Team 6 - Autonomous Aerial Vehicle

Final Year End 2013 Report

Due Date: April 26, 2013

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Table of Contents

Table of Figures

Problem Statement

The purpose of this project is to design and construct an autonomous air vehicle for the submission into the 2013 Undergraduate Students Unmanned Aerial Systems Competition. The aircraft must adhere to specific tasks which will be outlined within this report and will be evaluated on how well it performs these tasks, as well as maintain consistency with the associated design and technical report. Upon successful completion of these specified tasks and design class parameters, Team Six will take this autonomous aircraft to Maryland in the summer of 2013 to compete. Upon completion of this report it is still yet to be determined if team 6 will be going to the competition.

Justification and Background

Unmanned Air Vehicles are an increasingly valuable asset in various applications. UAVs eliminate the need for on-board pilots and as such, the limitations associated with providing a livable environment for the pilot. Their use has increased significantly since their inception, and the next step in this developing interest is to apply complete automation to the systems already being used. The current UAV accident rate is 100 times that of manned aircraft, which reveals the current level of this technology as compared to manned flight. The benefits for furthering this technology are plentiful in the private and public sector alike. Scenarios for data tracking, weather crafts and first responder missions have all utilized the UAV. The Association for Unmanned Vehicle Systems International (AUVSI) has created an objective-based competition that will enable undergraduate students to be introduced to the field of unmanned air vehicles, automation, and image processing. This competition will encourage the development of this technology and give engineering students an opportunity to facilitate an engineering project.

Concept of Operations

An earthquake has impacted a small island nation in the Caribbean. Several boatloads of pirates who have been operating in the area have landed and are attempting to take advantage of the ensuing chaos. The overwhelmed local government has put out a call for help and the US Marines have responded. Their tasking includes humanitarian relief and security. Your unmanned aerial system (UAS) is supporting their mission with intelligence, surveillance and reconnaissance (ISR). In order to support them, your UAS must comply with Special Instructions

(SPINS) for departure and arrival procedures, and then remain within assigned airspace. It will be tasked to search an area for items of interest, and may be tasked to conduct point reconnaissance if requested. Additionally, the UAS may be tasked to relay data from a third party Simulated Remote Information Center (SRIC). Immediate ISR tasking may be requested outside currently assigned airspace, causing the UAS operators to request deviations.

Objective

This is a performance-based competition which will be evaluated in three major criteria: a technical report, a pre-flight presentation and inspection, and the execution of the mission itself. The objectives for this mission are clearly outlined by the SAE Aero Design East committee. The team must design and construct and autonomous UAV that will launch, fly a predetermined path as well as search a specified area, identify targets, provide images of the targets, send these images and location information about the target to a home station, and finally return and land. A time of twenty minutes is allotted for maximum points. The degree of autonomy and quality of launch and recovery will also earn points.

Constraints

The constraints for this project are outlined in the 2013 Undergraduate Students Unmanned Aerial Systems Competition. According to the Seafarer chapter the constraints may change once the final rules and regulations are posted. The following list is given in this report exactly as it is written by the Seafarer Chapter in order to give the reader as much detail possible to understand what is necessary for this design project to meet its goal of competing(AUVSI; International).

- **Gross Weight Limit -** The aircraft may not exceed fifty five (55) pounds in weight.
- **Radios -** The use of 2.4 GHz radio is required for all competing aircraft.
- **Takeoff -** Takeoff shall take place within one of two designated Takeoff/Landing areas, depending on wind direction. This area will be paved asphalt surface, roughly 100 ft wide, with no height obstacles. Systems utilizing launchers and/or not performing wheeled landing may utilize the grass immediately adjacent to the runway; however, grass area will not be prepared. Takeoff from moving vehicles is prohibited. Launchers will be inspected by competition safety inspectors before they are allowed for use in the

competition. After takeoff, the air vehicle shall maintain steady, controlled flight at altitudes above 100 feet and under 750 ft MSL (Note: airfield elevation is approximately 10 ft MSL). Takeoff under manual control with transition to autonomous flight is permitted. Extra credit and a cash award will be provided for autonomous Takeoff.

- **Waypoint Navigation -** Air vehicles must autonomously navigate to selected waypoints, and will be restricted to assigned airspace and avoid no-fly zones. A predetermined course which includes changes in altitude and in heading will be followed. Teams will fly a predetermined course that includes changes in altitude and in heading, to the search area.

    - **Waypoints -** GPS coordinates (ddd.mm.ssss) and altitudes will be announced the day prior to the flight competition. However, because of the dynamic nature of modern warfare, it is possible that additional waypoint(s) and/or search area adjustment(s) will be required.

    - **Enroute Search** – Air vehicles will be required to fly specific altitudes while identifying several targets along the predefined entry route. One of the targets will be directly along the route when the vehicle is required to be at 500 ft MSL (± 50 ft). Another target will be up to 250 ft from the center of the flight path while the vehicle is required to be at 200 ft MSL (± 50 ft). The team will be given the position of the off-center target. UAS shall not vary from the flight paths (± 100 ft tolerance) briefed during the mission planning in order to obtain an image of the target; flight path deviations shall not be permitted as to avoid being shot down by hostile or friendly forces. Enroute way points shall be achieved in order.

    - **Targets -** Targets will be constructed of plywood of a given size, basic geometric shape, and color. For an example, see figure 1. Each target will be a different shape and a unique color; a different color alphanumeric will be painted on each target. There are an unknown number of targets in the area. The additional target will be more reflective of a realistic surveillance target. The minimum dimension of the targets (length or width) will be 2 feet, and the maximum dimension will be 8 feet. Alpha-numerics will be sized to fit within the overall dimensions of the target varying between 50-90% of the length/width of the target and between 2-6 inches in thickness, and will vary in color and contrast. The alphanumerics of the targets can be arranged to spell a “secret” message. Any team that can spell the message will receive bonus points and a cash prize.

Figure 1: Search and Rescue Targets

- **Area Search-** Once transitioning into the predefined search area via the entry/exit route, the air vehicle shall autonomously search for specific targets of interest. Air vehicles may search the area at any altitude between 100 and 750 ft MSL. Targets will be distributed throughout the search area. Competitors shall record the characteristics (location, shape, color, orientation, alpha, alpha color) of all observed targets on a target data sheet (and/or in electronic form) and provide this data to the judges at completion of the mission.
  - While executing the search mission, the team will be provided with a new search area (within the existing no fly zone boundaries) allowing you to locate “pop-up” targets. The “pop-up” target will be in the form of a human engaged in an activity of interest. There will be a minimum of 200 ft margin between the search area and the no fly zone boundary.
- **Landing-** Landing shall be performed completely within the designated takeoff/landing area. Transition to manual control is permitted for landing. Extra credit and a cash award will be provided for autonomous landing. Control in landing will be graded. Mission completion is when the air vehicle motion ceases, engine is shutdown, and the target data sheet and imagery have been provided to the judges.
- **Total Mission Time** - Total mission time is the time from declaration of mission start from the judges and permission to turn on transmitters until the vehicle has safely landed,

transmitters are shut off, and target data sheet (or spread sheet) is handed to the judges. Accuracy of results and time required to submit results will be measured. Missions completed between 20 and 40 minutes will receive some bonus points for each minute less than 40 minutes (must land vehicle, crashed and/or terminations do not earn bonus points); however, no additional points will be awarded for mission times less than 20 minutes. Significant points will be deducted for each minute over 40 minutes mission time, up to 60 minutes total where it is mandatory to turn in results. It should also be noted that each team will be given 40 minutes time to set up equipment prior to the beginning of the mission. After 40 minutes, the judges may declare mission start, regardless of the team's readiness to launch the mission. If 40 minutes has elapsed and the air vehicle has not achieved flight, the mission will be terminated.

- **Real Time Actionable Intelligence**-Extra credit will be given for providing complete and accurate information (actionable intelligence) during flight within the search area: once that information is provided, it cannot be modified later. Intelligence is actionable only if all six target characteristics (shape, background color, alphanumeric, alphanumeric color, orientation, and location) provided at that time and recorded on the target data sheet is correct. This will not be considered to be "real time" intelligence unless designated as such

Key Performance Parameters

While these measures will not disqualify a competitor, they are included in these constraints as failure to achieve the following thresholds will incur significant penalty.

- **Autonomy -** Maintain autonomy during way point navigation and area search.
- **Imagery -**Identify any two target characteristics (shape, background color, orientation, alphanumeric, and alphanumeric color).
- **Target Location -** Determine target location ddd.mmm.ssss within 250 ft.
- **Mission Time -** Less than 40 minutes total, imagery, location, identification provided at mission conclusion.
- **Operational Availability -** Complete 50% of missions within original tasking window.
- **In-Flight Re-Tasking -**Add a fly-to way point.

Safety Precautions

Flight operations of any type involve some level of risk to personnel and property. It is the responsibility of the individual teams to adhere to the safety guidelines beyond what ends up being stated in the rules and regulations. Before team six goes to the competition it will need to prove to sponsorship that it can operate, takeoff, fly and land within the boundaries of what is deemed as safe and efficient remote and autonomous flight. The list below contains some of the guidelines set forth by the Seafarer chapter for the 2013 competition

- The Maximum takeoff gross weight of the air vehicle shall be less than 55 lbs.
- The system shall provide sufficient information to the judges to ensure that it is operating within the no-fly/altitude boundaries on a continuous basis.
- The air vehicle shall be capable of manual override by the safety pilot during any phase of flight.
- The air vehicle shall automatically return home or terminate flight after loss of transmission signal for more than 30 sec.
- The air vehicle shall automatically terminate flight after loss of signal of more than3 minutes.
- The return home system, if installed, should be capable of activation by the safety pilot.
- The flight termination system shall be capable of activation by the safety pilot.
- Flight termination for fixed wing aircraft without an alternate recovery system (like a parachute) shall select:
    - Throttle closed
    - Full up elevator
    - Full right rudder
    - Full right (or left) aileron
    - Full Flaps down (if so equipped)
    - The Fail-safe check will demonstrate flight termination on the ground by switching off the transmit radio for 30 seconds or 3 minutes (whichever applies) and observing activation of flight terminate commands.
    - The maximum airspeed of the air vehicle shall not exceed 100 KIAS.

RC Licensing and Regulations

Team six is currently in the process of obtaining local licensing and flight capabilities. There has been contact made with several different organizations in order to find out the appropriate steps to have the ability to fly the aircraft without the use of an outside source. This will save time and money as next semester begins, giving the team ample air time without relying on outside means to pilot the aircraft. Tallahassee law requires that a licensed RC pilot fly aircrafts within specific airfields designated for remote vehicles. At the start of the spring semester, team member #3, Eric Milo, had received his AMA license. He had been the team pilot throughout the semester and was successful in maintaining full control of flight for all test flights. It was imperative that someone from the team be licensed to fly in order to perform an adequate number of test flights throughout the semester.

Model Aircraft Rules and Regulations

The following list of regulations comes from the FAA Modernization and Reform Act of 2012 set forth by the senate in an effort to govern the newly acclimated hobby(Senate). Minor regulations will vary from state to state, however being that the project competition is located in a different state, Team six will adhere to federal and state law and understands that federal law will take precedent in the event of any questions or misinterpretations.

