IPRO 312 Unmanned Aerial Systems

Project Plan

Fall 2010
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. 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 would like to develop 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 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.

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 plan on developing the control systems, and the signal and image processing capability of the UAS. Once these have been developed and refined in simulation and in 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. 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

General

Team name - IITUAS

Team Logos

Project Purpose & Objectives

The IPRO team will work to achieve five major objectives:

- Choose and modify the airframe to receive components as well as to maximize aerodynamic efficiency to meet established performance requirements.
- Integrate the control system into the airframe and tune the controlling software for the spe cific performance of the airframe and the sensors chosen, with emphasis on autonomous ta keoff and landing as well as pattern search and waypoint navigation.
- Develop and/or modify the imaging hardware and image processing software and integrate into the airframe for testing. Emphasis is to be placed on detecting GPS position and feature s determination of target.

- Design and develop the ground station, including transmitter/receiver station for radio, telemetry and video links, and the post processing workstation with emphasis on reducing signal degradation and interference.
- Test and optimize the airframe, autonomous control system, ground station and sensors, demonstrate target acquisition capability.
- Investigate FAA regulations and Federal/State policies for the use of UAS for flight operations and remote observing private properties with the goal of preparing a document specifying policy limitations and technical requirements.

Team Objectives

- Complete design of system (hardware, software)
- Complete sensor data collection mechanism
- Successful integration of components into UAS
- Complete ground station for telemetry, video and RC links
- Successful testing of UAS and optimization of UAS capabilities
- Establish policy limitations of UAS flight operations in national airspace and observing private properties

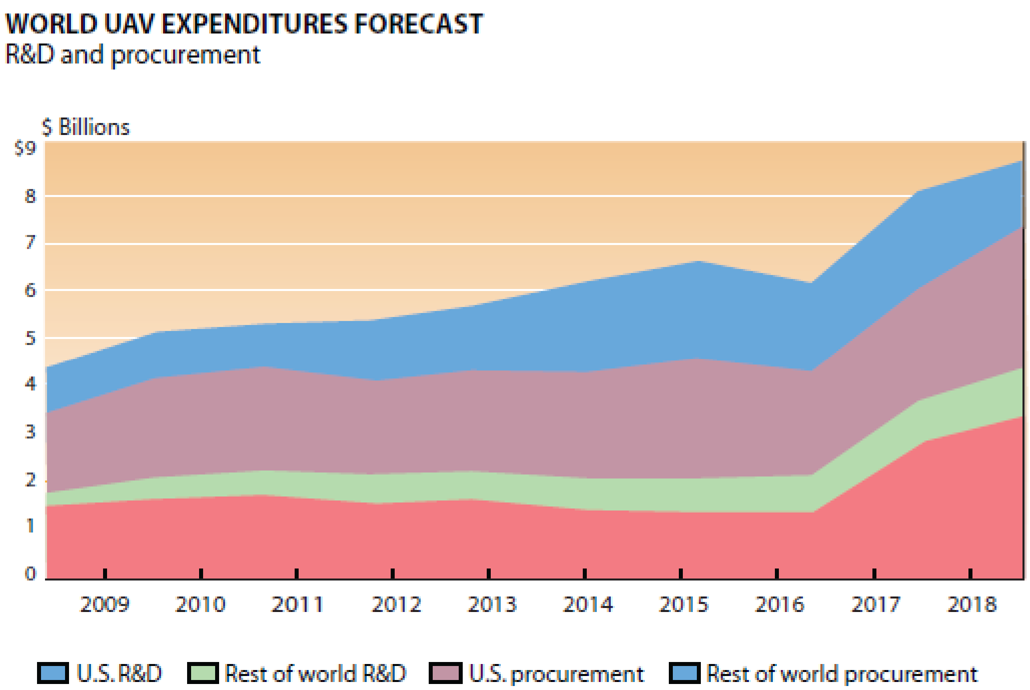
Team Values Statement

- 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. We are looking for funding from private sponsors such as Boeing. This IPRO is currently using resources from the AIAA club of IIT.

Technology Background

- 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 is written in C++ and runs in Linux, Windows, and Mac OS

  MinGW: "Minimalist GNU for Windows", this is an open source compiler for windows

  CMake: Cross-platform open source build system. It generates native make files and workspaces that can be used in the compiler environment of the user's choice.

  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. This can be used on either Linux or Windows.

