IPRO 312: Unmanned Aerial Systems

Final Report

Summary

The essential goal of this IPRO is to develop a low cost, electric powered, unmanned aerial vehicle (UAV) that is capable of autonomous flight and autonomous target recognition. 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, and the last team built the ground station where the autopilot and target recognition system will be integrated. This semester a working autopilot system has been developed, the ground station has been designed and the equipment for it has been ordered and needs to be assembled. The target detection component is in the training stages and a working object detector is expected to be developed in the next semester.

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 UAS solution that will utilize complete autonomy. The goal is to design and build a small-scale UAS that is capable of (i) 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 and (ii) 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 will be placed on smooth system integration as each one of these tasks is closely related to others. This IPRO project will also be an excellent platform to get hands-on exposure to rapidly developing and commonly available technologies such as GPS receiver modules, gyroscopes, infrared (IR) sensors, inertial measurement units (IMU), pressure sensors, auto-piloting systems and software development, lithium polymer (LiPo) battery powered electric propulsion systems, wireless telemetry and audio/video transmission, diversity antennas and antenna tracking systems, etc.

Organization/Approach

To efficiently complete our goal of developing a UAV capable of autonomous flight and an image processing system controlled by a ground station, the team was split into three sub-teams: vision team, autopilot team, and ground station team. A legal team also researched any legal implications of UAVs so our team will not break any rules when doing test flights.

Vision Team

The vision team had the challenge of developing an image processing system capable of identifying a target of interest and tracking that target. To process video from the UAV, a camera with optimal resolution needs to be attached to the aircraft and transmitted to the ground station where the video is processed. The image processing system was to be developed by using an open source vision library, OpenCV to detect the objects. Sample images needed to be created and the program needed to be trained in order to successfully detect the targets. The goals for the vision team included:

Install OpenCV on Linux environment

Create random training images

Use training images in haarcascade

Implement haarcascade into object detect

The first goal of the vision team was to install OpenCV into a Linux environment. OpenCV is an open source vision library aimed at real time computer vision and it was originally developed by Intel. The reason why OpenCV was chosen is because it is open source which would make it the most cost effective choice; however, the challenge of using an open source system is that there is no support for the program, which makes the program harder to work with. OpenCV and other necessary components were installed in a Linux environment because it is easier to use in Linux than other operating systems. Vision Team was able to successfully install OpenCV and the rest of the software components within the first three weeks of the semester and allowing the team to begin the rest of the process.

The second challenge of developing the image detection system was creating thousands of random negative and positive sample images to be used for training. An example of the target needed to be detected by the UAV is shown below

The targets of interests are basic shapes (circle, square, triangle, pentagon, hexagon, star, and octagon) with overlaying alphanumeric characters. First OpenCV was used to create these images, but it did not produce images randomly enough, so instead a code was written in MATLAB that created the shapes, rotated the shapes at random angles, and overlaid the shape onto a random background. This process took up most of the semester since there was a need for a large variety of images due to the requirements of the target detection system for the AUVSI competition. The vision team also had to take the time learn the MATLAB based image processing toolbox and the inbuilt functions along with image processing methods from the basics.

When the training images were made, the haarcascade classifier could be implemented to create training data for the object detect program. Haarcascade is an OpenCV program that creates training data from positive images and negative images. Parameters can be varied for training data. This classifier takes about a week to process, so creating a classifier for every object that needs to be identified will take some time.

Autopilot Team

The autopilot team worked primarily on installing and programming the autopilot system for the aircraft. Throughout the semester, the autopilot needed to assemble, connect, and test various components of the autopilot system. These components are listed below:

- sensors: ATmega1280 microprocessor, flash memory, 3-axis gyroscope,
- accelerometer, magnetometer, differential air pressure sensor,
- absolute air pressure sensor, temperature sensor, long range
- ultrasonic range-finder, GPS receiver, XBee long range radio modem
- transceivers operating in 900 MHz spectrum.
- Connected 72 MHz RC radio system to autopilot hardware for manual control and autopilot mode switching.
- Tested sensors and hardware to assure correct functionality.

The autopilot team also needed to implement software functionalities into the autopilot code. Like the image detection code, the autopilot code is also open source and had to be modified for the particular aircraft we used (Easy Star). The tasks for implementing software functionalities is listed below:

- Stabilized flight using 3-axis gyroscope and accelerometer sensors.
- Autonomous landing with controlled rate of descent using ultrasound
- range-finder.
    - Autonomous takeoff using air temperature, air pressure sensors and
- GPS receiver.
    - Autonomous waypoint navigation, and return home using 3-axis
- gyroscope and accelerometer, air speed, altitude sensors and GPS
- receiver.
    - Flight plan modification (i.e.: addition of new waypoints) while in flight.
    - Continuous transmission of telemetry information to ground station.