- The aircraft is flown strictly for hobby or recreational use.
- The aircraft is operated in accordance with a community-based set of safety guidelines and within the programming of a nationwide community-based organization.
- The aircraft is limited to not more than 55 pounds unless otherwise certified through a design, construction, inspection, flight test, and operational safety program administered by a community-based organization.
- The aircraft is operated in a manner that does not interfere with and gives way to any manned aircraft.
- When flown within 5 miles of an airport, the operator of the aircraft provides the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport) with prior notice of the operation (model aircraft operators flying from a

permanent location within 5 miles of an airport should establish a mutually-agreed upon operating procedure with the airport operator and the airport air traffic control tower (when an air traffic facility is located at the airport)).

- *Statutory Construction*.--Nothing in this section shall be construed to limit the authority of the Administrator to pursue enforcement action against persons operating model aircraft who endanger the safety of the national airspace system.
- *Model Aircraft Defined*.--In this section, the term ``model aircraft'' means an unmanned aircraft that is—
    - Capable of sustained flight in the atmosphere.
    - Flown within visual line of sight of the person operating the aircraft.
    - Flown for hobby or recreational purposes.

Major Components Overview

In order to successfully make it to the AUVSI competition, this year's autonomous aerial vehicle team is using a portion of last year's team's research and resources coupled with our own research and new objectives.

There are three major aspects of the competition that need to be addressed. First is flight. An aircraft platform that can support all of our needs and satisfy all of the requirements must be chosen. Second, is imaging and target recognition. A camera needs to be attached to the plane that can successfully and efficiently scan the ground for targets, as well as relay that information to a ground station. Finally, the third major component of the competition is that the first and second components have to be done autonomously. There needs to be an autopilot system integrated into the aircrafts controls such that once in the air, there are no corrections performed by the pilot.

Figure 2: Senior Telemaster - Acquired from last year's team

As previously stated, one of the first decision that needed to be made was to determine the aircraft that was to be used in the competition. Last year's team purchased a fixed wing aircraft which we had in our possession. The RC plane is called the Senior Telemaster and can be seen in Figure 2 above. Other common aircrafts used in the AUVSI competition are the helicopter, and the quadrotor seen in Figure 3 below.

Figure 3: (Left) Helicopter with mounted camera (Angelo, The Flying Eye Project)

(Right) Quadrotor with mounted camera (Jantzen, Final Design Package, Senior Design WebPage)

A decision matrix was used to determine what would be the most effective aircraft platform. The matrix can be seen below in Table 1. The criteria used in the decision matrix were determined and are as follows in order of importance: cost, lift to power capabilities, stability, ease of flight, and maneuverability.

Aircraft Decision Matrix		Senior Telemaster		Helicopter		Quadrotor	
Criteria	Max Weight	Grade	Weight	Grade	Weight	Grade	Weight
Cost	0.30	5	1.5	2	0.6	3	0.90
Lift to Power	0.25	4	1.0	3	0.75	2	0.50
Stability	0.20	3	0.6	2	0.40	3	0.60
Ease of Flight	0.15	3	0.45	2	0.30	4	0.60
Maneuverability	0.10	2	0.20	4	0.40	4	0.40
Total	**1**		**3.75**		**2.45**		**3.0**

Table 1: Aircraft Decision Matrix

As Table 1 shows, the Senior Telemaster is the best option. The reason for it being the best option is mainly due to the fact that we already had the plane on hand, which greatly reduces our cost. A large part of this project is to complete the tasks required while adhering to the given budget. Not having to take the cost of an aircraft out of our budget helps to accomplish that much easier. The airplane also has a higher lift to power (input power) ratio than both the helicopter and the quadrotor. This allows us to add components to the aircraft including but limited to a camera, GPS, autopilot, and not affect the characteristics of flight very much.

During the spring semester a power analysis was performed for the plane. An electric motor was compared to a nitro powered motor. As stated in the competition rules, teams are given 60 minutes to complete the mission. To get an electrically powered plane to fly for the allotted 60 minutes would require very large and expensive batteries, while the alternative (nitro powered) would be much easier to achieve and less expensive. Therefore a Magnum XL .91 cubic inch 4-stroke motor was purchased and installed on the plane as seen below in Figure 4.

Figure 4: - Magnum XL .91 CI 4-stroke

In order to supply the motor with sufficient fuel to complete the mission a few test needed to be run to determine the rate at which fuel was used for "cruise speed" flight. A linear interpolation was used to calculate the amount of fuel that was used over a specific interval of time at a controlled throttle. It was determined that the motor can run for approximately 2.5 min for every 1 oz of fuel. The original fuel tank installed in the plane was 16 ounces and provided 40 minutes of flight. An additional 6 oz fuel tank was installed in-line with the main tank to achieve 55 minutes of flight. The two fuel tanks can be seen installed in the fuselage below in Figure 5. The fuel line configuration for the two tanks can also be seen below in Figure 6.

Figure 5: Dual fuel tanks: main tank (left), feeder tank (right)

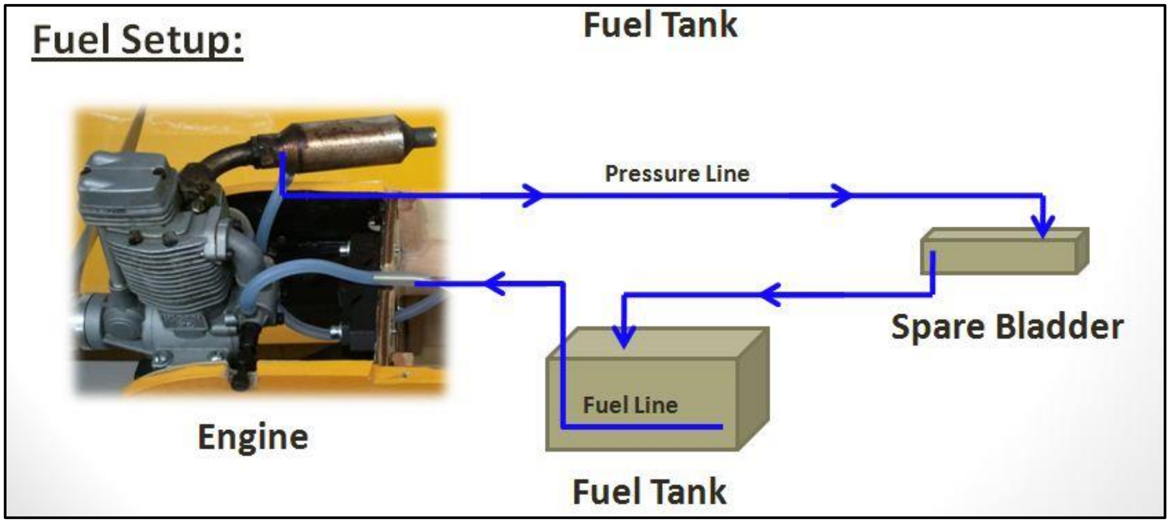

Figure 6: Dual fuel tank fuel line configuration

During the spring semester there were various repairs/improvements that needed to be made on the plane to ensure proper functionality. One of the first issues we noticed once we got the plane in the air was in the rudder and elevator cables. The cables were hollow plastic, and would buckle under very little stress. In order to fix the problem a new rudder rod was made out of a wooden dowel and the existing plastic elevator rods were used to sleeve a slender steel rod. The new rods installed in the plane's fuselage can be seen in Figure 7 below. By switching to these sturdier servo rods we greatly increased the plane's flight stability. The stability did come at a slight cost of the additional weight added to the plane by the thicker servo rods; however the additional weight was minimal.

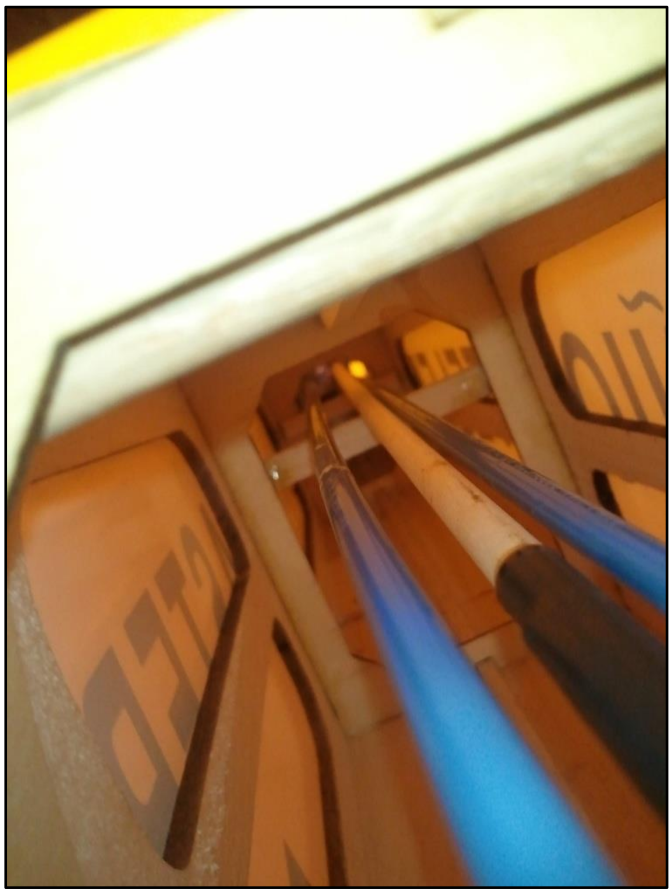

Figure 7: New rudder and elevator servo rods

As we continued to run test flights, we began to notice a weak spot in the tail of the plane where the fuselage was beginning to split. It was immediately decided that we could not run anymore test flights until the tail was repaired. We made a small bracket out of tin to reinforce the tail and make sure everything stayed together. The bracket can be seen below in Figure 8. Tin was chosen for the bracket because it has a very high strength-to-weight ratio.

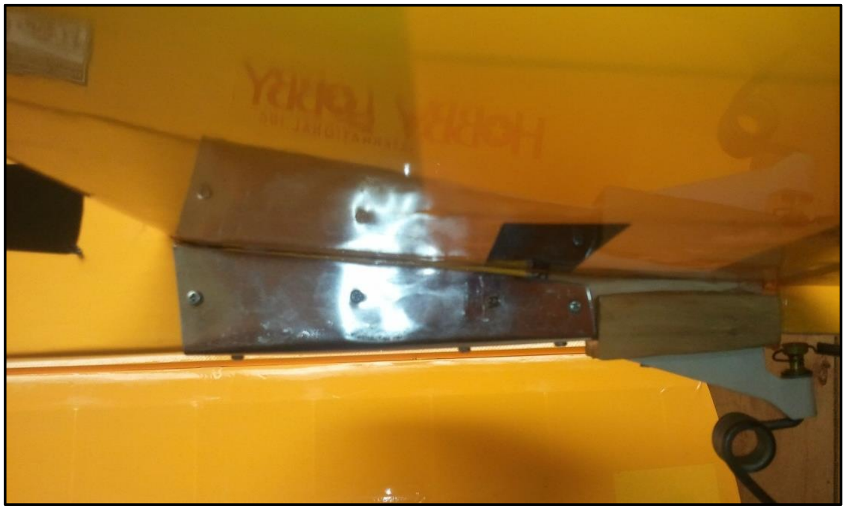

Figure 8: Tin bracket reinforcing the tail portion of the fuselage

The imaging system was the next choice to be made. Last year's group did some research and created a decision matrix in order to determine which camera would be best. They ended up deciding on the Sony FCB Block camera for the competition. The Sony camera has the capability of sending images as analog Video Blanking Syncs (VBS) and a high speed serial interface. In addition to having 18x optical zoom, the Sony camera also has the ability to customize the on-screen display. This customization will allow us to put information such as altitude, air speed, GPS location, and heading on the screen for easy viewing(Robotics, DIY Drones Amateur UAV Superstore). The decision matrix and camera selection can be seen in Table 2 and Figure 4 below.