- 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

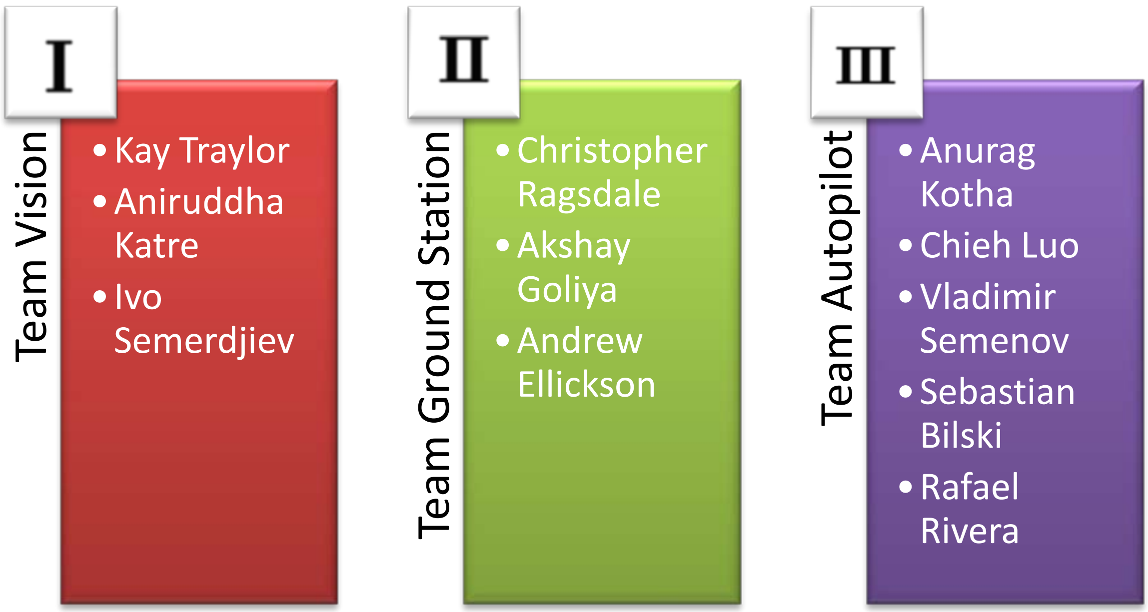
  The ground station will consist of a laptop that will receive live video feed from the onboard camera and process that video feed using the software being developed by the vision team. In addition to being able to send commands to the autopilot. If necessary the ground station will be used to manually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

- Ethical Considerations

A team of students will be looking into ethical consideration concerning UAVs. The biggest ethical consideration to be investigated will be legal issues pertaining to personal privacy. To what extent can a UAV be used? Is there a limit as to the locations and applications a UAV can be used? Could a paparazzi use a UAV to get a closer look at celebrities? Additionally, another legal issue that is of interest to this project are legal frequencies that can be used to fly the UAV. In different countries, different frequencies are restricted and some even require a license. These two issues, in addition to any more ethical issues that this IPRO team comes across will be investigated by the ethics team.

