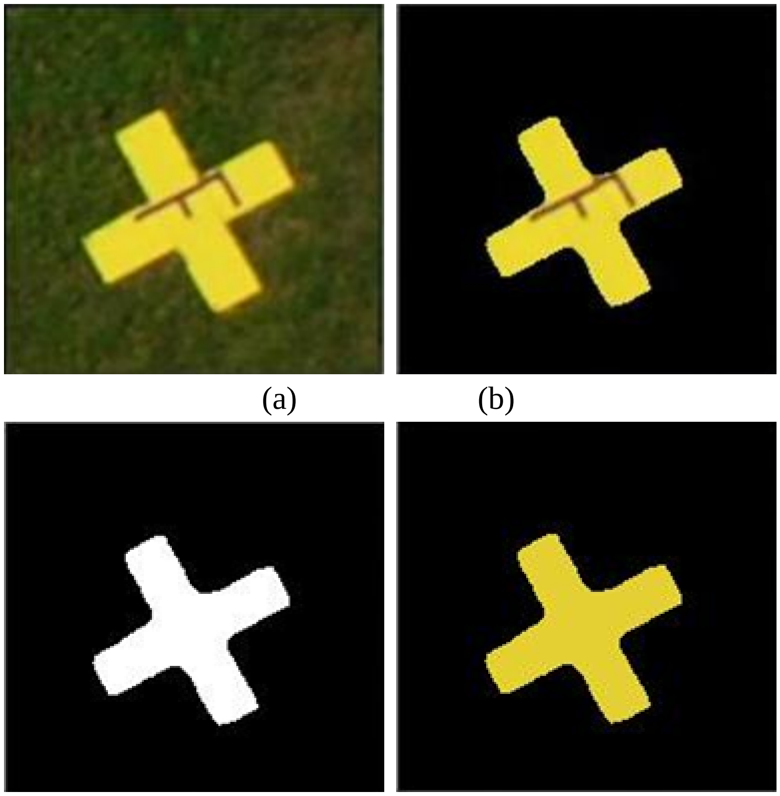
As the ground station receives a picture, a program written in OpenCV computes the gradient of the RGB values on the picture and draws contours of large gradient, as shown in Fig. (3).

(a)

(b)

Figure 3: The contours (b) of the color-contrasted objects on the ground (a).

If the dimension inside a contour is smaller than the largest possible target, the area is marked as a potential target. Then the program computes the GPS location of the potential target with relevant flight information. The procedures of target detection are shown in Fig. (4).



(a) (b)

(c) (d)

Figure 4: Detection of a target. (a) Original image of a target on the ground; (b) Target distinguished from background by color contrast; (c) Contour of the target; (d) Target detected with its color.

In the second step, identification, it is assumed that the image of the target extracted from the picture may not have enough resolution to identify its alphanumeric and even its shape. According to the searching plan described before, each target occupies about 10pix * 10pix on the picture, which is much less than that in Fig. (4). But this resolution could be enough for a well-designed algorithm to identify the alphanumeric painted in the target as well as its color, as shown in Fig. (5)

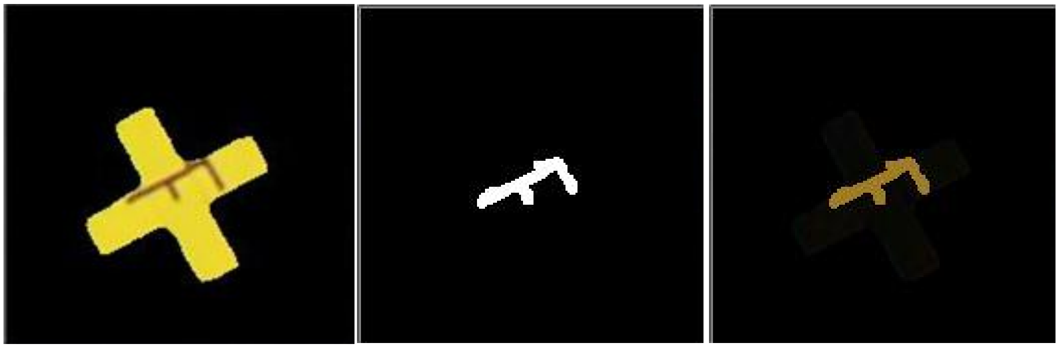

(a) (b) (c)

Figure 5: Identification of the alphanumeric on target. (a) Detected target with its alphanumeric; (b) Contour of the alphanumeric; (c) Color of the alphanumeric.