Camera Decision Matrix		Nikon D300 DSLR		Sony KX-181 HQ		Sony FCB Block		Axis 212 PTZ	
Criteria	weight	Grade	Weighted G	Grade	Weighted G	Grade	Weighted G	Grade	Weighted G
Weight	0.2	2	0.4	5	1	4	0.8	3	0.6
Mounting	0.08	3	0.24	3	0.24	4	0.32	5	0.4
Resolution	0.15	5	0.75	3	0.45	3	0.45	3	0.45
Zoom	0.1	5	0.5	0	0	5	0.5	3	0.3
TX Ability	0.08	3	0.24	3	0.24	5	0.4	4	0.32
Price	0.15	1	0.15	5	0.75	3	0.45	2	0.3
Toughness	0.05	4	0.2	1	0.05	2	0.1	5	0.25
Power Req.	0.1	5	0.5	4	0.4	3	0.3	3	0.3
Dimensions	0.09	1	0.09	5	0.45	3	0.27	1	0.09
Total		**29**	**3.07**	**29**	**3.58**	**32**	**3.59**	**29**	**3.01**

Table 2: Imaging system decision matrix 2

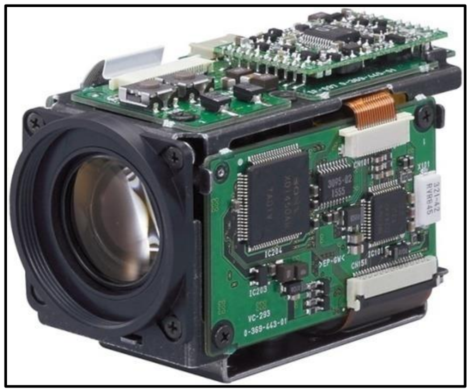

Figure 9: Sony FCB Block Camera, (Shagieva, Singularity HUB)

At the beginning of the spring semester we were having trouble getting the Sony FCB Block camera to function properly. There were cables missing, and the user interface was very complex. After a couple weeks of trying to get the camera to respond, it was determined that it would be beneficial to switch to a different camera. The camera chosen was the Sony CCD camera with 700 TVL resolution, shown below in figure 10.

Figure 10: Sony CCD Camera

Once the airplane is equipped with the camera, we will next need to install the autopilot system. As previously stated the autopilot system will control the aircraft throughout the entire mission. It is our goal to even have the plane takeoff and land via autopilot. The main autopilot systems used by RC enthusiast are the ArduPilot Mega and the Paparazzi Tiny. Both systems were compared in a decision matrix that can be seen in Table 3 below.

Autopilot Decision Matrix		ArduPilot Mega 2.5		Paparazzi Tiny	
Criteria	Max Weight	Grade	Weight	Grade	Weight
Power Usage	0.35	3	1.05	3	0.6
Programming	0.30	4	1.20	2	0.75
Ground Station	0.20	4	0.80	4	0.40
Size/Weight	0.15	2	0.30	3	0.30
Total	**1**		**3.35**		**2.90**

Table 3: Autopilot decision matrix

The ArduPilot Mega 2.5 was chosen for our plane. The main factors in making this decision were that the ArduPilot can be more easily programmed by our team members and that the user-interface on the ground station software that comes with the autopilot is more user friendly than that on the Paparazzi. An image of the ArduPilot Mega 2.5 can be seen below in Figure 11.

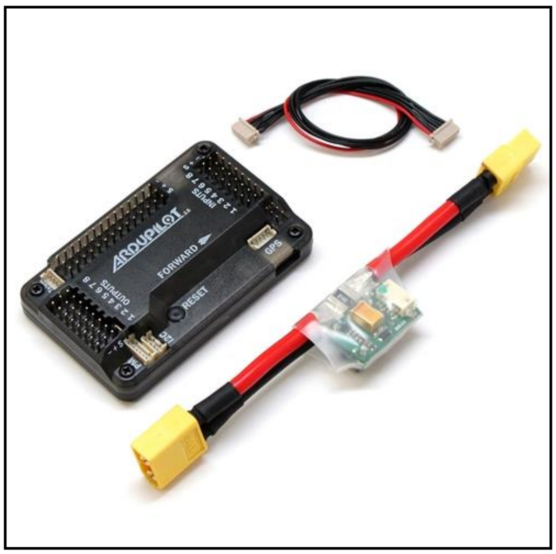

Figure 11: ArduPilot Mega 2.5 (fully assembled)(Technologies, HCLTech.com)

In addition to the ArduPilot Mega 2.5, we also purchased the 3DR Radio Telemetry Kit. The telemetry kit is made to be used with the ArduPilot Mega and allows the user at the ground station to communicate with the autopilot in real-time, allowing for the updating of waypoints, altitude corrections, as well as many other in flight changes.

Image Processing

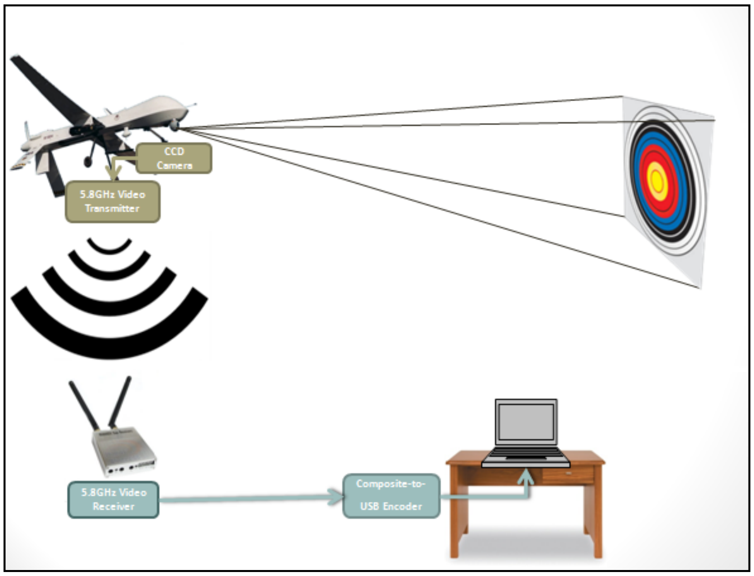

Figure 12: Top-Level Design for Image Processing

The primary objective for image processing within the scope of this competition is to extrapolate six characteristics from each ground target. This is accomplished through the use of three subsystems, transmission, receiving, and software. The top level design for the image processing system that we have designed is shown below:

Transmission Subsystem

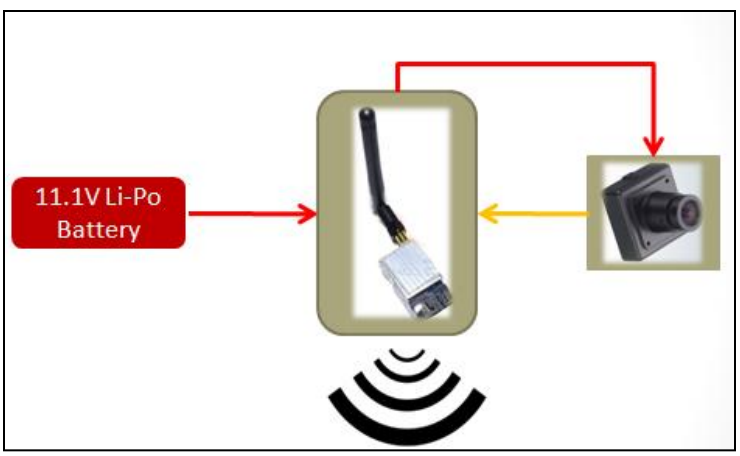

Figure 13: Top-Level Design for Transmission Subsystem

Image processing begins with our transmission subsystem (shown above in brown), located on the air vehicle. The objective of this subsystem is to take the composite analog video signal obtained from the camera and successfully transmit it down to our receiving subsystem in order to be processed.

The power requirements for our transmission system are handled by an 11.1V Lithium-Polymer DC battery, rated at 2200mAH. We chose this battery because it has a relatively high energy to weight ratio and can be recharged while still in the air vehicle. Originally, we had pursued an energy storage device with a lower initial cost, a nickel–metal hydride, but after being depleted in only 2 hours of use, we chose to purchase a recharchable Li-Po and we are content with the results thus far.

This battery powers our video transmitter, a TX-V584 (shown in figure 13). The transmitter has an output power of 400mW and operates at a sampling frequency of 5.8 GHz. We were drawn to this transmitter because the large operating frequency ensures no interference between our radio controller (2.4 GHz operating frequency) or telemetry communication (900 MHz operating frequency). The final piece of equipment in the transmission system is the camera. We chose a Sony CCD camera, which has 700 TVL resolution.

Receiving Subsystem

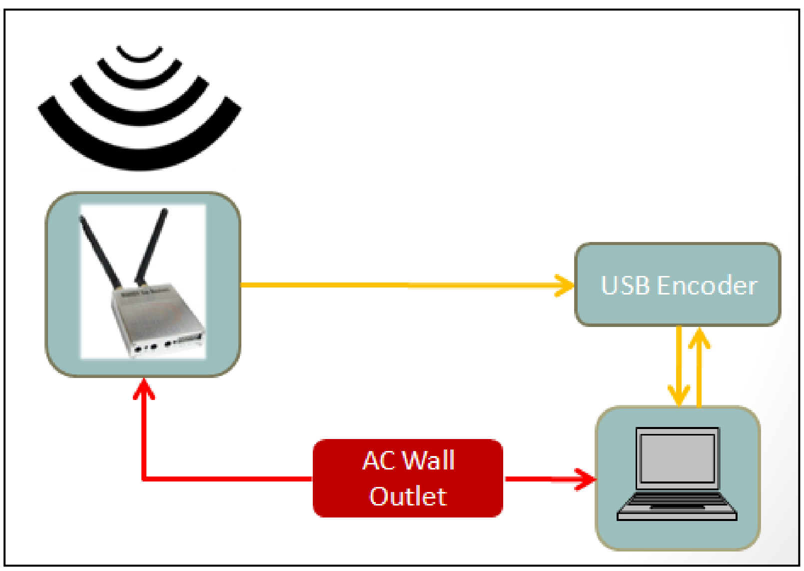

Figure 14: Top-Level Design for Receiving Subsystem

Once our video signal has been successfully transmitted, the burden is now placed upon our receiving subsystem (shown in figure 14). The primary objective of this system is to accept the analog video signal and prepare it for manipulation with our software. The receiving subsystem is composed of three components: receiver, encoder, and laptop.

Our video receiver operates at 5.8GHz and supplies a composite video signal to our encoder. The encoder takes that analog video signal and translates it to a digital USB format. The signal is now recognized by the laptop and prepared for manipulation by the software.