Work Breakdown Structure

Team Structure



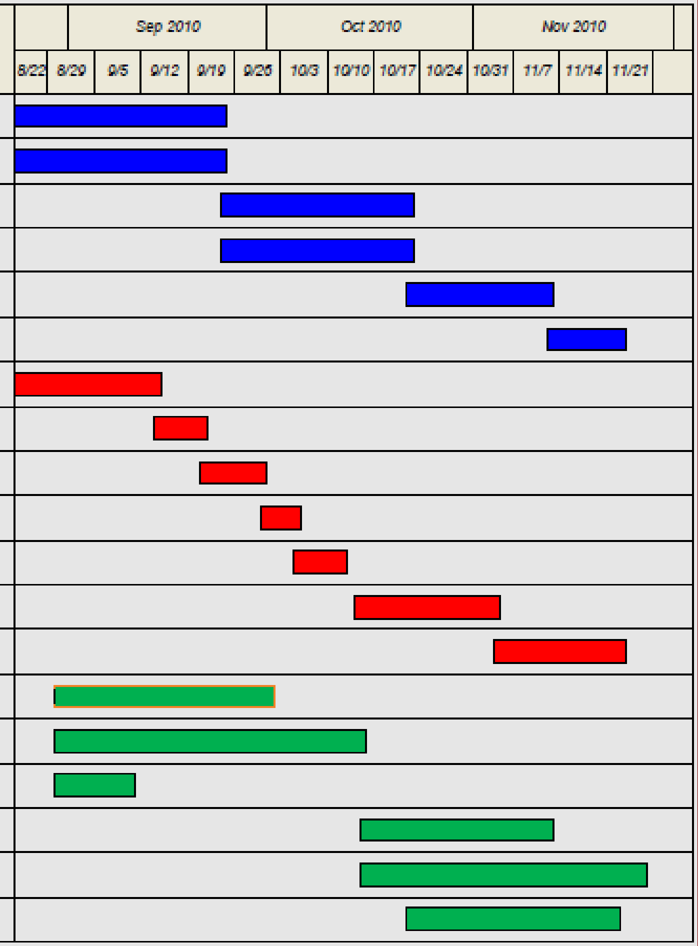
Major Tasks

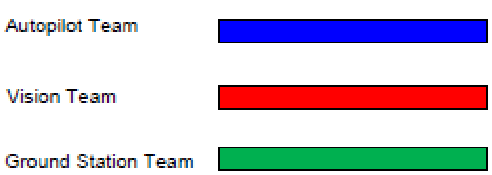
Design/Assemble an aerial vehicle capable of-

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

Timeline

ID	Task Name	Start	Finish	Duration
1	Component Procurement	8/24/2010	9/24/2010	4w 4d
2	Airframe Assembly	8/24/2010	9/24/2010	4w 4d
3	Manual Test Flying	9/24/2010	10/22/2010	4w 1d
4	Develop Control Software	9/24/2010	10/22/2010	4w 1d
5	Control System Integration	10/22/2010	11/12/2010	3w 1d
6	Testing and Verification	11/12/2010	11/23/2010	1w 3d
7	Setup of Software	8/24/2010	9/14/2010	3w 1d
8	Writing and Compiling Software	9/14/2010	9/21/2010	1w 1d
9	Haartraining and Cascade Training	9/21/2010	9/30/2010	1w 3d
10	Video/Picture Input Testing	9/30/2010	10/5/2010	4d
11	Number/Letter Detection Training	10/5/2010	10/12/2010	1w 1d
12	System Integration into UAS	10/14/2010	11/4/2010	3w 1d
13	Testing and Verification	11/4/2010	11/23/2010	2w 4d
14	Antenna Research and Procurement	8/30/2010	10/1/2010	5w
15	Computer Procurement	8/30/2010	10/15/2010	7w
16	Project Plan and Background Research	8/30/2010	9/10/2010	2w
17	Case Procurement	10/15/2010	11/12/2010	4w 1d
18	System Interfacing	10/15/2010	11/26/2010	6w 1d
19	Testing and Verification	10/22/2010	11/22/2010	4w 2d





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 and to collect a sample video for the vision detection software.

Data

- When the target detect 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 Aircraft
  - Team Aircraft should have a program developed that will allow an RC plane to fly autonomously and perhaps even land and take off autonomously.
- Ground Station
  - The ground station will be able to identify GPS locations of targets detected by the vision software.

Deliverables

- The goal of this IPRO is 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 programming the aircraft to fly autonomously will be programming it to take-off and land autonomously. It may be necessary to manually take off and land the UAV.
- 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 next June. Ultimately, this project may be tailored for applications such as those listed in section C.

Project Budget

2	7C Controller	280	560	7-channel 2.4Ghz for the EasyStars
1	10C Controller (Futaba)	550	550	10-channel PCM
2	Simple Planes	40	80	Foamies (park fliers)
2	Brushless motors	15	30	for foamies
2	ESC	20	40	for foamies
1	power supply	130	130	DC Dlx Digital Peak Charger, 1-24
2	parallel charging cables	15	30	Parallel (6x) EC5 Charge Cable
4	batteries (Rhino 1050)	15	60	Batteries for foamies
1	Charger	150	150	2nd battery charger
4	Butcher Paper	16	64	UAS targets
2	Patch Antenna 8dbi	90	90	AN1308 HIGH GAIN PATCH ANTENNA 1.3 Ghz 8dBi
2	whip antenna	30	60	AN2409 HIGH GAIN WHIP ANTENNA 2.4 GHz 9dBi
1	low pass filter noise reduction	45	45	900 MHz low pass filter noise reduction
1	Tripod for UAV ground station	30	30	Tripod for FPV Ground Station 53-Inches
1	Antenna Tracker, Servo Controllers	105	105	Ez Antenna Tracker - tracking and servo controller
1	FPV 180 Metal gear servo with full 180 degree turn	20	20	
2	Heavy Duty Servos for Antenna trackers	45	90	SM8466M - Large Heavy Duty Analog Servo
1	Video Amplifier/bufffer	22	22	Video Amplifier/Buffer with 4 ajustable video outputs
1	Small Microphone	15	15	Tiny-Mic Amplified Microphone with Volume Control
1	Adjustable switch regulator	20	20	ASR-10 - Adjustable Switching Regulator

