Journal Paper

2014 AUVSI SUAS Competition

University of Texas at Austin Unmanned Aerial Vehicle Team

Kratos

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Abstract

The purpose of this report is to provide a description of the UAV Kratos designed by the UT Austin UAV Team for the 2014 AUVSI SUAS competition, and to show the design processes used in its creation. Kratos is a heavily modified Sig Kadet Senior with an increased wing span and rudder height. The avionics system include an Ardupilot Mega board for autopilot capabilities, a camera and gimbal system for onboard imaging, and a BeagleBoard for wireless networking. The image processing is handled on the ground by a C/C++ program using the OpenCV library. The autopilot is controlled on the ground by Mission Planner, which allows the pilot to issue new commands to the air vehicle throughout the flight. Finally, mission procedure and search trajectory are covered, providing more information on the expected performance of Kratos at competition.

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1. Introduction

1.1. UT UAV Team

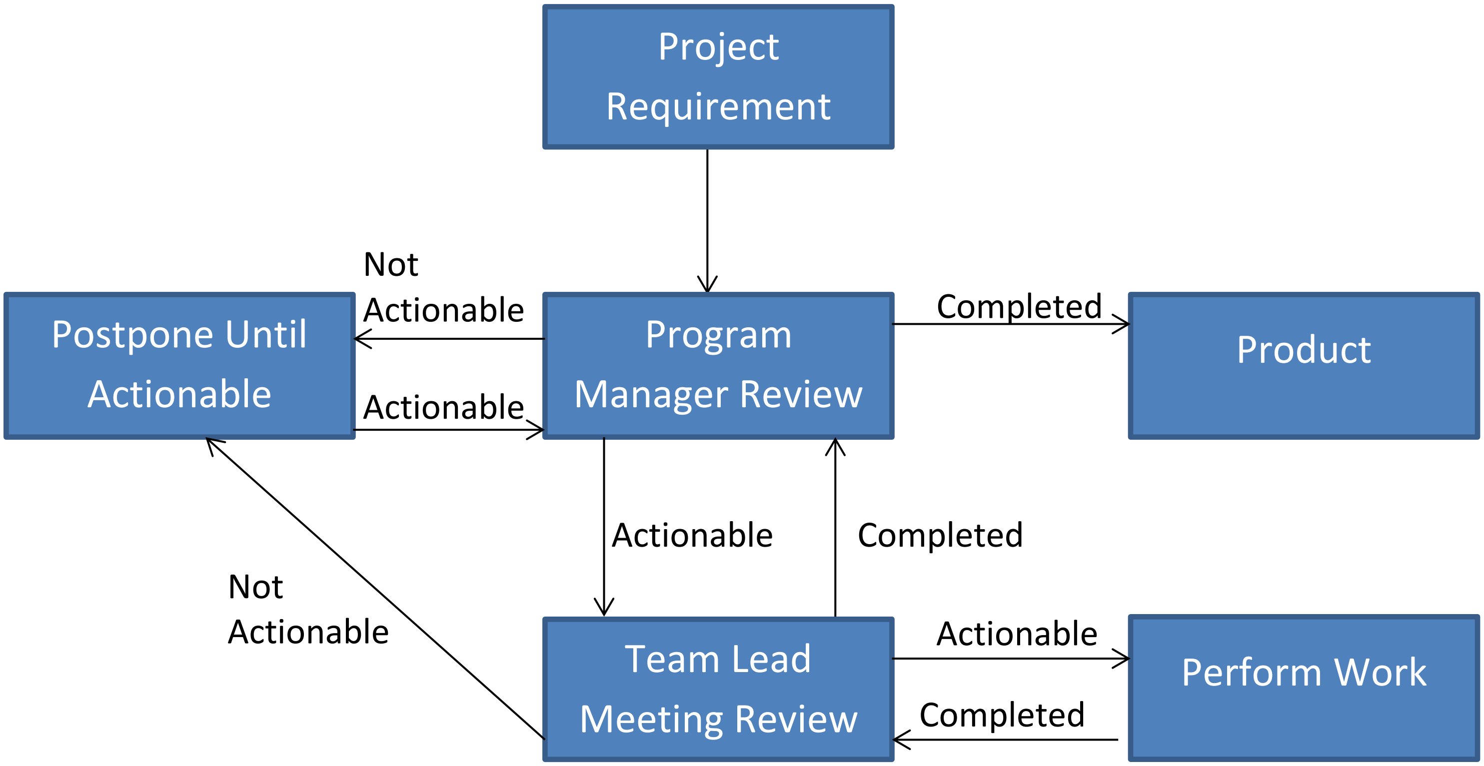
The UT Unmanned Aerial Vehicle Team has decided to return this year to the AUVSI SUAS Competition following a successful foray into the quadcopter scene. The team is comprised of undergraduate Aerospace Engineering majors and advised by both Dr. Armand Chaput and Mark Maughmer II.