Software Subsystem

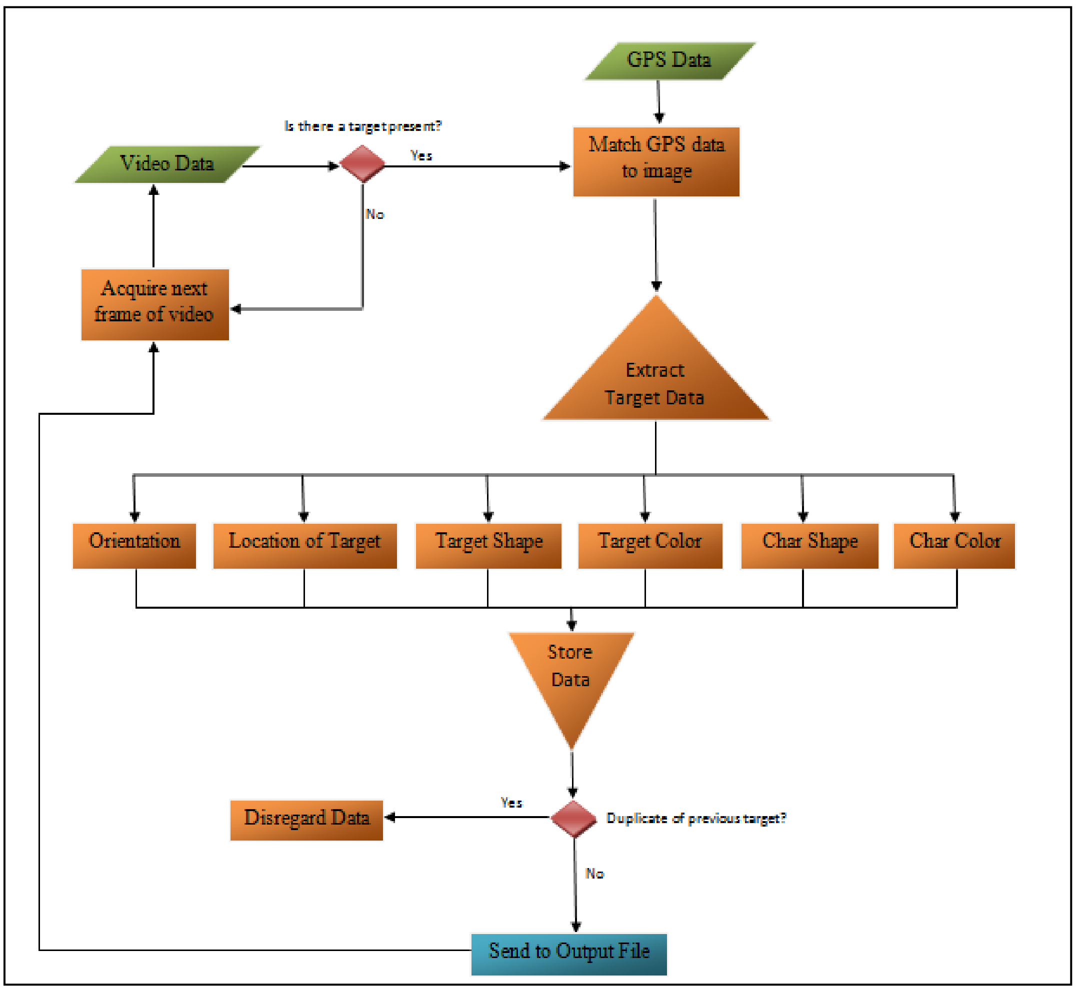

Figure 15: Top-Level Design for Software Subsystem

As previously stated, the general purpose of image processing within our competition is to extract relevant information from the ground targets using image processing algorithms. The above figure displays the logical flow chart for the software system we have designed. Before starting work on a solution it is important to define the constraints of the competition with respect to the target. The 2013 competition rules state: "Targets will be constructed of plywood of a given size, basic geometric shape, and color."

From the perspective of a programmer, this statement is concerning because “basic” is subjective in nature. Nonetheless, logical assumptions are made to define the possibilities of what a target can and cannot be. For a better understanding of the information needed to be determined from each target, an example target labeled with each characteristic is shown below.

Figure 16: Target Characteristics

To accomplish this information extraction, we have chosen to utilize the open-source computer vision library developed by Intel, OpenCV. OpenCV began in 1999 as an internal initiative within Intel to promote CPU intensive applications, and has since become the primary development tool for researchers and computer scientists in the field of computer vision [1]. The library itself consists of over 500 C and C++ algorithms, all optimized for effiency by Intel, to be used for image and video analysis [1]. For use within our project, extensive time has been spent in researching to determine which OpenCV algorithms are best suited for determining each respective target characteristic. This process has resulted in the develop of a modular approach to our image processing system . This modular design is shown in figure 17.

Target Recognition

The first goal of our ground software, once successfully receiving the inputs from the air vehicle, will be to determine if, within that particular frame of video, a target is present. This is accomplished using a blob-feature detection algorithm in OpenCV known as Maximally Stable Extremal Regions (or for short MSER). The MSER function requires the frame of the video to be a data type manipulatable in OpenCV. OpenCV provides the cvMAT matrix class which allows us to store images and video into an OpenCV defined matrix, and then manipulate them.

A smoothing filter is then applied to the image in order to filter high frequency content and then inputted to our MSER function. The desired filter for this logic is one that smooths evenly throughout the image without smoothing the edges out. Many types of filtering algorithms exist in OpenCV, though for this application it has been found that a Gaussian filter is most appropriate and therefore the function cvSmooth() was chosen. Now that the image has been smoothed, the of edges of the target need to detected by our MSER feature detector. Below is a figure depicting this algorithm functioning.

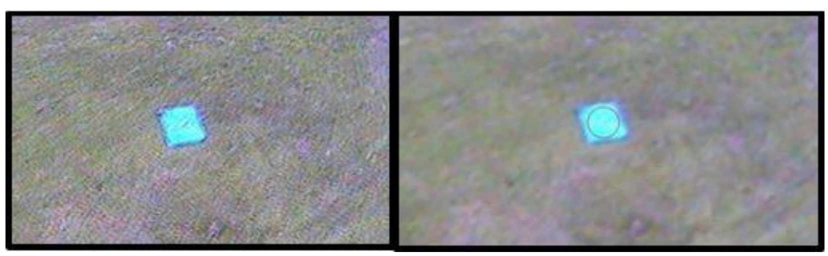

Figure 17: Modular design

The next step in the process, now that a target has been found within the image, is to match the original image to the corresponding GPS data. Matlab code has been written with respect to this algorithm, though at the time of writing this report has not been translated to the C++ language OpenCV runs. At this point, all the inputs have been prepared, and the target characteristics are ready to be extracted. For testing, were able to use recorded video from test flights. We extracted targets from test flight videos like the one shown above and used them as inputs for our image processing system.

Color Recognition

The first step in the process of identifying the color of the character and target is to convert the original image to the OpenCV manipulatable Mat data type. Once this is done, a filter is needed to reduce the noise from the background environment. When identifying the existence of a target we chose to apply a Gaussian smoothing filter in order to retain the edges of target within the image. For the process of color recognition, the retaining the colors is much more important and so through researching other filters in the OpenCV library, we found that the median blur filter is much more suitable for this application. This filter acts as a smudging agent, which works very well for determining the target color but at the consequence of completely eliminating information of the character in some cases.

After filtering the original image, the next step in the process of color detection is to convert the image from its current RGB (red, green, blue) color space to the HSV (hue, saturation, value). It is relatively common knowledge that combinations of the colors red, green, and blue can produce every other color in the visible spectrum. Using this additive property as a foundation, you can therefore visualize any color as just a point on a Cartesian coordinate system with axes of RGB instead of XYZ. The HSV color space arises as a cylindrical coordinate representation of the Cartesian RGB. It is valuable for our project to apply this conversion because it allows us to narrow our search of color in each image to just one variable, the hue (or H in HSV). Once the conversion to HSV is successful, we utilize another tool in image processing, the histogram, along with a logical assumption, to extract the color of each target.

A histogram is a table that is defined as a count of the number of pixels for a desired value, and for our project that desired value is the hue. By creating a histogram of the hue values, we can then determine the most dominant hue in the image. We assume that because of the median blur filter applied earlier, along with the natural randomness of the background environment, the most dominant hue in the image must be that of the target. Once the dominant hue is found in the image, simple math can be used to see which color corresponds to that hue. Below is the output from the algorithm we have developed from this logic:

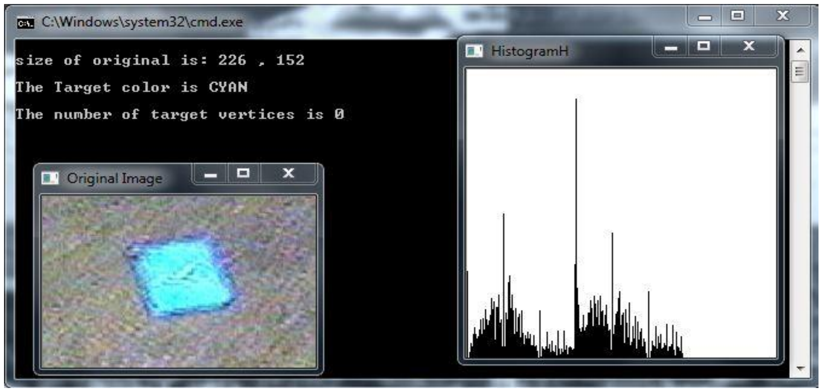

Figure 18: Cyan Recognition

The figure shows the original target image as well as the histogram for the hue values of the filtered image. The histogram shows several significant peaks. These peaks are the result of the background environment, and the largest peak represents the hue of our ground target. The background in the image is non-uniform and therefore its resultant hue is more spread out when compared to the hand-painted target.

It is important to note that though this method works for all example targets used in testing, the logic is not flawless. By exclusively targeting the hue value, the algorithm will not successfully identify targets painted white or black.

Target Shape Recognition

The next module we developed was the algorithm for detecting the character and target shape. Similar to the algorithm developed for target color, the first step in this process is to convert the received image to the OpenCV Mat object type and then a smoothing filter is applied to reduce background noise.

After this is completed, the image is converted from a 3-Channel RGB image, to 3 single channel images (one channel for RGB respectively). This is done to improve efficiency and reduce computation time for the remaining processes in the algorithm. From here, a canny edge detector is applied to locate and connect the edges in each channel (keep in mind that depending on the color of the target, one of the channels will be much better for shape detection). The canny edge detector function requires the input of threshold values for the actual edge detection. The threshold set on the edge detection will determine whether the character is isolated, or the target shape. After the edges are detected, contours are extrapolated from the resulting images using the functions cvFindContours and cvDrawContours. Once the contours are found, it is logical to assume that intersecting contours implies a vertex of the target polygon (for extracting target shape) or a vertex of the alphanumeric character.