2	High Res. Mini Camera	190	190	SN555 very high resolution Color Camera 550 Lines PAL SONY®
1	Video Transmitter	200	200	TX-V1024 1000mW 2.4 GHz plug and play transmitter only
1	Data Link Transmitter	300	300	Seagull 900 MHz Transmitter
1	UAV Airframe	200	200	Mentor ARF
2	Video receiver	80	160	1.3GHz 300mW audio/video transmitter
	Plugs/Cables/Connectors	100	100	
1	IR Sensors/interface/interfacekit	120	120	RB-Phi-03
1	GPS Module	80	80	eLogger GPS-V4 Expander Module (10-Hz)
1	Tracking Antenna Pan/Tilt Kit	90	90	Tracking Antenna Pan/Tilt Kit
6	3S 5000 mAh Lipo Batteries	45	270	VENOM 20C 5000mAh 7.4V 2-Cell R/C LiPo CAR BATTERY - UNI Plug (1555)
1	Camera pan/tilt mechanism	45	45	EasyPod Pan & Tilt Kit
	5V DC regulator	15	15	DC-DC Regulator Module:From 6.0-8.4VDC to 5VDC (1 Amp Max)
1	Power Supply filter, L-C Type	12	12	Power Supply Filter, L-C Type
10	Torrid Ferrite Core EMI/RFI Suppresors	1	10	Toroidal Ferrite ring 16mm (0.7") noise suppressor
1	Easy Cap USB 2.0 Video Capture	25	25	EasyCap USB 2.0 Video Capture Adapter
1	Quad Core Laptop for real-time image processing and target detection in ground station	2500	2500	Studio XPS 16
2	(mega 16/15) motors for easy stars	100	200	Mega Brushless ACn16 Series –

				Standard Motors
1	Motors for mentors	100	100	
1	ESC IceLite 75A	90	90	HobbyWing Platinum-80A-PRO-V1 Brushless ESC
1	Data Link receiver	100	100	R2400-DELUXE 2.4Ghz Portable High Sensitivity Receiver
5	Servos for plane	40	200	HITEC HS-645MG HIGH TORQUE 2BB METAL GEAR SERVO
2	GS407 U-Blox5 GPS 4Hz	89.9	179.8	Onboard GPS
2	ArduPilot Mega IMU Shield/OilPan V1.4 (With pin headers)	57.2	114.4	Connectors and headers for ArduPilot Mega + altitude pressure/temperature sensor
2	ArduPilot Mega	59.95	119.9	Onboard Autopilot microcontroller board
2	ArduIMU+ V2 (Flat)	99.9	199.8	Onboard IMU
1	ArduStation	57.2	57.2	Ground station telemetry receiver MC board + LCD
2	XBee Adapter kit - v1.1	10	20	XBee adapter board (onboard)
2	XBee Pro 900 Wire Antenna	42.95	85.9	Onboard Zigbee telemetry transmitter
1	XBee Pro 900 RPSMA	71.95	71.95	Ground Zigbee telemetry receiver
1	900MHz Duck Antenna RP-SMA	7.95	7.95	Ground Zigbee telemetry receiver antenna
1	FTDI Cable 3.3V	17.95	17.95	Cable for programming Arduino microcontroller boards
2	MPXV7002DP	19.95	39.9	Differential Pressure Sensor
2	Infrared XYZ Horizon Sensor	99.9	199.8	Aircraft orientation sensor
2	HMC5843	49.95	99.9	Triple Axis Magnetometer
2	Infrared Proximity Sensor Long Range	14.95	29.9	Sharp GP2Y0A02YK0F, 15cm to 150cm (5 ft), works with Arduino
2	Ultrasound Rangefinder	already have		up to 25ft?