If the program fails to identify a target, the UAS will fly over the target at a relatively low attitude after finish searching the entire area, and take a closer shot of the (potential) target for identification. Currently the program of detection is being improved, and that for identification is being developed and the transmission system is currently undergoing integration with the ground station.

iii. <u>Ground Station Team</u>

The IIT-UAS Ground Control Station (GCS) is the integration of all the individual UAS subsystems to one focal point in order to monitor, communicate, update and control (if necessary) the aircraft by the most efficient means possible. Additionally, it was decided that the IIT-UAS GCS must also have the following desired attributes:

- Durability/Survivability
- Portability
- Reliability

As a result the IIT-UAS GCS incorporates multiple hardware, and software, components that were determined to be necessary for the GCS to have the stipulated attributes and support mission success. The following is the list of components which make up the complete IIT-UAS GCS:

- Hardware
    - Lenovo ThinkPad laptop
    - Aluminum Antenna Tracker rigging
    - Pelican Storm case
    - Xbee Rx/Tx antenna
    - Bi-directional patch antenna
    - 2-Channel Video Diversity Controller
    - 2 Video Receiver
    - Tripod
    - 15” HD LCD monitor (2 monitors)

- X-cell LiPo battery
  - Futaba, 10 Channnel, 72MHz Controller
  - Global Positioning System (GPS)
- Software
  - QGroundControl Station (open source)
  - antenna tracking software
  - OpenCV Image Detection
  - Intel Thread Building Blocks (TBB)

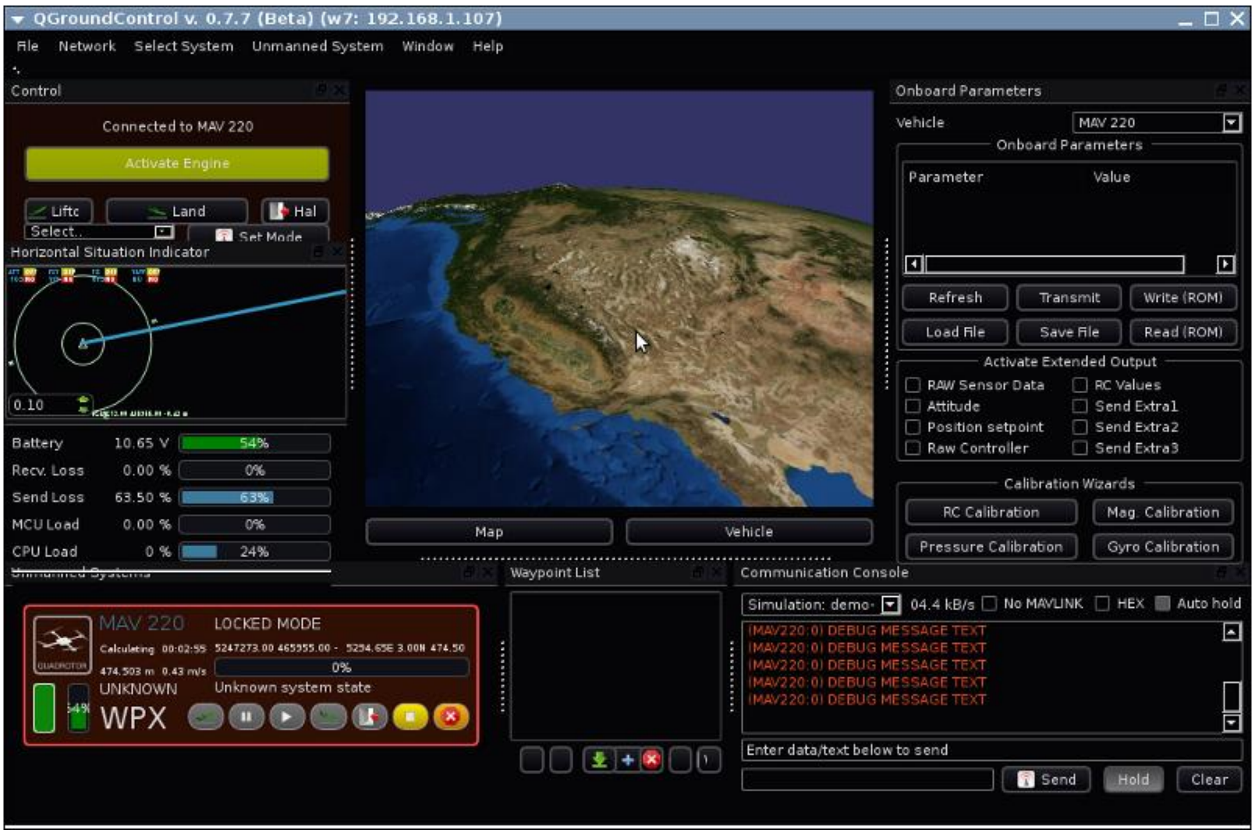


Figure 6: QGroundControl Station Software

At the GCS location a crew of team members are in charge of constantly monitoring all GCS screens, UAS performance and received UAS data. As a safety measure one team member is specifically tasked with the assignment of handling the UAS controller and be on the alert in case there is a loss of communication between the UAS and the GCS and the UAS does not begin to return to home. In such a case, the team member manually changes the flight mode of the UAS to regain control of the UAS and return it home.

The brand of the laptop utilized is not of particular importance, however, its graphics display, computing power and computing performance are critical to the mission. Particularly, when the computer is to run the various dependent/interdependent programs simultaneously. Thus, the chosen laptop contains a quad-core processor and an NVIDIA GPU. Furthermore, the computer's multi-core processing performance is further enhanced through the application of Intel's TBB.