It is at this stage in the algorithm where the logic for extrapolating target shape and character differentiate. In the case of character identification, now that the alphanumeric has been completely isolated in the image, a computer learning algorithm can be applied to identify the character. On the other hand, shape identification relies more on mathematics and geometry to accomplish identification. Intersecting contour lines implies a vertex and the number of vertices gives the n value of an n-gon polygon, next is determining the angle between these intersections, this will help differentiate between a trapezoid (4-gon) and a square (also a 4-gon). Below, in figure 19, is the output from the algorithm we have developed from this logic. Notice that the canny edge detection only works well for only one of the RGB channels, this is because the target is orange (red dominant), and therefore the red channel's edge detection is successful.

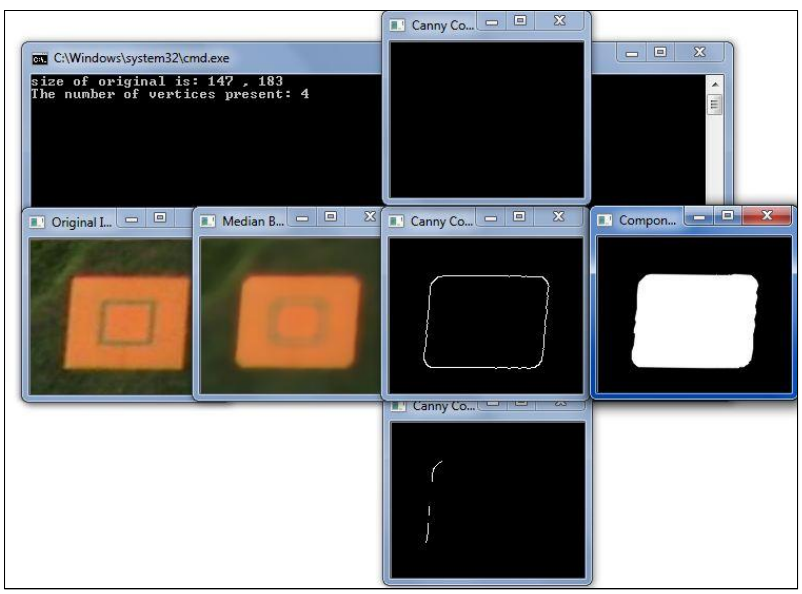

Figure 19: Algorithm Output

Cardinal Direction Extraction

The next algorithm we have developed for our image processing system is determining the GPS location of the target. The logic for this module is dependent on the orientation of the camera on the air vehicle. For most of the mission, the camera will remain normal to the plane and ground. This means that the image can be treated as a two-dimensional plane, and therefore determining the targets location is just a matter of geometry (though it should be noted that the math changes relative to the air vehicle's altitude).

The other case is when we are attempting to find off-center targets and the camera is required to be tilted relative to the air vehicle. When this is occurring, perspective distortion becomes an issue on the camera and if left unresolved the output will have a significant probability of error. To correct for this distortion, we have researched different methods within OpenCV and decided on the affine transformation to resolve this problem. The affine transformation allows for quick and efficient perspective distortion (and in this case correction).

System Output

Once the above algorithms have extracted the relevant target information, the next step in our image processing system is to output the results. First though, because we are using a video feed for input it is necessary to make sure that the target we have just processed is not a duplicate of a previously found target. This problem is to be expected when analyzing multiple frames per second. The solution to this problem is to cross-reference the extracted data with that of targets previously found, if a target does not possess an arbitrary number of unique characteristics it can safely be assumed to be a duplicate.

Now the extrapolated data is ready to be outputted and saved in the appropriate format. Our competition rules state that the output file for the target characteristics be a text file which has a new line for each discovered target. This is accomplished using a C++ script, each column in the file represents data for that target, and each row represents a new target.

Gimbal System

Gimbal Concept

The gimbal system is an electro-mechanical device responsible for moving the camera towards targets. For most of the mission time it is necessary to have the camera pointed perpendicularly to the ground (this will avoid any distortions that could make image processing harder) and to do so, two Futaba standard servos are controlled by the Ardupilot board. As the plane moves in roll and pitch directions, the servos work against the movement to keep camera position. Below is a picture that illustrates roll, pitch and yaw movements of a plane.

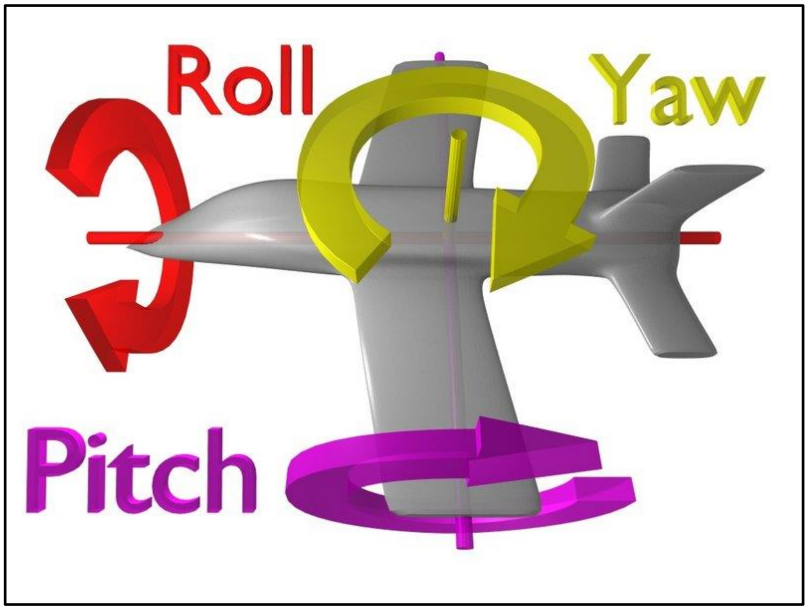

Figure 20: Roll, yaw and pitch movements.

First Design

The first gimbal system was built using some components inherited from last year's team working on the same project, which were designed for a much bigger and heavier camera. In this system, the servo responsible for pitch movement would stay relatively static to the plane's frame when accomplishing this movement. The roll movement was performed by a servo mounted in an aluminum cumbersome structure.

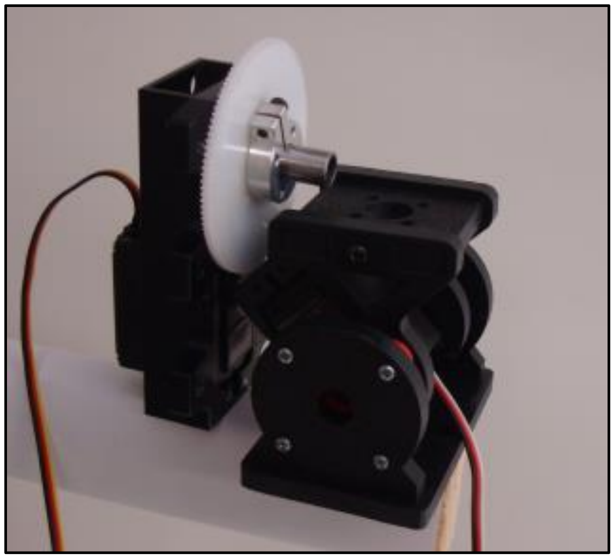

Figure 21: First gimbal system design.

New Design

As the camera used for acquiring video for image processing needed to be changed, the first system could be redesigned, having several unnecessary components eliminated. This task was done using pro-engineer software. Below is a picture of the new design.

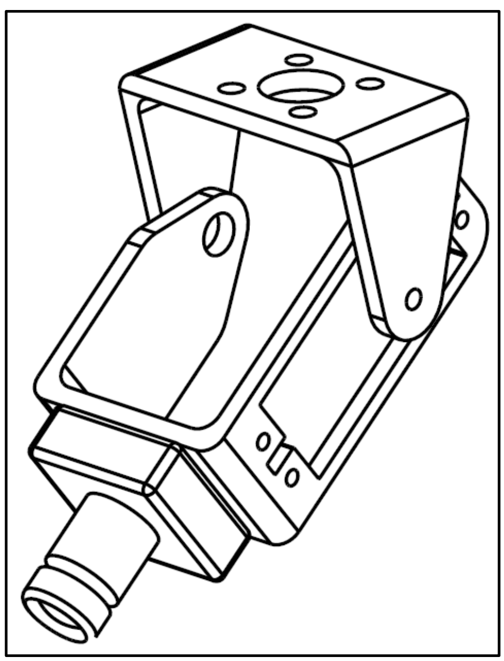

Figure 22: Redesigned gimbal system

The new gimbal system designed has the servo responsible for pitch direction moving together with the camera and part of the structure. The two main structural components were built by machining aluminum and bending it to acquire U shape. Another L bracket was also machined to connect the components below to the roll servo. Using a plastic servo connection, an aluminum screw hub, 4 bolts, U bracket (holds camera), 18 screws and 2 nuts, the system can be mounted. After some flight tests, the plastic connection that attaches the entire system to the roll servo needed two be changed for a stronger one because it repetitively failed during hard landings. The resulting design is shown below.

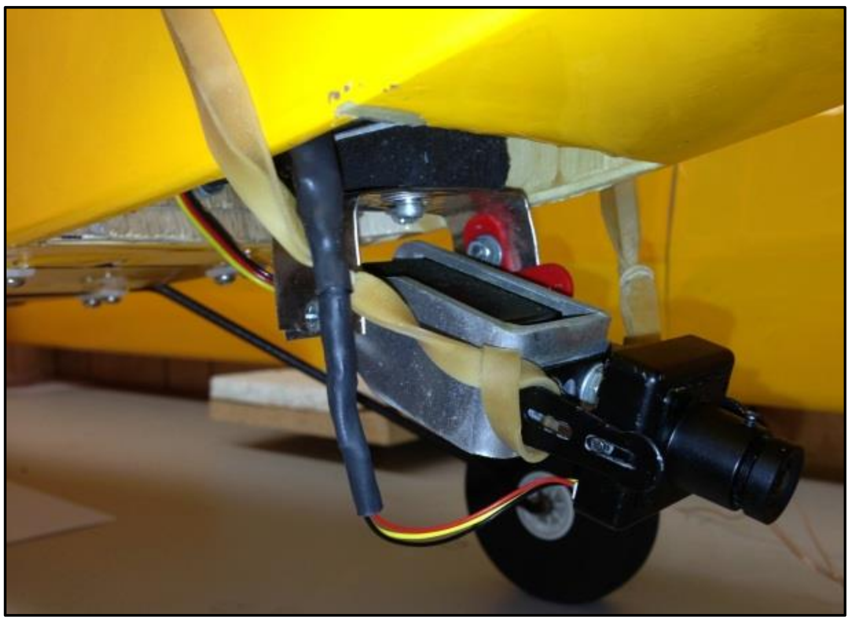

Figure 23: Final system assembled

Final Design Performance

The new design implementation was a success and the system worked properly during the latest flight tests. The two servos were correctly calibrated on the ground, with the autopilot board positioned horizontally (this task requires setting values in the mission planer software). The position of the system in the plane’s frame had to be carefully chosen and by placing it a few inches above the landing gears it was possible to achieve important features:

- Wider angle of view;

- Less center of gravity dislocation;
- Higher ground clearance (avoids possible damages to camera).

Vibrations

The fuel combustion engine used for plane's propulsion is responsible for spreading vibrations to the entire plane's frame. One of the main bad results is the video quality loss. Tests using damping materials were made in several strategic spots. Below is a picture of a damping pad placed between the fuel engine assembly and the main firewall of the body frame.

