IPRO 312 Unmanned Aerial Systems

Project Plan

Spring 2011
Instructor: Prof. Murat Vural

Abstract

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. The design of UAS is truly an interdisciplinary task as it requires 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 a ground station such as real time data analysis and antenna tracking.

In this IPRO project, we are developing an electric powered low cost UAS solution that utilizes larger autonomy than most current UAS designs. 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 will 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 this semester 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.

The IPRO team will also address broader issues concerning (i) the testing and use of UAS in national air space for flight operations (provided by the FAA) and remote observing (both federal and state policies), and (ii) the use of surveillance equipment by private observers or even local government offices to observe private property. To this end, IPRO team will analyze government documents to establish limits of current civilian UAS usage with the objective of (i) identifying specific areas where technology can be expanded quickly, and (ii) creation of a document specifying the policy limitations and technical requirements for UAS flight operations and remote observing, which will be extremely valuable beyond this project and serve as a guide for future development.

In the Fall 2010 portion of this IPRO we developed the control systems, and the signal and image processing capability of the UAS. The Spring 2011 portion of this IPRO will focus on system integration and having a final product by IPRO day. Refining the final system will require simulation and static testing. We hope to demonstrate the capabilities, with a series of test flights and trials in varying conditions and with varying targets, with the goal of refining the software and expanding the overall capabilities of the design. After this semester, this IPRO will compete in the 2011 AUVSI UAV International Student Competition to demonstrate the capabilities of our design.This IPRO would start as an engineering, research, and development project with the eventual promise of transitioning into an EnPRO for marketing and developing a low cost commercial version of the product.

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Team Information

Objectives

- Integrate the control system into the airframe and tune the controlling software fo r the specific performance of the airframe and the sensors chosen, with emphasi s on autonomous takeoff and landing as well as pattern search and waypoint nav igation.
- Modify the imaging hardware and image processing software and integrate into t he airframe for testing. Emphasis is to be placed on detecting GPS position and f eatures determination of target.
- Further develop the ground station, including transmitter/receiver station for radio , telemetry and video links, and the post processing workstation with emphasis o n reducing signal degradation and interference.
- Test and optimize the airframe, autonomous control system, ground station and s ensors, demonstrate target acquisition capability.
- Investigate FAA regulations and Federal/State policies for the use of UAS for flig ht operations and remote observing private properties with the goal of preparing a document specifying policy limitations and technical requirements.
- Integrate all system components into the airframe and ground station and reduce interference and optimize signal transmission.
- Compete in the 2011 AUVSI UAV International Student Competition

Team Objectives

- Complete design of system(hardware, software)
  - Autopilot: Determine any bugs or signal interference issues in software and hardware through test flights .
  - Image Processing: Complete image detection program and develop an optimal method for onboard digital signal processing. Develop a post processing algorithm to classify recognized targets.
- Complete sensor data collection mechanism
- Successful integration of components into aircraft and ground station
- Complete ground station for telemetry, video and RC links
- Successful testing of UAS through test flights and computer simulations and optimization of UAS capabilities

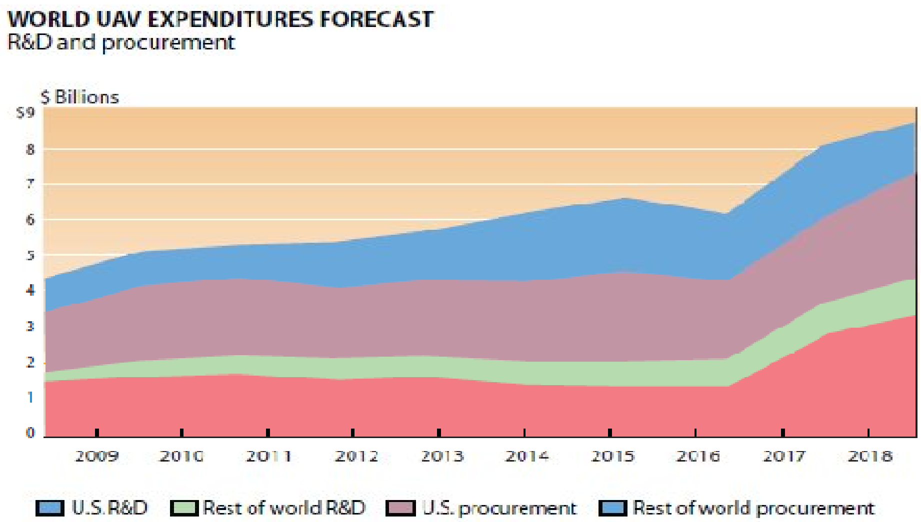
Team Values Statement

- To treat one another with respect
- To make honest commitments and honor them
- To be punctual and regular on daily assignments
- To work in a group and communicate efficiently
- Openness to learning new technology/skills
- When confrontation arises, they shall be handled appropriately by the team leader and then by the instructor
- Volunteering where ever required and having a fair task assignment.