The laptop is the primary user interface, specifically it is the method by which "in flight" mission objective updates are communicated from the GCS to the UAS, and flight data and images are communicated from the UAS to the GCS. Communication between the GCS and the UAS is accomplished by means of two antennas:

1. A Xbee Rx/Tx antenna is responsible for sending mission objective updates (i.e. waypoints, flight hard deck/ceiling, etc.) and receiving flight environment data (i.e. air speed, telemetry, orientation, etc.). This antenna operates at 900 MHz and is mounted directly to the laptop via USB.
2. A bi-directional patch antenna is responsible for the transmission of live image/video feed from the UAS to the GCS. This antenna operates at 2.4 GHz and is mounted to an aluminum antenna tracker rig, emphasizing every desired attribute of the GCS.

At the GCS, the graphical data output of the laptop is split between the laptop main screen and an externally connected 15" LCD monitor, which is mounted to the internal surface of the lid of the Pelican Storm case. In addition, a second LCD monitor, also mounted to the internal surface of the case lid, displays the live image feed being received from the camera mounted on the UAS.

The laptop uses QGroundControl/MAVLink (QGC) open source software to process and display all the data transmitted from the UAS in real-time, along with displaying mission status and waypoints on a 2D moving map. Examples of the data being transmitted are:

- Throttle %
- Yaw
- Pitch
- Roll
- Air speed
- Ground speed
- Temperature
- Elevation
- UAS GPS coordinates
- Battery charge level

The mission objective updates (i.e. additional waypoints, new flight plan, new search patterns, etc.) are input via the waypoint widget or the 2D map found on the QGroundControl/MAVLink graphical user interface (GUI). All received data, input data and commands are logged with time stamps and tagged with GPS coordinates. To ensure safety QGC GUI also incorporates safety protocols such as:

- "Kill UAS" command in case of situations which require for the termination of vehicle motor operation.
- "Return to Home" command in case of an unexpected problems encountered during flight

All components are packaged inside the Pelican Storm case during transportation and are concealed within the case during operation, with the exception of the antenna tracking rig and tripod. While performing mission operations the antenna tracking rig is transferred out of the storm case and positioned externally.

Conclusions and Recommendations

Although the semester has come to an end, this IPRO will continue working to complete this project in order to compete in the AUVSI Student Competition. The ground station is where all integration takes place in the UAS. Both the autopilot and the vision system need to be further integrated and tested together with the entire UAS.

The autopilot needs to perform more test flights to test the other 4 modes. Autopilot mode tests:

- Autonomous takeoff
- Navigation to waypoints
- Autonomous landing
- Fail-safe feature

The vision system also needs to further test and integrate with the rest of the UAS. The vision program needs to be tested in a test flight to ensure that the camera is providing satisfactory images and is being transmitted properly to the ground station.

This IPRO hopes to finish testing and developing the UAS by the end of May. This IPRO will not continue onto the next semester as the AUVSI Student UAV competition is this June. Another team from the AIAA club in IIT will continue development of this UAS for future competitions.

Appendix

IPRO 312 SPRING 2011

For more information about the AUVSI Student UAV Competition go to:

http://pma263webdev.bowheadsupport.com/studentcomp2010/default.html

- **Faculty Advisor:** Dr. Murat Vural
- **Team Members:**
    - Kay Traylor (Vision Team & Project Manager)
    - Lidens Cheng (Autopilot & Media, Autopilot team leader)
    - Brian Schubert (Ground Station)
    - Nishanth Samala (Autopilot)
    - Bernie Mendez (Ground Station & Media)
    - Tushar Nair (Ground Station & Treasurer)
    - Lan Jiang (Vision Team, Vision Code Developer)
    - Yaofu Zhao(Vision Team)
    - Artemio Perez (Ground Station team leader)
    - Matthew Simpson (Ground Station/Autopilot, Integration)

- **Additional Contributors**
    - Anirudha Katre
    - Andrew Ellickson
    - Chi Lo

- **Budget**

item	quantity	cost	total cost	
Hardware - Eyeofmine.com	1	383.45	383.45	17-Mar-11
Hardware - Digikey	1	21.1	21.1	4-Mar-11
Home Depot Gift Card	1	25.67	25.67	1-Mar-11
Computer Equipment - Amazon	1	24.99	24.99	Feb. 24, 2011
Electronic Comp - dyi-drones.com	1	44.13	44.13	Feb. 22, 2011
Electrical Comp - Sparkfun.com	1	50.48	50.48	Feb. 22, 2011
Supplies - Goodwinds.com	1	142.09	142.09	Feb. 21, 2011
Hardware - ReadyMadeRC	1	148.62	148.62	Feb. 21, 2011
Equipment - B&H Photo	1	359.5	359.5	Feb. 21, 2011
Electronics - Parts-express	1	32.68	32.68	Feb. 21, 2011
Electronics - DPcav.com	1	41.28	41.28	Feb. 21, 2011
Electronics - Newegg.com	1	341.41	341.41	Feb. 21, 2011
BeagleBoard	1	149	149	Feb. 21, 2011
Poster Printing	1	48	48	April 27 2011
		TOTAL	1812.4	