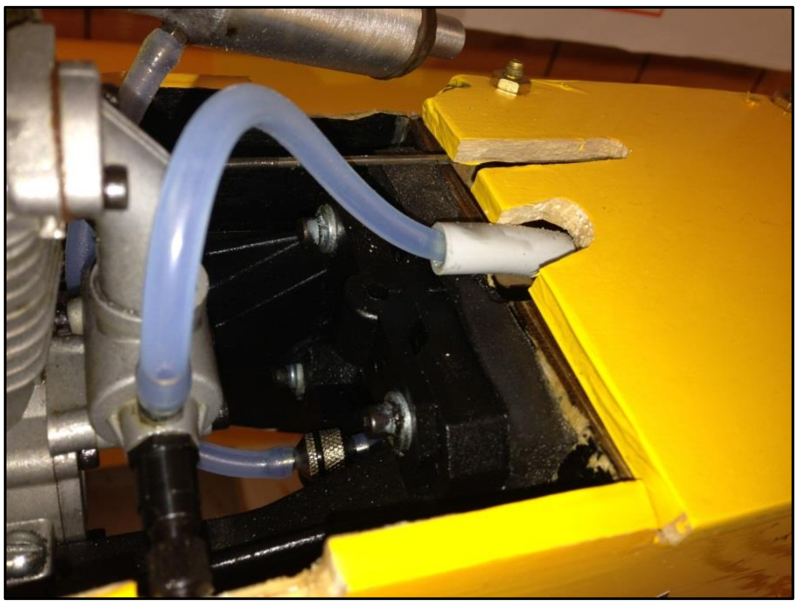

Figure 24: Vibration pad

The picture above also shows that the screws and bolts used for assembling the engine needed to have Loctite on it for security reasons. This step helped avoiding most of the structural parts of the plane getting loose. As it is possible to be seen in Figure 4, the electrical cable responsible for transmitting video needed to be reinforced to avoid signal loss. Also, one damping square was added between the L bracket and one of the U brackets of the gimbal. Rubber bands similar to the ones used for assembling the wings to the main body were also used. By placing two of them in opposite sides, between the U structure responsible for holding the camera and hooks screwed to the sides of the fuselage, it was possible to make the system more stabilized (the two forces are going to be canceled in most of the system positions, not severely affecting or forcing the two servos). The picture below shows the rubber bands displacement.

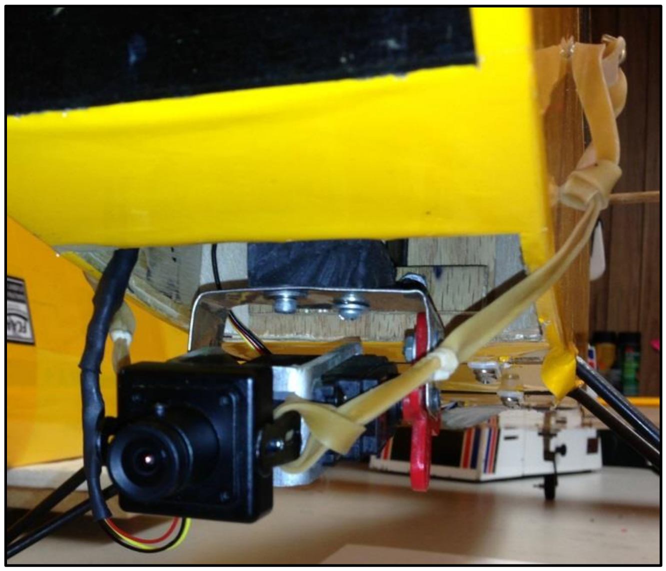

Figure 25: Rubber bands

Lastly, it is important to state that there is always a drag force acting on the gimbal system during flight. The two servos automatically fight against the force to keep camera position and avoid slightly inclined video.

Gimbal System Possible Improvements

The system responsible for moving the camera towards targets plays one of the most important roles in the entire mission. By having this idea in mind, the reasons for keeping improving the gimbal system becomes very obvious, especially when the performance of the device is not as good as it can be.

The first gimbal system inherited by team 6 was designed for a Sony block camera, which was oversized and excessively heavy for flying purposes. As the camera needed to be changed because of flat cable replacing problems, the system had its dimensions reduced and unnecessary parts removed. Although it became a lot more efficient, it still could be rebuilt (in case more time was available) in an even more effective way. One important step for upgrading it would be the change of the Futaba 180 degrees standard servos that runs the equipment for smaller ones. In the pictures below it is possible to see the current servo type (left) and the ideal one (right).

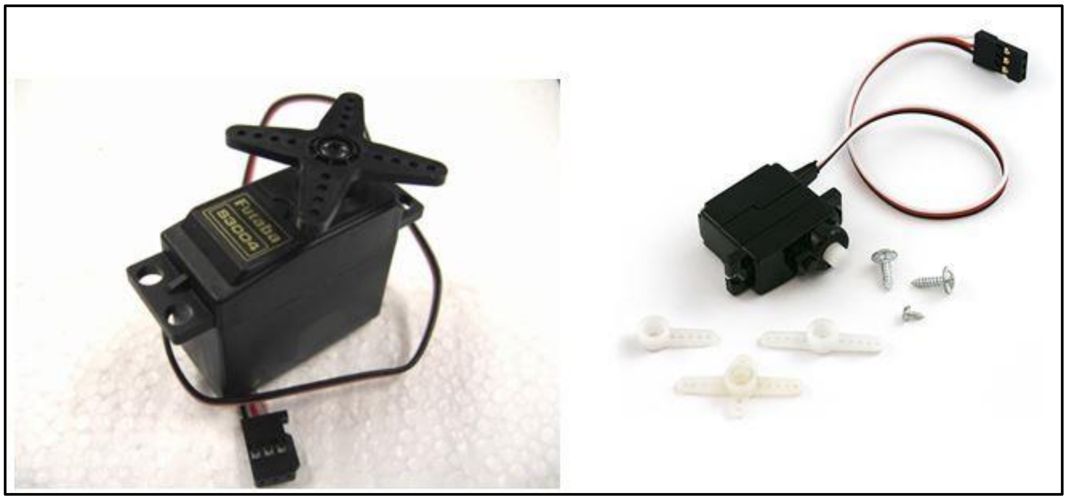

Figure 26: Standard size servo (left) and small size servo (right).

The main advantage of this upgrade would be the increase in the side view angle of the system due to its reduced dimensions. Besides the fact that it implies redesigning the structural parts, there are several benefits: reducing weight on the plane; reducing electrical power consumption (less mass is being moved to change camera position); having the possibility of implementing a fair and consequently reducing the drag force caused by it. On the other hand, something that really needs special attention when it comes about building a much smaller gimbal is vibrations. Smaller and lighter devices tend to have bigger amplitude of vibrations (in some cases, by decreasing the mass, the system will end up increasing its amplitude of vibration, nearly conserving the kinetic energy). This brings the need of an appropriated damping system that could be built using rubber bands or springs.

Autopilot and Navigation System.

The autopilot system that we chose to implement in our aircraft is the ArduPilot Mega 2.5. This autopilot system comes pre-soldered and tested, which reduced the possibility of errors when assembling the system and allows for more time to be spent integrating the autopilot with the other systems of the aircraft and completing the objectives of the project. The board comes equipped with a 3-axis gyro, to measure any change in the aircrafts axis of rotation (yaw, pitch, and roll), an accelerometer, to measure the static acceleration of gravity for tilt-sensing applications and the dynamic acceleration resulting from motion or shock, a magnetometer, to measure the strength and direction of the magnetic fields to act as a digital compass, and a barometer, to measure the atmospheric pressure to acquire altitude readings. The board also has a 4 MP Dataflash chip for automatic datalogging. The ports of the board are highlighted in Figure 1 below, most notably the input and output ports that allow the autopilot to be inserted between the receiver and the servos, the USB Port, the new wireless telemetry port.

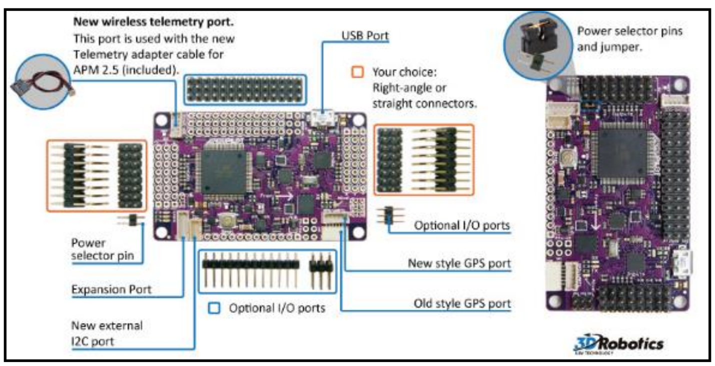

Figure 27: ArduPilot Mega 2.5

The autopilot is completely open source and is Arduino compatible. We have downloaded the Arduino software in case any changes to the programming of the autopilot need to be made. The software uses the C/C++ programming language. A simple example program to blink one of the LED lights is shown below, in Figure 2. The screenshot also shows how we can connect our Arduino Mega board to the Arduino software by selecting the appropriate board under the tools tab.

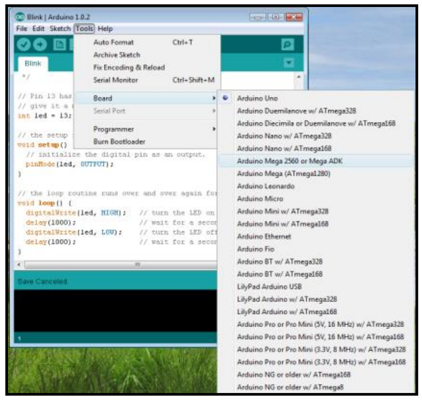

Figure 28: Arduino Software

The first upgrade we purchased was the 3DR GPS uBlock LEA-6. The 3DR GPS has a larger ceramic patch antenna, a rechargeable 3V lithium backup battery for warm starts, and I2C EEPROM for configuration storage. This GPS boasts a lower power consumption, maximum sensitivity, and faster acquisition witch lead to the decision to purchase the upgrade instead of using the standard Mediatek GPS. The 3DR GPS is shown below in Figure 29.

Figure 29: 3DR GPS uBlock LEA-6 (1)

The second upgrade we purchased was the 3DR Radio Telemetry Kit. We will use the 915 Mhz edition because this is the frequency that is legal in the United States and we would need to acquire the appropriate amateur radio license to operate at 433 Mhz. This telemetry kit uses open source firmware, has a transmit power of up to 20dBm (100mW), air data rates up to 250 kbps, uses frequency hopping spread spectrum (FHSS), and adaptive time division multiplexing (TDM). It has a built in error correcting code that can correct up to 25% data bit errors and has adaptive flow control when used with the APM Mission Planner. Firmware upgrades and configuration are also fully supported in the APM Mission Planner. This Telemetry kit allows the real time transfer of data from the aircraft to our station on the ground. The 3DR Radio

Telemetry kit is smaller, cheaper, and has a larger range (about 1 mile compared to roughly 3/4ths of a mile) than the standard Xbee radio set. The telemetry kit is shown below in Figure 30. On the left side is the 3DR Radio 915 MHz “Air” module that will be connected to the IMU in the aircraft and on the right is the 3DR Radio USB-915 Mhz “Ground” module that will be connected to the computer at our ground station.