1.2. Team Organization and Design Process

The team is led by a Program Manager, who oversees and coordinates three sub-teams, each led by a Team Lead. These sub-teams each work on their own tasks, which are decided upon every week in a Team Lead meeting. The Team Leads then relay this information to their sub-teams and dictate how the tasks are to be completed.

This form of organization increases overall efficiency and allows for specialization. It also creates a better learning environment for newer or less experienced members, as the Team Leads can focus on teaching a small group while they work.

The design process used by the UT UAV Team is a simplified version of that used in professional engineering firms. Before every new phase of the project begins, such as imaging system design or avionics installation, the Program Manager and Team Leads come together and create a set of specifications and objectives. Because the objectives are made clear at the start, timelines are more accurate and communication is simpler between sub-teams. This also makes work more efficient, since there is less second-guessing and problems are more quickly identified and resolved. At the end of each project phase, the Team Leads must present their work at the Team Lead meeting in order to ensure that they are ready to move on to their next project. The Program Manager reviews the original specifications and must confirm that each one is met. Any requirements not yet met are noted and must be completed before the sub-team can continue.



1.3. Team Objectives

At the beginning of the semester, the UT UAV Team made a point of opening recruitment to anyone interested in unmanned systems, with the goal in mind of creating a strong basis for the following years and a tradition of exposing underclassmen to engineering practices outside of the classroom. Primarily, we work to give students the opportunity to apply their knowledge of Aerospace Engineering to a project they actually enjoy, in a low stress environment. Secondarily, the Team Leads are tasked with teaching inexperienced members in tasks ranging from soldering to programming in C/C++ to using autopilot software. Finally, we aim to produce a system of which we can be proud, knowing that it will successfully complete the tasks for which it was made.

1.4. Mission Requirements

Below is a table of the tasks which the UT UAV Team has decided to attempt during the competition. Those in green are tasks where we expect to meet the Objective, while those in yellow are tasks where we expect to only meet the threshold in one or more requirements.

Task	Expected Performance
7.1 Autonomous Flight	Autonomous takeoff, flight, waypoint capture, and landing.
7.2 Search Area	Identify target shape, background color, alphanumeric, alphanumeric color, and location within 100 feet; autonomously fly the search area; and decipher the secret anagram.
7.3 ADLC	Identify target position, shape, background color, alphanumeric, and alphanumeric color with under a 25% false alarm rate.
7.4 Actionable Intelligence	Identify target location and all 5 characteristics within 50 ft for a single target.
7.5 Off-Axis Target	Provide an image of the off-axis target, identify target shape and background color
7.6 Emergent Task	Add the last known position of the emergent target as a waypoint, manually search for the emergent target, and provide an image of the target, location within 50 feet, and adequate description of the target’s activity.
7.7 SRIC	Download the secret SRIC message and perform the task defined, dependent upon time remaining.
7.8 Interoperability	Provide a standard positioning reference to the judges.

1.5. Safety

As with any project in the aerospace industry, safety is of the utmost importance for the UT UAV Team, especially due to the relative inexperience of our members. Although it is impossible to completely avoid all accidents, the team mitigates them for both people and the air vehicle. This is achieved through a variety of methods, both when working in the lab and out on the field.

Of course, safety for the students is the priority. In the lab, anyone who wishes to use the soldering iron or power tools must first demonstrate competence to their Team Lead. If they do not know how to use a tool, the Team Lead, Program Manager, or Mark will teach them. On the field, a larger number of precautions are taken to maintain a safe environment for the team. Only one person is allowed onto the field with the safety pilot to relay information back to the ground crew, and all motor testing is done well away from the team. The plane itself has a power button leading to the speed control so that the motor cannot turn on accidentally. Finally, the safety transmitter must be on every time the avionics or propulsion systems are powered.