Background

Project Background

The nature of UAS development is very conducive to the success of small companies, and in the current industrial environment the small companies developing UAS technology have been able to compete with great success against larger companies. As the uses for unmanned aerial systems grows both in number and diversity of application, there will be an increased demand for self-sufficient, long duration, and efficient UAS designs. This will depend on the ingenuity of the aircraft designers as well as the resourcefulness of the computer programmers, who will need to develop creative solutions to the problems presented by the environment and circumstances of the UAS' use. With the required performance improvement associated with the growth of the industry the research and development investment will increase proportionally over the next 8 years or more as shown in Fig. 1.



The increasing trend has been predicted based on the current and recent developments in the UAS industry. This trend will largely depend on the ability of new ideas to be applied to the development of UAS technology and will be largely funded through both government and private research and development programs. The projected trend is also not just applicable to the United States as shown above, as there exists a large global market that could benefit from a UAS for many civil and military applications. A potential of a $9 billion market exists for UAS in the next ten years and this is something that is still at a level where small companies and research teams can make a large contribution to the field and thereby gain a foothold in the industry.

Fig. 2. Scan Eagle used by the Marine Corp.
Fig. 3. Killer Bee UAS currently in development.

The smaller scale UAS designs (shown in Figs. 2 and 3) that currently are on the market, lack some of the functionality of the larger systems. This is a major problem for the people who use the systems as they rely on them for accurate and timely information often used to make important decisions. As of now there are a few systems that are under development in the smaller scale category such as the Scan Eagle, and the Killer Bee. These UAS are being developed for military use and are meant to satisfy command center launched surveillance capability, for commanders to gather and relay actionable intelligence quickly and accurately to the ground forces. This area of UAS design can benefit from a lot of improvements and coming up with a cheaper and more effective solution is a key goal for many companies and teams. Another government branch that is currently interested in the use of a UAS for surveillance purposes is the U.S. Customs and Border Protection Agency, which will use the UAS to conduct border patrol operations in both daytime and nighttime operations using infrared and lowlight optics, a system which is automated would allow for a greater area covered by a single person overseeing the operation. This will eventually spill over into the civilian sector as UAS are developed for surveying and agriculture, where the larger scale UAS are just too expensive for the type of work being conducted and in fact pose a potential liability if they are damaged or destroyed over a populated area. With the smaller UAS capable of similar performance the liability is reduced both in the human cost and in the expense of losing an aircraft, making this scale an ideal one for most uses in the civilian sector.

This is where this project comes into play, creating a system that is both capable and has the beneficial qualities of being relatively cheap and being of a small enough scale to reduce liability. The ready availability of R/C airplane components for this small size scale also is an advantage as only slight modifications are needed for things like servos and motors to provide the performance needed in the project. This will further reduce cost and will also make repairs and replacements cheaper, which becomes very important in marketing and keeping the lifetime costs associated with the UAS down to a minimum. If we can reduce the cost of upkeep and the initial investment then the use of UAS will effectively be opened up to a larger consumer market, which will potentially find uses for the UAS that we won't even imagine.

Our team will also address broader issues concerning (i) the testing and use of UAS in national air space for flight operations (provided by the FAA) and remote observing (both federal and state policies), and (ii) the use of surveillance equipment by private observers or even local government offices to observe private property. To this end, IPRO team will analyze government documents to establish limits of current civilian UAS usage with the objective of (i) identifying specific areas where technology can be expanded quickly, and (ii) creation of a document specifying the policy limitations and technical requirements for UAS flight operations and remote observing, which will be extremely valuable beyond this project and serve as a guide for future development.

Sponsor Background

Currently, this IPRO has no sponsor. This IPRO is currently using resources from the AIAA club of IIT.

Technology Background

All software developed for this project is open source is being developed for a Linux environment.

• Team Vision

Team Vision will be using open source programs to develop a vision detection software. The following open source software’s will be used:

OpenCV: an open source library of programming functions mainly aimed at real time computer vision. It will be used in a Linux environment

QT Creator: Cross platform C++ integrated development environment which allows a team of developers to share a project across different development platforms with a common tool for development and debugging.