2	Connectors and voltage converters	75	150	Budget for miscellaneous connectors, headers and converters.
2	???	??		New speed controller for the motor
2	???	??		Internal Brushless Motors for EasyStar
1	Futaba 10C	??		10 channel transmitter 72MHZ
8		??		Batteries for Mentor
1	USB Logic Analyzer	149.95	149.95	
1	DC Power Supply	TBD		
1	Multimeter	TBD		
	Soldering Station	TBD		
	USB to Ethernet	33.66	33.66	
	Wifi Router	19.99	19.99	
	BiQuad Wifi Antenna	90	90	
	Digital Camera	400	400	
	Wifi Adapter			
	Ground Station Case	300	300	Pelican Waterproof Case
	Long Range Video System	899	899	LUV-200S
	Sun Shroud	30	30	
	Travel Budget	15	75	travel to test fly (5 times)
12 Seats	Event Travel Budget	200	2400	Travel for team to MD (by air)
	Hotel Budget	200	4000	
44		**3112.3**	**16989.95**	

Team Roles

Team Leader- Kay Traylor

iGroups Manager- Akshay Goliya

Andrew Ellickson

4th Year ME [redacted] aellicks@iit.edu

Individual Strength to contribute- Building computers, making hardware do things it was not built to do.

Akshay Goliya

4th Year EE [redacted] agoliya@iit.edu

Individual Strength to contribute- Desire to work in a team. I am currently majoring in Electrical Engineering so, have significant knowledge related to the technical side of the project.
New Knowledge/Skill to develop- Programming skills, Control Systems and RC systems
Expectations about the project- Looking forward to work in a team of motivated students.

Anurag Kotha

4th Year AE [redacted] agoliya@iit.edu

Individual Strength to contribute- I have been working on this project from a long time. I have knowledge of AHRS systems.
New Knowledge/Skill to develop- Technical knowledge of AHRS and mounting the autopilot system in the airplane. Also learn about ground station components and their functions.
Expectations about the project- To get the UAV fly, land and takeoff by itself. Also get it to recognize targets.

Aniruddha Katre

4th Year AE [redacted] akatre@iit.edu

Individual Strength to contribute- Matlab, C++, and LabView
New Knowledge/Skill to develop- knowledge about image processing using C++/Matlab and circuits
Expectations about the project- To get the UAV working by the end of semester with capable target detection and image processing system.

Chieh Luo

4th Year EE [redacted] Cluo5@iit.edu

Individual Strength to contribute- Desire to work in a team. I am currently majoring in Electrical Engineering so, have significant knowledge related to the technical side of the project

Christopher Ragsdale

4th Year AE/ME [redacted] cragsdal@iit.edu

Individual Strength to contribute- CAD modeling and simulation both of mechanical systems and aerodynamics using finite element and panel methods.

New Knowledge/Skill to develop- Software development and coding, antenna sizing and signal processing, systems engineering.

Expectations about the project- To complete a working autonomously navigating UAV and ground station capable of transmitting and processing visual and location data with minimal human intervention.

Ivo Semerdjiev

5th Year Arch [redacted] isemerdj@iit.edu

Individual Strength to contribute- graphics, visual presentations, willing to learn new things

New Knowledge/Skill to develop- RC Airplanes/Cars/Boats, etc

Expectations about the project- get it done

Kay Traylor

3rd Year BME [redacted] 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.

Rafael Rivera

3rd Year ME [redacted] rrivera3@iit.edu

Individual Strength to contribute- Previous RC experience in airframe design and flight control systems.

New Knowledge/Skill to develop- I hope to become more knowledgeable in writing code which will communicate with all the equipment in the auto pilot platform.

Expectations about the project- I expect we will be able to have the UA up and flying in full auto pilot by the end of semester, but realistically programming takeoff and landing parameters might give us problems.

Sebastian Bilski

4th Year CS [redacted] sbilski@iit.edu

Individual Strength to contribute- Military background. Experience working with/leading both small and large groups.

New Knowledge/Skill to develop- Working on a larger scale project in a less rigid, military environment.

Expectations about the project- Looking forward to working with people with different majors and skill sets. Hoping for a relatively smooth experience, and getting better at working together with people with different backgrounds.

Vladimir Semenov

4th Year CE [redacted] semevla@iit.edu

Individual Strength to contribute- Programming GUI/web applications, database applications, network applications, OLAP, embedded systems, multi-threaded/parallel applications, robot systems. C, C++, Python, Perl, PHP, C#, Java, Haskell, x86 assembly, ARM assembly, 68k assembly, VHDL, ABEL, Verilog. ASIC, digital, analogue design.

New Knowledge/Skill to develop- Familiarity with medium range radio systems, sensors used for aircraft stabilization and navigation, interpreting and acting upon sensor data in autopilot programming, miniature aircraft construction

Expectations about the project- To have flight worthy UAV at the end of the semester capable of navigating way points on autopilot, recognizing ground targets, and taking off and landing autonomously.