The following table contains a summary of all risks, mitigation plans, and fallback plans for the competition:

Problem	Cause	Mitigation Plan	Fallback Plan	Effect
Loss of RC Link	External electromagnetic interference, RC dies	Closely follow transmissions regulations, charge RC the night before and pack an extra battery	Return to landing after 30 seconds, spiral to ground after 3 minutes.	Mission continues with caution in the first case, mission failure in the second.
Loss of ground station signal	Faulty servo wire, external electromagnetic interference, Mission Planner crashes	Secure all wires with clips, closely follow transmissions regulations, test connection preflight.	Safety pilot takes control until signal is regained	Mission continues without autonomous flight
Onboard autopilot failure	Faulty servo wire, local electromagnetic interference	Secure all wires with clips, move high power components to the extremities.	Safety pilot takes control, continues flight.	Mission continues without autonomous flight.
Structural Failure	Loose screws/bolts, stress failure	Secure bolts firmly and test them before flight, reinforce high-load points with Kevlar.	Safety pilot takes control, attempts to land air vehicle.	Ground crew attempts to fix problem. If incapable, mission failure results.
Control Surface Failure	Servo failure, faulty servo connection	Control surface testing preflight.	Safety pilot takes control and either attempts landing or continues mission	Mission continues unless problem cannot be resolved or flown with.

Loss of image transmission	Electromagnetic interference, faulty wire connections, camera is damaged	Test signal preflight, test gimbal preflight, follow transmissions regulations	Complete waypoint navigation then land air vehicle and attempt to fix.	Partial mission failure.
Engine failure	Speed control failure, battery failure, motor or propeller failure	Motor testing before flight, check battery voltage/charge batteries thirty minutes prior	Safety pilot takes control, attempts to land air vehicle	Mission failure
Gimbal failure	Servo failure or loss of signal to secondary RC	Test gimbal rotation preflight, use wire clips	Fly directly over targets.	Off-axis target task no longer possible, search area task takes longer.

1.6. Testing Process

The air vehicle the UT UAV Team uses was originally modified by the Senior Design II class in Spring 2013. We have since replaced most of the interior components and changed to a fuselage with less wear and tear. However, the majority of testing, such as optimal wing shape, empennage size, air speed, etc. has already been performed. Since the purpose of the journal paper is to focus on what our team has done specifically, not as much emphasis will be placed upon the trade studies performed by the senior class before us. That being said, our analysis of the results will be mentioned to provide a background for our decisions.

2. Air Vehicle Design

2.1. Air Vehicle Overview

Kratos is the variant design of the ready-to-fly model kit Sig Kadet Senior. Most of the air vehicle is constructed out of balsa wood, except the wings in which composite materials are present to increase structural strength. Kratos has a large wing area that allows it to fly at low speeds for surveillance and target detection, along with a large fuselage for easy housing of the avionics and camera gimbal.

2.2. Airframe Description

2.2.1. Fuselage

Kratos's fuselage is given shape by balsa wood trusses and strengthened with plywood where needed, such as the firewall/motor mount and the location where the wings connect to the body. The landing gear is made out of XXXXX and was put in after the previous landing gear degraded over testing. The size of Kratos allowed for the position of the propulsion batteries, two 5000 mAh 4-cell batteries, to be near the nose of the air vehicle directly behind the firewall. This placement also contributed to the stabilization of the CG of Kratos. In order to accommodate for the camera gimbal, a bottom section of the fuselage had to be cut out. This meant the camera and gimbal system would likely produce more drag, but due to the low flying speeds, any additional drag created was unnoticeable during testing.

2.2.2. Wings

The wings are made out of balsa ribs joined together with a balsa spar. The airfoil used is the Clark Y and has a chord of 12 inches with an overall span of 120 inches. To arrive at these choices for chord and span, at trade study was performed using the SAVEz method. As seen in Figures 2-1 below, the chord that maximizes the endurance factor and the SE score is 13.5 inches. However the team ended up using a 12 inch chord since it yields similar EF and SE scores to that of 13.5 in chord, and it allows for easier and sturdier attachment of the wings onto the fuselage. The span of 120 inches was decided after the chord of 12 inches was picked and was used in an aspect ratio trade study using the SAVEz method once again.