• Team Autopilot

Ardupilot software used to program autopilot. This will allow a user to input commands from the ground station which will allow the UAV to fly autonomously.

• Ground Station

The ground station will consist of a laptop that will receive live video feed from the onboard camera and process that video feed using the software being developed by the vision team. It will also be able to send commands and receive transmissions from the autopilot onboard the aircraft. If necessary the ground station will be used to manually control the aircraft. In addition, the ground station is also

Ethical Considerations

There are several ethical considerations concerning this project due to the FAA rules and guidelines. Our model airplane must obey the Model Aircraft rules, which were released in 1981. The rules specify that a model aircraft can fly up to a maximum of 400 feet above ground level. It must also be visible to the operator at all times. In addition, the aircraft must provide notification if it is within 3 miles of an airport and there can never be fireworks on board. Furthermore, since our plane is participating in the annual AUVSI competition, it will be flown in a special airspace. Generally speaking, when it comes to UAS, other ethical considerations include the use of UAS in remote observing operations and surveillance of private property by private companies and the government.

Work Breakdown Structure

Team Structure

AUTO PILOT

Team Members: Lidens Cheng, Nishanth Samala, Matt Simpson

Leader: Lidens Cheng

VISUAL

Team Members: Kay Traylor, Yaofu Zhou, Jiang Lan, Bernie Mendez

Leader: Kay Traylor

GROUND STATION

Team Members: Artemio Perez, Tushar Nair, Brian Schubert
Leader: Artemio Perez

Kay Traylor

3rd Year BME 312.513.4908 ktraylor10@gmail.com

Individual Strength to contribute- Experience in electrical engineering concepts and building circuits. Experience in programming in java and Matlab. Highly motivated and eager to learn anything to make this project a success.
New Knowledge/Skill to develop- Will develop skills in programming, particularly image processing. Learn how to build a UAV.
Expectations about the project- Here will be a great deal of information for everyone to learn, but with hard work this project will hopefully end up a success and will be able to compete in the AUVSI competition next June.

Bernie Mendez

4th Political Science and Psychology — bmendez@iit.edu

Individual Strengths to Contribute: Navigation training and leadership experience. Created navigation courses for Fire Battalion US Army, skilled in GPS, IR and night vision operations, some JAVA and C++ programming experience, finance experience in Not-for Profit organizations and IIT student government Finance Board.
New Knowledge/skills to develop: More programming skills
Expectations about the project: Kick ass at competition.

Lidens Cheng

4th Physics — lcheng5@iit.edu

Individual Strengths to Contribute: knowledge of C, C++,
New Knowledge/skills to develop: Learn a lot more about UAV and autopilot systems.
Expectations about the project: Hopefully, the vision, autopilot, and ground station aspects of the project will all function and integrate successfully by the competition in June.

Artemio Perez

5th Aerospace and Mechanical Engineering — aperez7@iit.edu

Individual Strength to Contribute: Substantial leadership and team work experience, along with great organizational skills. Experience working in the aerospace industry as a Co-Op/Intern from 2007 to 2010. Some programming experience but most importantly very excited about learning the internal workings of a UAV.
New Knowledge/Skill to Develop: Strengthen programming skills, learn/learn about the programming required for such UAVs and to develop my knowledge of system integration.
Expectation about the Project: LOTS of work to be accomplished during this semester but with the appropriate management and organization all of our goals can be achieved. Expecting to win the AUVSI competition.