- Real time display, logging and graphing of telemetry in ground station
- Transmitted information is roll, pitch, yaw, rollspeed, pitchspeed, yawspeed, altitude (best estimate), GPS altitude, altimeter altitude, range-finder altitude, differential pressur sensor, airspeed, GPS ground speed, GPS 3D speed, IMU heading, magnetometer heading, GPS heading, temperature, current autopilot, waypoint, distance to next waypoint, altitude of next waypoint, battery level, current control mode.
- Ground station software can read autopilot configuration parameters in flight.
- Ground station can create/save/load flight plans and upload/download
- flight plans to/from autopilot.
    - Heading detection using 3-axis magnetometer, GPS receiver and IMU.
    - Battery level reading of 3C LiPo batteries and transmission to ground station.
    - Synthesized speech notifications and alerts in ground station software.

The goals for the autopilot team next semester include:

- Definition of search zones and nofly zones using GPS coordinates in GCS and AP software.
- In flight modification of autopilot configuration parameters through ground station software.
    - Range testing of radio components.

Ground Station Team

Camera choice and wireless down-link were the first challenge the ground station team approached. The challenge from the camera system was solved, while not ideally, by a standard definition wireless camera set-up. The reason a standard definition system was chosen was due to weight and size constraints of the airframe. Research will continue into the nest semester on the camera system, with the intent of improving the image quality obtained by the airframe.

The next item researched was the laptop. Five different configurations from varying manufacturers were looked at, with the deciding factors being price, performance, and a sunlight viewable screen. The required level of performance was determined by the needs of the vision team.

Throughout the semester, the ground station team was also put in charge of ordering and obtaining all the items required by each team. The overall budget was also the responsibility of the ground station team.

Lastly, the case for the ground station components has been chosen, , but will not be completed until the middle of next semester , due to the changing set-ups of the overall project.

Analysis and Findings

One of the primary goals of this IPRO team was to reduce the overall cost required to produce a fully functioning Unmanned Aerial System (UAS). Currently, a fully functioning UAS built using the same parameters as the UAS built by the team can cost up to $10,000. However, by reducing costs but still maintaining the capability would make our UAS better than the rest. Due to this reason we had to approach this problem from the basics.

Since the cost of this UAS was to be lowered, commercially available equipment such as a pre-programmed fully functioning autopilot system or ground station system could not be bought. The best way to deal with this problem was to use equipment based on open source code to develop our UAS. Using open source software is the best possible way of reducing costs because any program or software developed using open source is available to the public free of cost. Furthermore, the developed code is very easy to edit due to the numerous amounts of people available for help via forums and other means. Once we understood the capabilities of using a versatile open source code, the IPRO 312 team decided to use it as a base for our autopilot system and looked into similar means for developing a capable target detection system and ground station setup as well.

Upon further research, the team decided to use Arduino Mega, a system specifically made for creating a UAV capable of autonomous flight. There were many other open source systems available for the same purpose; however the Arduino Mega was the most well documented of them all. The Arduino Mega autopilot system is developed by DIY-Drones, a company based in California that focuses mainly on RC Flying and UAV's. The Arduino Mega is a relatively new autopilot system with its predecessor being the Arduino. The Autopilot Team in the term of this semester managed to order and configure all the components necessary to achieve a successful autonomous flight. The final system created by assembling all the units together was then tested by connecting it to commercially available flight simulation software called the X-Plane. This software allows the user to interface the Arduino Mega with a virtual aircraft in order to fly the aircraft via inputs and corrections supplied by the Arduino autopilot system. Making a functioning autopilot system that responds as per the input parameters within one semester while starting from the basics of budgeting and ordering parts is one of the major accomplishments of the IPRO 312 team.

The vision team also made significant progress through the course of this semester. Starting from the choice for camera used for the video acquisition and the choice of transmitter and receiver combination to actually writing the Object Detect software, the vision team had a lot of ground to cover. Within the first two weeks when the budget was being processed for approval from the SAF, the vision team finalized the progress timeline for the semester. The camera was chosen by the entire IPRO 312 team within the first two weeks as well, allowing the vision team to work on the image processing part of their task.