The calculations determined the aspect ratio maximizing the EF and SE score was 10, as seen in Figures 2-2.

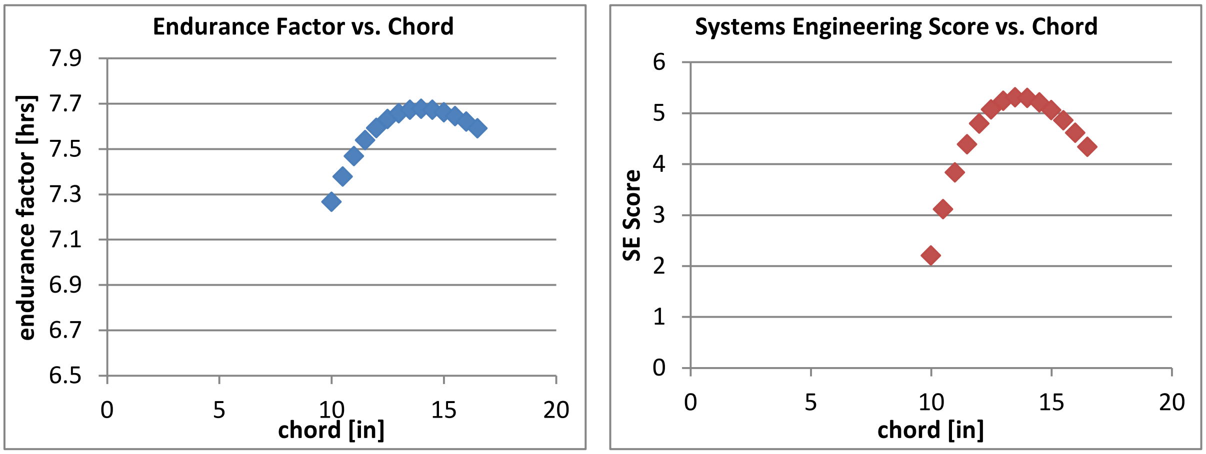


Figure 2-1

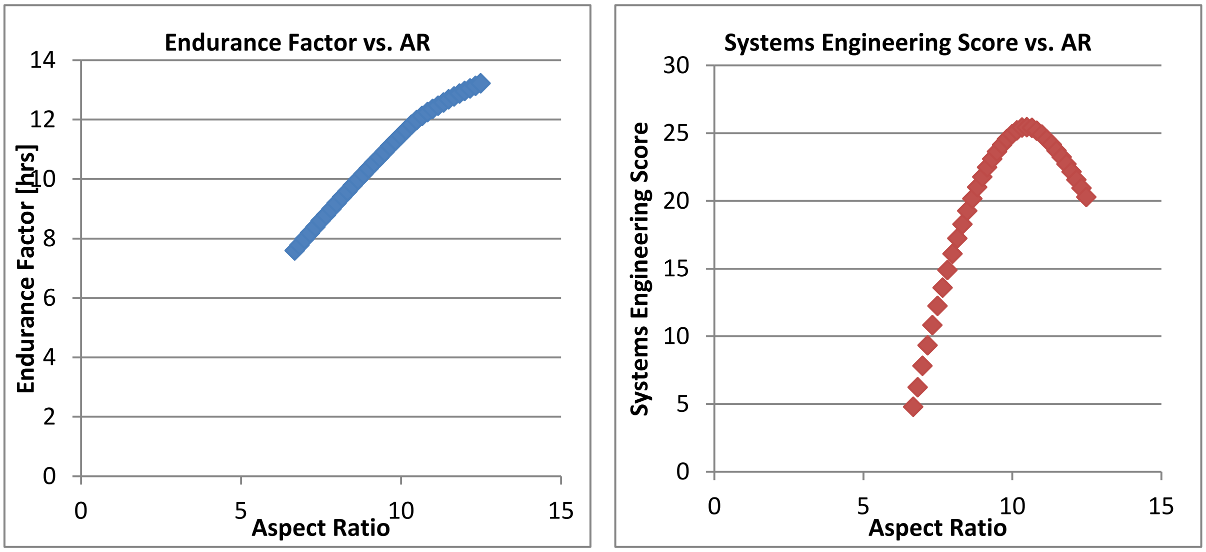


Figure 2-2

To strengthen the wings after a structural failure caused them to fold in flight, the central spar holding together the ribs was notched and implanted with carbon fiber and Kevlar strips for the first two feet of the root. Furthermore, in order to strengthen the housing for the metal bar, thicker plywood with more carbon fiber strips was installed as the top and bottom of the housing, the wrapped with Kevlar for even greater reinforcement. To complete the wings, Monokote was used to cover the wing skeleton.