Brian Schubert

3rd Electrical Engineering — Schubert_brian@yahoo.com

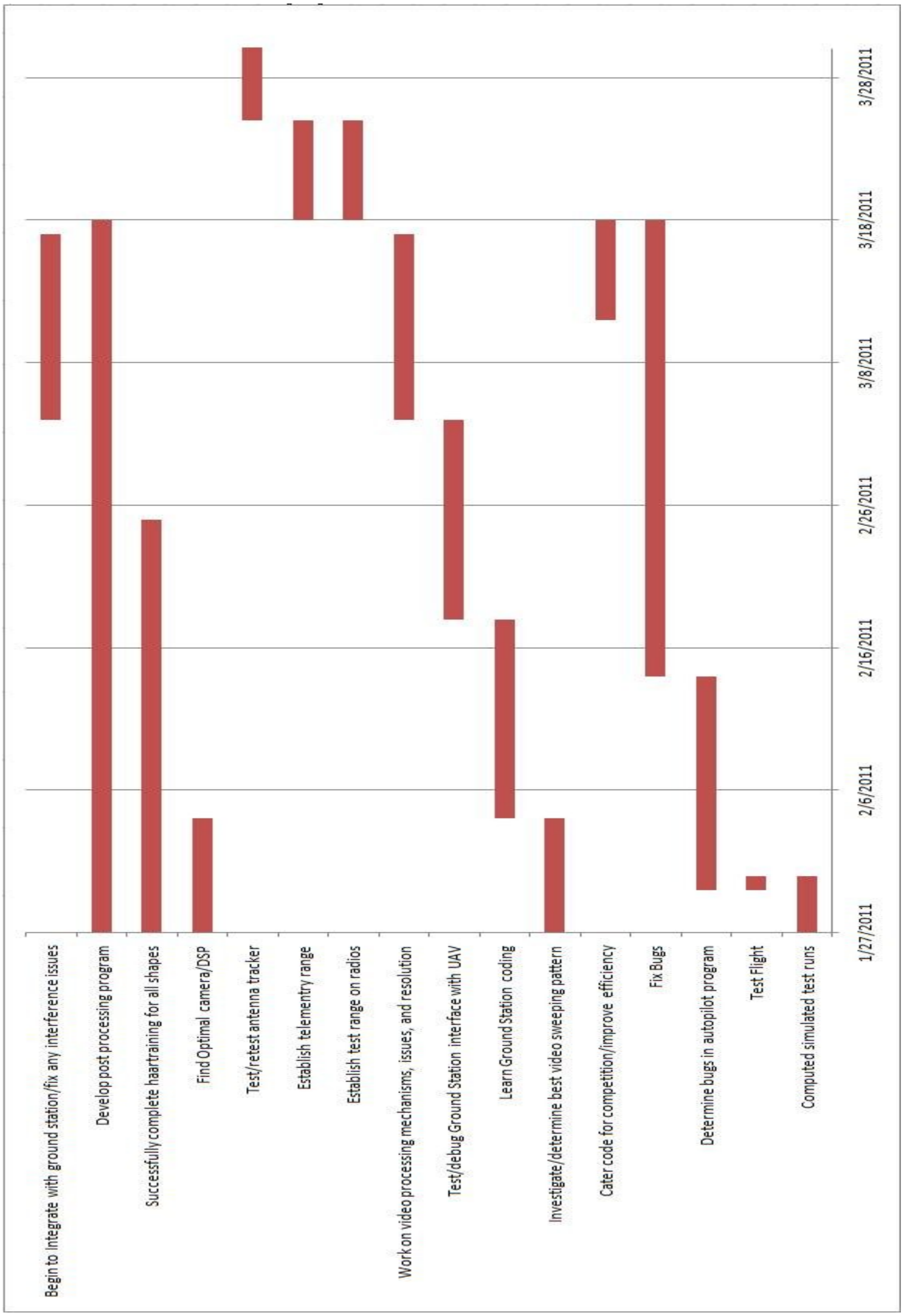
Individual Strengths to Contribute: Experience in Electrical and Electronics Engineering. LabView and instrument I/O, as well as MatLab and Java programming. Self starting disciplined employee who can be given an assignment and see it through with minimal management oversight.
New Knowledge/skills to develop: Knowledge of signal processing and embedded systems. Learn how to build and program a UAV
Expectations about the project: To further my knowledge particularly field relative to my career goals. To build a successful UAV to compete in the AUVSI competition next June.

Major Tasks

Design/Assemble an aerial vehicle capable of-

- Autonomous take-off & landing
- Waypoint navigation via GPS co-ordinates
- Automatic target search & detection
- Analysis of target
- Using sensors inputs
- Going in safety mode/manual control

Timeline


Begin to Integrate with ground station/fix any interference issues
Develop post processing program
Successfully complete haartraining for all shapes
Find Optimal camera/DSP
Test/retest antenna tracker
Establish telementry range
Establish test range on radios
Work on video processing mechanisms, issues, and resolution
Test/debug Ground Station interface with UAV
Learn Ground Station coding
Investigate/determine best video sweeping pattern
Cater code for competition/improve efficiency
Fix Bugs
Determine bugs in autopilot program
Test Flight
Computed simulated test runs
1/27/2011
2/6/2011
2/16/2011
2/26/2011
3/8/2011
3/18/2011
3/28/2011

Expected Results

Expected Activities

- Two to three test flights throughout the semester in legal airfields. The purpose of these test flights will be to test the autopilot software and to test the vision detection software.
- Completion of system by April

Data

- When the target detection software is further developed, it will be necessary to test the program with a realistic video feed. Team Vision will need to obtain a video from a flying aircraft from 250 feet to 750 feet altitude that contains test targets. This video will be used to determine the extent to which the image software needs to be debugged or retrained.
- When the program is complete, it should be able to receive a live video feed, detect targets that it was trained to detect and track those targets. The GPS location and a time stamp of each target will be included in the output of the program.