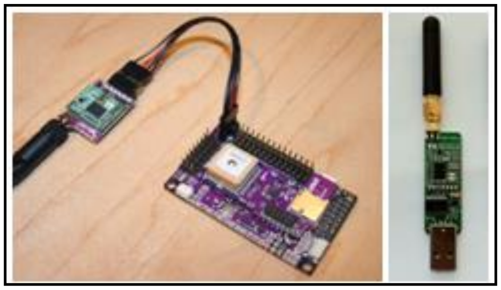

Figure 30: 3DR Radio Telemetry Kit

The final upgrade we purchased was an airspeed sensor, which required additional tuning and added another layer of control to setup, but was recommended for windy conditions, slow flight, and autonomous landings. The sensor itself it a differential pressure sensor board that measures the difference in the “active” air pressure from the front of the Pitot tube and the “static” ambient air pressure measured from the opening on the side of the Pitot tube. The airspeed sensor was connected to the Ardupilot Mega 2.5 at the A0 port and enabled in the software under the “Configuration” tab under “Hardware Options”. This addition enabled the use of more concise and reliable code in our firmware.

Figure 31: Air Speed Sensor

As previously stated in the report, the threshold for autonomous flight in our competition is to be able to complete waypoint navigation, change a waypoint midflight, and to conduct a search area. The competition also has some cash bonus objectives such as autonomous takeoff and landing and changing a search area midflight.

We have downloaded the APM Mission Planner software to complete the autonomous phases of the competition. A screenshot of the "Flight Planner" tab is shown below in Figure 6. The green balloons represent the waypoints and the red balloons represent a search area. Waypoints can be added by pointing and clicking on the screen and, once created, can be dragged to any desired location. When a waypoint is added it will be shown in the waypoint box below. The command at each waypoint can be set by clicking on the waypoint under the command column and choosing an option from the drop down box that appears. The options include: WAYPOINT, LAND, TAKEOFF, etc. The altitude for each waypoint can also be set in this waypoint box. These waypoints are then wrote and read onto the autopilot to be executed.

A search area is created by right clicking on the screen in "Mission Planner" and selecting "Draw Polygon". Once all the necessary polygon points have been added, the polygon created can be saved as a search area. The polygon points can be moved, the same way as the waypoints, by clicking and dragging them to the desired location. Then waypoints can be created to cover the search area in a serpentine fashion, however, due to the turning radius of our aircraft, this method is extremely inefficient and we decided to optimize our flight path throughout the search area by creating a spiral path to overcome our turning radius constraint.

The final threshold for autonomous flight is being able to alter waypoints midflight. A screenshot of the "Flight Data" tab of the APM Mission Planner is shown below in Figure 7. On the left is the data that will be streamed from the Telemetry Kit. In the "Quick" tab, shown in the screenshot, data such as the altitude, ground speed, distance to waypoint, etc. are illustrated. The "Gauges" tab includes gauges that display the speed, vertical speed indicator (VSI), altitude, and heading. The "Actions" tab allows us to select actions such as a preflight calibration, mission start, and setting changes to the current target waypoint. Changing a target waypoint can be executed by right clicking on the screen to the right. As the screenshot shows, a drop down box will appear where there is a "Fly to Here" option. This option will create a new waypoint at the location selected. The Flight Data tab also includes a "Status" tab with various reading such as roll, pitch, yaw, distance traveled, time in air, ground speed, vertical speed, latitude, longitude, altitude, etc. and a “Telemetry Logs” tab. As a side note, one of the targets that we must find will be off the target path and, therefore, the gimble system must be able to turn the camera to locate this target. This will be achieved by using the “Point Camera Here” feature in the same drop down box.

That concludes the thresholds for autonomous flight and, as you can see, APM Mission Planner coupled with the Ardupilot Mega 2.5 allows us to complete all of these requirements. Now we will discuss the cash bonus objectives that we were able to achieve.

The first cash bonus objective that we were able to achieve was changing the waypoint midflight. During testing we discovered that while the plane is in flight waypoints could still be wrote and read to the autopilot as long as the autopilot maintained a good connection. This enables us to set up a new search area, save and load it, add waypoints to navigate throughout the search area, and write and read all of these new commands to the autopilot midflight.

The other cash objective bonus we were able to achieve was autonomous takeoff. In the waypoint box, one of the available commands is “TAKEOFF”. When the “TAKEOFF” command is selected the desired pitch angle of takeoff will need to be set, as well as, the height that you want the “TAKEOFF” command to end and continue to the next waypoint. In the example below the pitch angle is set to 15 degrees and the altitude is set to 50 meters. The home position will be set from the position of the GPS when the autopilot is connected to the APM. The home position can also be changed to the planes current location by selecting the “Home Location” command in the “Flight Planner” tab. The “TAKEOFF” command will accelerate to the maximum throttle set until the desired altitude is reached. We set the parameters so that the maximum throttle is 100% and we also set the throttle slew rate to increase at 60% per second. The final parameter that we changed was to only allow the rudder to steer during autonomous takeoff and landing so that the plane’s wings would not dip due to the ailerons.

The final cash bonus objective for autonomous flight is autonomous landing. The “LAND” command will land the aircraft autonomously. The latitude, longitude, and altitude (usually 0 – relative to the home altitude) of the desired landing point will need to be entered in the waypoint box. How this command works is when the autopilot senses that it is within 2 seconds of touchdown or lower than 3 meters off the ground the APM will shut down the throttle and hold the correct heading, thus landing the aircraft autonomously. However, we have not yet tested this feature and are still considering whether or not we will attempt to achieve this bonus objective.

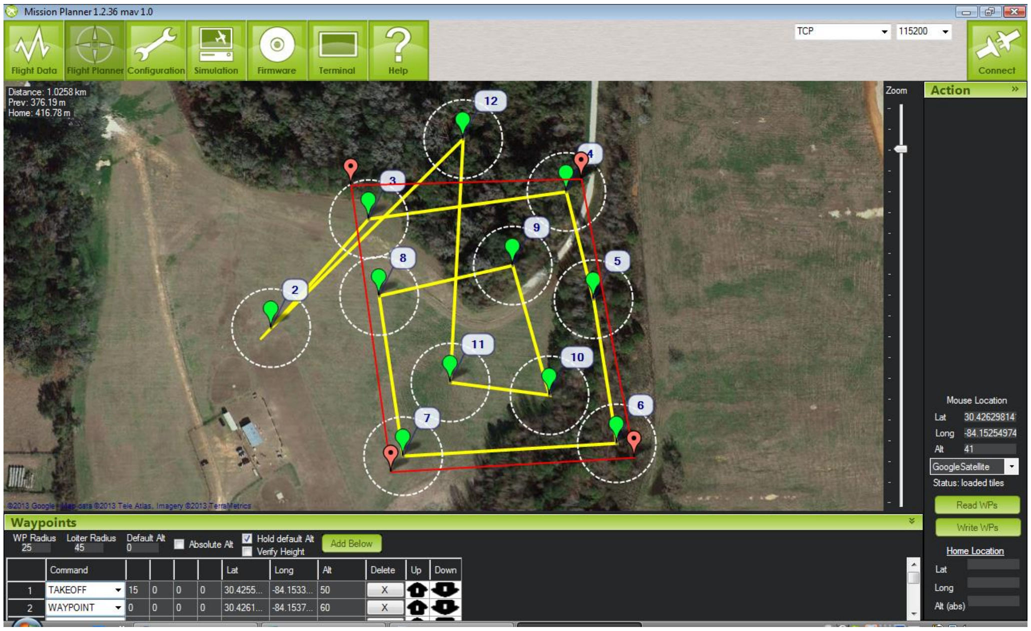

Figure 32: APM Flight Planner

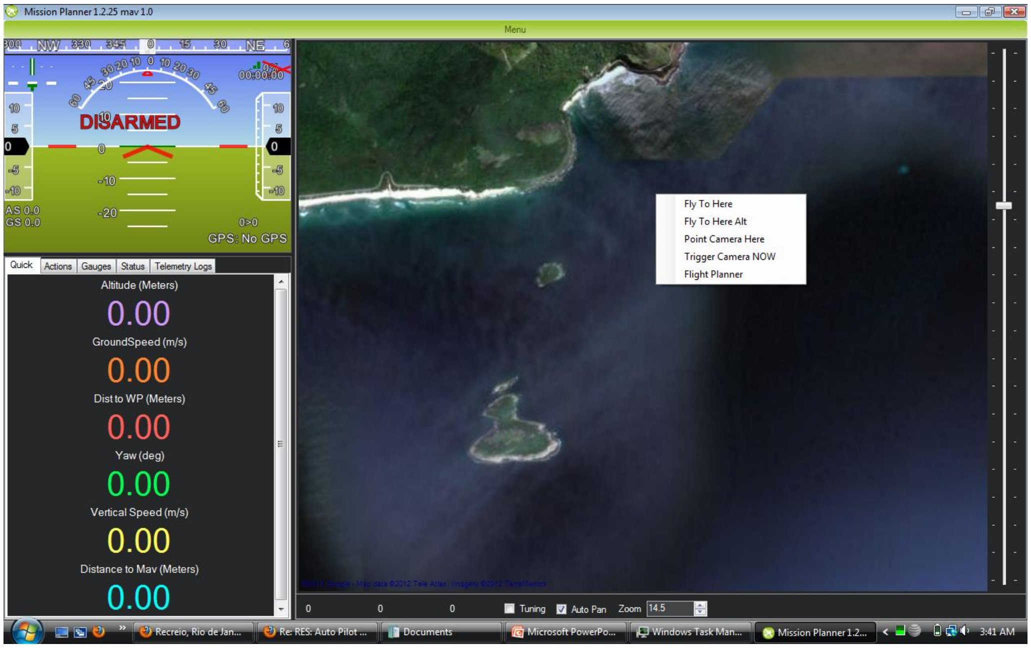

Figure 33: APM Flight Data

Before flight, the servos, throttle, and switches must be calibrated. This is done by using the transmitter to set the minimum and maximum values for each in the “Calibration” tab after the autopilot is connected to the software. The gimble is calibrated in a different subsection, but still in the “Calibration” tab. This is done by setting the minimum and maximum values for both servos (pitch and roll) and selecting the stabilizing option.

Finally, our competition makes a special emphasis on safety. It is a requirement that we are able to switch from autonomous flight to having the aircraft be controlled by an RC transmitter at any point during the flight. This is satisfied when we set the switches in configuration. Our plane is controlled by a 6J 6 Channel Dig. Prop. System Transmitter, shown below in Figure 8, that operates at 2.4 GHz. As of now, the transmitter is only used to land the aircraft, but if we accomplish autonomous landing the transmitter will strictly as backup. Also, the competition requires the aircraft to return home if there is a loss of transmit signal of 30 seconds. APM Mission Planner has a function to return and loiter around home after 20 seconds of lost transmit signal. The competition also requires a controlled crash to be performed after a loss of transmit signal of 3 minutes. Mission Planner does not have a function for this requirement, but all the software is completely open source, so we can alter the firmware to satisfy this requirement.