2.2.3. Propulsion

Two motors were the subject of testing in order to determine to propulsion system for Kratos, with the main question being thrust to power measurements because the two motors were of the same mass and dimensions. The Scorpion 4020-630 Kv motor scored the highest at both low and high throttle measurements, as seen in Figure 2-4.

The propeller measures 15 x 10 inches, which provides slightly higher efficiency and thrust over the original, at the cost of some maneuverability. However, in surveillance, time in the air is more important than maneuverability, so it was a worthwhile tradeoff.

Finally, the speed control is a Phoenix Edge 75, which provides programming capabilities and a high maximum amp draw of 75 amps, which is over 20% less than the maximum current draw of the motor. This provides safety for the air vehicle and more direct control for the team.

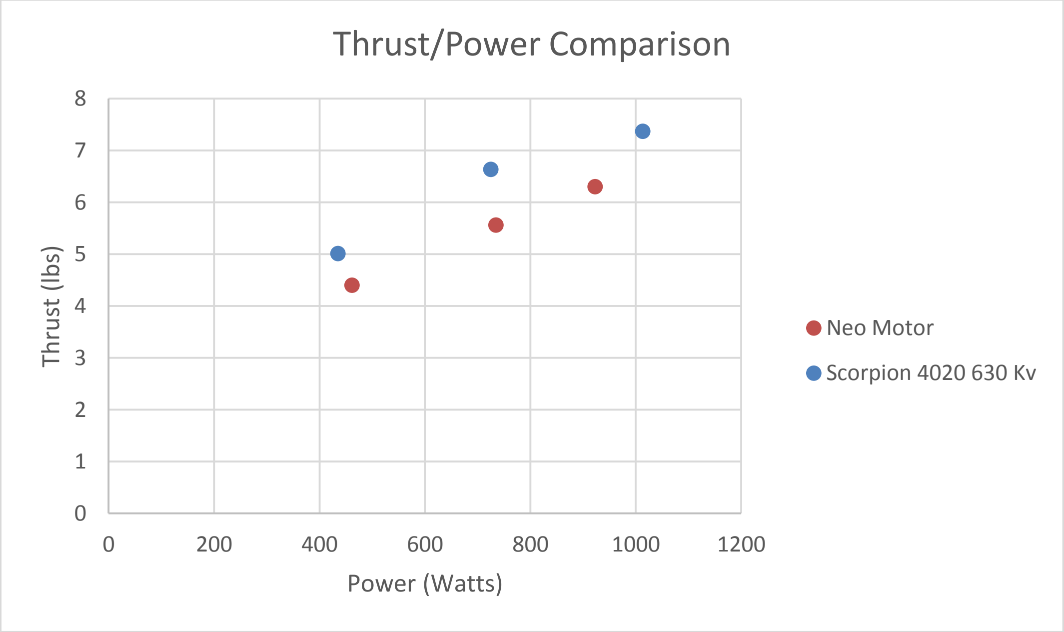


Figure 2-3

2.3. Avionics Description

2.3.1. Navigation

Kratos uses the Ardupilot Mega board, 3DR Radio, a GPS module, and a JRX transceiver for its autonomous capabilities. The student lab at UT Austin has always used Ardupilot Mega for autopilot projects. The familiarity of the faculty and other students with APM 2.5 reduces the learning curve for our team. Servo wires are used to send information to the motor and control surfaces, while a GPS gets positional data at the front of the fuselage. It also has inputs for our transceivers, wind speed, gyroscopic data, and altitude.