As mentioned earlier, the vision team primarily used two softwares; OpenCV and MATLAB. The members of the vision team were not experienced with software development, as a result had to start working by first learning the intricacies of the project. Upon research, a basic step by step process was determined on how to approach this problem. The first step was to install all the required softwares on a Linux environment. Next on the list was creating the numerous sample images required to train our program to detect objects. We then planned to use an inbuilt function of OpenCV, which stands for Open Computer Vision, to train our program to recognize shapes. The inbuilt function called

Haartraining requires approximately 3,000 positive sample images and 5,000 negative sample images per shape in order to successfully train our program.

We spent two weeks trying to understand and write a code based in OpenCV that generated the images as per our requirements, those being that the shapes have to be randomly colored and oriented with a size of 100x100 pixels and are a perfect fit at any angle of rotation when overlaid onto the negative background images. Since we made no significant process with writing such a code in OpenCV, we turned to Plan B which was to use MATLAB to create these images since we, as engineering students, had more experience using MATLAB than other softwares. Using the inbuilt functions and toolboxes along with some image processing theory common to all types of programming languages we managed to produce the required number of images by the end of October. Following this we moved on to training our software using Haartraining. The Haartraining process takes approximately 5 to 7 days per shape and as a result creating the classifiers for all shapes will be very time consuming. We ran into some problems such as segmentation faults and minor errors in the input parameters during this step as well. However, we finally were able to run the program successfully and acquired an output file that can be used in our main program in order to detect square shaped targets of any color. However, the team has not had the time yet to test the output file to see if it works as per expectations.

In respect to the ground station, it was concluded that the antenna tracking hardware needs to be more robust than the current set-up. Additionally, if better image quality is desired, the image processing must be moved onto the airframe, or I digital to analog converting system must be implemented.

Halfway through the semester, we realized that some aspects of flying a UAS might leave our team on treacherous ethical and legal grounds. Thus we had two of our team members redirect a part of their efforts to researching any laws regarding UASs along with any other ethical issues that we might face. Their research was very thorough and reassured the team that none of our actions were illegal. In order to prevent any invasion of privacy or other such ethical problems, we ensured that any testing was conducted without causing distress to anyone.

Now that all the components of the UAS were in working order and no laws were being violated, we decided to conduct test flights. We were able to conduct two test flights this semester, with both of them resulting in crashes. Our UAV's were tested on the Northerly Islands, a former airfield in close proximity to the Adler Planetarium. Upon analyzing the reasons behind the first crash, it was understood that the steadily worsening weather conditions caused it. It was a direct result of high winds causing the left wing of our UAV to break off mid flight. Fortunately, none of the electronic equipment was damaged and our team was able to modify a spare airframe for another test flight. This second test flight however, was a direct result of an unorganized planning effort prior to the flight. Due to slight miscommunication we had a last minute dash to assemble all the required parts in order to have a successful test flight. However, we did not double check our assembly and think through the communication process of the different components onboard the UAV with the equipment on the ground. After takeoff, the frequency at which the video transmission was occurring interfered with the frequency of the various components of the autopilot system causing the crash. We managed to salvage all the electronic components on the UAV a second time. Various ideas are being taken under considerations to make the IPRO 312 next semester progress much more efficiently.

Conclusions and Recommendations

Significant progress was made this semester towards approaching the final goal of this project. Not only did the team get a functioning, although still relatively untested, autopilot system, the team also has a working antenna tracking system and an almost ready to test object detection software. The next semester will see this IPRO team pull all the parts together swiftly in order to get a fully functioning UAS capable of detecting targets at an average altitude of 500 feet. In order to make this goal successful, the current IPRO 312 team has decided to make a list of things that will result in an efficient next semester.

The very first step in this list is the creation of a pre-flight checklist and diagnostic manual. Having a pre-flight checklist with any and all considerations taken into account will result in ensuring that any failures in the test flights will not be due to human error while the manual will make the debugging and analysis process much more efficient and organized. The crashes this semester would easily have been averted by having a checklist such as the one proposed. Another step next semester will be approaching sponsors. Currently we receive funding from the Student Activities Fund at IIT, however with the nature of our project being equipment intensive we find ourselves in need of more funding. As a result, we plan on approaching possible sponsors for possible funding. If we receive more funding we can get more equipment that although not critical to progress will enable us to progress faster with better results.

The final and the most important short term goal for this project is to get the UAS flying efficiently enough to allow us to participate in the AUVSI competition from June 15th to 19th. This competition is sponsored by the American Institute of Aeronautics and Astronautics (AIAA) and co-sponsored by major companies in the Aerospace Industry.

With all the progress under the teams belt along with ideas to make the progress next semester even more efficient this IPRO was in the team's opinion very successful. We achieved most goals listed at the beginning of this semester with time to spare as well as managed to think of ways to enhance this project for the future members and making their tasks easy.

Appendices

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