Figure 34: Futaba 7CAP 7-Channel Transmitter and Receiver

Budget

The budget for Team Six comes from the FIPSI coordinator and our sponsor, Dr. Shih. The team was given a $2000 budget to be able to purchase the needed equipment to complete the autonomous aerial vehicle and be successful in the competition. The chart below displays a breakdown of the electrical, mechanical and miscellaneous items spent over the course of both semesters. Since the scope of this project was to fly autonomously, there had to be a lot of electrical systems implemented out the airframe. This in turn led to the huge portion of the budget being used to purchase the electrical items. The major items included for these components are the autopilot, GPS navigation, camera, transmitter and tons of batteries. The mechanical components only consisted of about 16% of the purchased budget. This was largely due to the fact that the airframe that was used for this project was already purchased and assembled. Therefore, the more expensive and efficient supplies for the electrical components were able to be purchased to have a better performance in the autonomous flight. The mechanical systems implemented on the plane were the gimbal, gimbal servos, power system, dampening, etc. The remaining 3% of the purchased budget was used by the minor repairs and cosmetic fixes on the airframe itself.

From the $2000 budget, the remaining balance results roughly around $340. Therefore, team six was able to purchase all the needed items to complete the thresholds for the competition without going over the allotted budget.

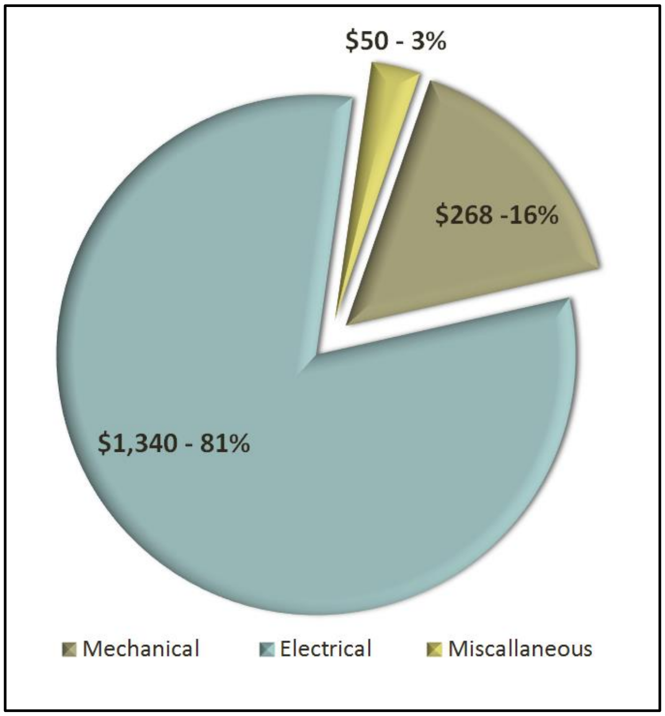

Figure 35: Budget Breakdown

Schedule

Over the course of the two semesters, the team has stayed on schedule with every task set from the beginning. The figure below shows a Gantt chart for the remaining two months in the spring semester. This chart depicts just a few of the objectives that were set from the beginning of the project in order to clearly state the current and remaining status until the competition in June. The blue star represents the open house final presentation and poster session. From that point there are still tests that will be conducted to determine if the team will have all of the completed thresholds to go to competition. The team has set a goal of completing the last threshold before graduation to make this decision. The AUVSI has given all the competing teams until May 30th to receive a full refund of the registration if they decide to drop out. Therefore, team six has about another month to perfect all the thresholds in order to have a chance of being successful in the competition.

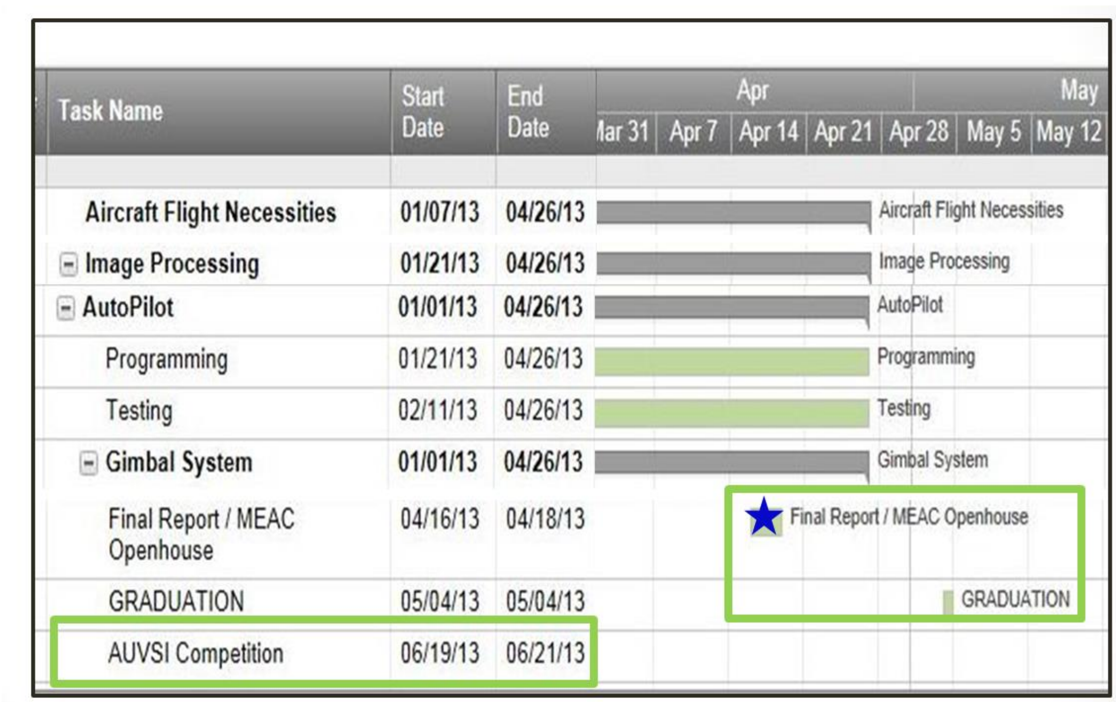

Figure 36: Spring Schedule

Conclusion

Team 6 has had the benefit of a unique experience with the FIPSE program. Three of the team members, Rob, Cris, and Matt lived in Brazil for the fall semester of this project. This has presented us with interesting challenges of working on a team in which we could not physically meet. This strengthened the communication skills as a team and learned to rely on our teammates to relay important information which was not otherwise available to us. Each team, Team Brazil and Team America, had depended on each other to provide to us the material needed to keep current in the class and on the project. This dynamic in the project greatly benefitted the team for the duration of the project. Then, when Team Brazil returned to the States, we as a group gained another team member, Ernandes, who has brought even more creativity and contribution to the project. These are just some of the factors that have helped us develop professionally from the FIPSE program- and personally. The American students were completely immersed in another culture for five months while gaining not only a new language, but a new perspective and as well a new skill-set.

Measurable progress

We inherited an airframe from last year's design team, and made it air-worthy by adding and upgrading components. We began this year at the most basic levels of development in the field of autonomous flight and image processing, and now have a UAV autonomously capable of take-off, flying a specified flight path and searching a wide area while continuously executing real-time photo processing with the turn of a knob. As of the presentation of this project, there is one remaining threshold to meet before competition eligibility: the engine shut-off safety feature mentioned earlier in this report that will activate after three minutes of lost communication between the transmitter and UAV. The competition is on June 19, and we have until May 30 to decide whether we will be fit for competition. The team fully expects to have all thresholds completed by this deadline.

Looking back over the year, we have attempted to identify some decisions that could have been made differently. Firstly, we would like to observe that more thorough evaluation of the specific design could have been accomplished, as opposed to building toward the allowable limits. For example, an hour was given for maximum flight time, and we thought it would be wise to work around this flight time instead of measuring how long our flight would last. This had an effect on our power plant selection and airframe selection.

Final Recommendations

- Consider different type of vehicle/Construct a new airframe
  - We chose a fixed-wing body style, and through the course of the project we grew curious about investigating the possibilities of a quad-rotor. Whichever is to be selected, we recommend that the frame is build/modified for maintenance. Much work is done in the confines of the fuselage, or onboard equipment housing compartment and much time could be saved by considering this in airframe design.
- Consider electric motor
  - Team 6 chose a piston engine which causes significant vibrations. There were challenges that would not have presented themselves with an electric motor. This relates to the aforementioned observation of building to maximum flight time.
- Computer engineering
  - Image processing is programming intensive
- Get a pilot on the team
  - Flight tests are crucial to the success of this project. Having a reliable pilot that does not need to be reserved or scheduled is extraordinarily valuable.

Works Cited

Anderson, Chris. " DIY Drones. 3D Robotics Inc." 10 December 2012. *http://www.diydrones.com/>*. Internet. 2012.

Angelo. "The Flying Eye Project." december 2012. *http://www.theflying -eyeprojectusa.com/rc_heli_camera_for_sale.htm.* Internet. 10 december 2012.

Bradski, Gary R., and Adrian Kaehler. *Learning OpenCV: Computer Vision with the OpenCV Library*. Sebastopol, CA: O'Reilly, 2008. Print.

International, Association for Unmanned Vehicle Systems. *AUVSI Seafarer Chapter*. 31 October 2012. Internet. 20 November 2012.

Jantzen, Ryan. "Final Design Package, Senior Design WebPage." 2011. *December 2012 <http://eng.fsu.edu/me/senior_design/2012/team14/deliverables/Final_Design_Package_V1.pdf>* . Internet. 10 December 2012.

Laganière, R. *OpenCV 2 Computer Vision Application Programming Cookbook: Over 50 Recipes to Master This Library of Programming Functions for Real-time Computer Vision.* Birmingham, UK: Packt Pub: Packt Pub, 2011. Print.

Robotics, 3D. " DIY Drones Amateur UAV Superstore." December 2012. *http://store.diydrones.com/APM_2_5_Assembled_p/br-apmpwrkt.htm>*. Internet. 10 December 2012.

Senate, United States. "http://www.modelaircraft.org/files/HR658_020112.pdf." 2012. *Model Aircraft-FAA.* Internet. 10 December 2012.

Shagieva, Lena. " Singularity HUB." December 2012. *<http://singularityhub.com/2011/04/24/phenomenal-video-footage-of-extreme-sports-from-rc-helicopters/>*. 2012.

Stack, John, and Albert E. Von Doehoff. "Test of 16 Related Airfoils at High Speeds." David, John. *Fundamentals of Aerodynamics*. New York: New York: McGraw-Hill, 1984. 492. Print.

Technologies, HCL. *Enhanced Vision System*. 2012. December 2012. <http://www.hcltech.com/aerospace-and-defense/enhanced-vision-system>.

Special Thanks

We would like to acknowledge FIPSE for sponsoring our project and Dr. Shih for making the FIPSE program available to us. It was an amazing experience that is greatly appreciated and has had a significant positive impact on those who participated. Special thanks to Dr. Shih, Dr. Frank, and Dr. Amin, our project advisors, our Senior Design TA's Richard Carter and Peter Rivera, the Mechanical Department faculty and the Electrical Department faculty of the FAMU-FSU College of Engineering for their valuable consultation and advice, Jim Ogorek and those at Hobby Town USA and the Seminole Airfield for sharing their experience and knowledge in flying vehicles, the 2013 Senior Class of the College of Engineering and, of course, all of our friends and families who have supported us throughout all of the challenges faced throughout this program.

2013

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