Potential Products

- Military Applications
- Police-finding runaway suspects
- Agriculture-survey areas to be planted, keep track of cattle
- Construction-survey potential construction sites
- Map updating- Google maps, update maps with more accurate images of sites

Potential Outputs

- Team Vision
  - By the end of the semester, Team Vision plans to have vision detection software that can successfully detect and track certain targets that are expected to be in the AUVSI competition.
- Team Autopilot
  - By the end of the semester, Team Autopilot plans to have a functioning autopilot software that can provide autonomous flights. The plane should be able successfully take off, remain stable throughout the flight, and successfully land. If bugs are found in the autopilot software during test runs, Team Autopilot plans to fix them and improve the efficiency of the code.
- Ground Station

Deliverables

- The goal of this IPRO is to continue to develop an unmanned aerial vehicle that can fly autonomously and detect certain targets from a maximum altitude of 750 feet. The information collected by the UAV will be transmitted to the ground station which will process the video and track the location of the UAV using a GPS system. The final product will include an airplane equipped with an autopilot, a camera, and a transmitter. Additionally, the ground station will be a laptop that receives images from the camera, time stamps those images, and tracks the GPS location of the UAV with little error.

Challenges, Risks, Assumptions

- One challenge in developing the image detection software will be ensuring the program not only detects the specified targets, but also does not detect false positives.
- Transmitting the video from the aircraft to the ground station will be a challenge as it is not guaranteed that the video quality will be optimum.
- The most challenging aspect of autopilot is for the plane to land autonomously.
- A fail safe feature must be installed into the UAV in case communication is lost with the aircraft.

The ultimate goal for this project is to have a functioning UAV that can autonomously fly and detect defined targets in order to compete in the annual AUVSI competition in June. Ultimately, this project may be tailored for applications such as those listed in section C.

Budget

item	quantity	cost	total cost
UAV Airframe	$295.98		
Multiplex Mentor	2	$147.99	$295.98
antenna tracker	$218.98		
AT Pro-1000 Heavy Duty Tracking Station	1	$218.98	$218.98
UAV parts	$298.27		
Mentor Canopy	2	$13.99	$27.98
Mentor Replacement Parts	2	$21.99	$43.98
Extra Sidecar for Antenna Pan/Tilt system	1	$8.99	$8.99
High Pass Antenna Filter for 2.4GHz TX	1	$37.95	$37.95
L-C Filter for Wireless A/V Systems	1	$12.95	$12.95
ArduPilot Mega	1	$59.95	$59.95
ArduIMU+ V2	1	$99.00	$99.00
Toroids	3	$2.49	$7.47
Blade mSR RTF	2	$129.99	$259.98
Blade 120 SR RTF	2	$159.99	$319.98
Night Vapor RTF	2	$129.99	$259.98
hard cases	$585.45		
Hardigg Storm Case iM2950	1	$219.50	$219.50
Hardigg Storm Case Lid Bezel Kit	1	$66.50	$66.50
Hardigg Storm Case Base Bezel Kit	1	$73.50	$73.50
Hardigg Storm Case iM3220	1	$225.95	$225.95
motors and ECS	$149.98		
Brushless Motor	2	$74.99	$149.98
camera	$564.95		
Industrial Camera	1	$564.95	$564.95
pan & tilt	$98.42		
SPT200 Direct Drive Pan & Tilt System	2	$49.21	$98.42
RC tx	$429.99		
DX8 8CH Transmitter	1	$429.99	$429.99
wifi/Data link	$235.57		
900MHz 12dBi Yagi Antenna	1	$39.99	$39.99
600mW High Power USB 2.0 Wireless Adapter	2	$39.99	$79.98
Wifi Router	1	$29.00	$29.00
Wifi Long Range Dish	1	$86.60	$86.60
Misc Tools and Items	$451.53		

wall hangers	5	$29.99	$149.95
paint	4	$6.00	$24.00
Bezels	2	$50.00	$100.00
Step Drill Bit	1	$48.80	$48.80
Corded Drill	1	$78.00	$78.00
connectors and bulk wire	1	$22.84	$22.84
Brother PT1290	1	$27.94	$27.94
Total			**$4,169.06**