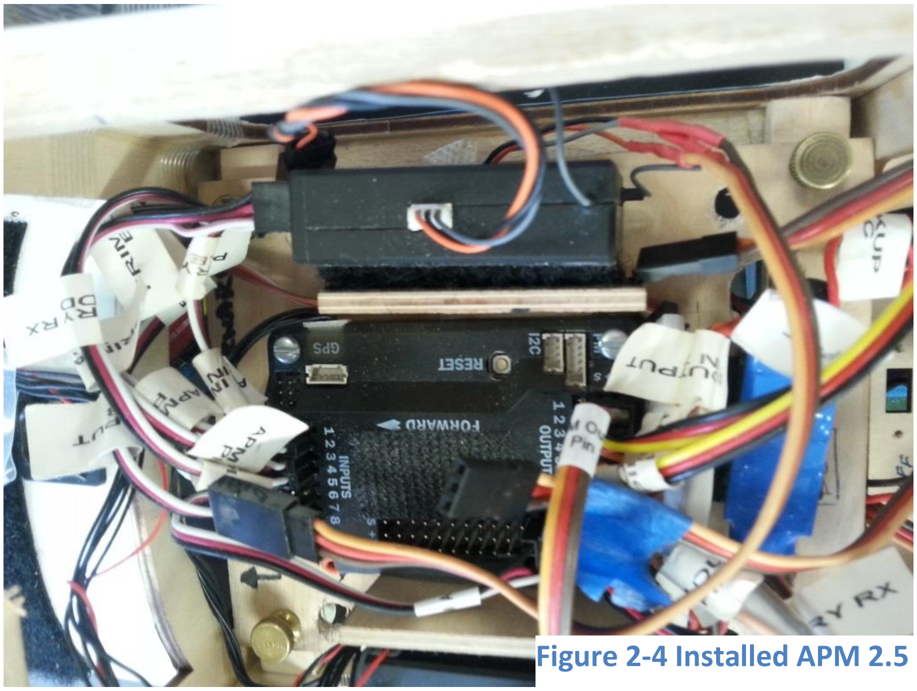


Figure 2-4 Installed APM 2.5

2.3.2. Communication

Communication is performed between the air vehicle and the ground station in a variety of ways. First off, communication between Mission Planner on the ground and the Ardupilot Mega onboard is facilitated by a 3DR radio antenna on the bottom of the plane. The communications between the remote controls and the air vehicle requires two JR DSM-X receivers per remote. Finally, video transmission is accomplished via a high power Range Video transmitter.

Knowing that electromagnetic interference can be potentially hazardous to mission success, we have arranged all transmitters and receivers to be as far away from each other as possible. As an added precaution, we shielded the video transmission wire due to its high current draw and placed it at the tip of a wing. Finally, the 3DR radio is shielded by the grounding plate at the back of the fuselage.

All radio transmissions have been checked and fall within the guidelines set forth by AUVSI. Nonetheless, we have implemented backup measures in the case of a loss of signal between the safety pilot and air vehicle, similar to what happened in 2012. The onboard autopilot has been programmed to initially return to landing after 30 seconds of lost signal. If signal is lost for three minutes and the plane has not been landed, then it will enter into the crash sequence designated within the rules. Given previous incidents, we take this matter very seriously and plan to do our best to ensure that the air vehicle will not crash due to a loss of RC communications.

2.3.3. WiFi

WiFi communications are all performed by the Beagle Board, a Linux-based computer. Connected to it is a 2.4 GHz b/g/n wireless adapter. The Beagle Board is very light, weighing just over half a pound when paired with the wireless adapter, and requires very little power. The adapter itself is located at the far back of the plan, just underneath the empennage. Overall, the system is efficient for what we can accomplish with it, so we have made the decision to include it in the plane.

2.4. Gimbal Design

For the mission, a yaw-pitch gimbal was designed and 3D printed (thanks to the ME department here at UT) using SolidWorks. The camera sits on a basket while the basket is pinned to a pronged connector where a servo sits on the top. This servo controls the pitching action of the camera using a gear-and-chain system seen in Figure 2-4. The gear ratio used is about 1:1.5, with the larger gear attached to the basket and smaller gear on the servo for reducing the torque load.

This configuration does limit the pitching to a bit less than 45 degrees from the vertical; however, with the camera's field of view, the requirement of a 60 degree field of view from the vertical is still met. The basket-connector assembly is then bolted to a metal turntable that is rotated 180 degrees by another servo. Since the majority of the inertia that the second servo sees lies along the axis of rotation, no gear system was needed. The gimbal was 3D printed out of ABS plastic, making it not only a strong, lightweight component, but also allowing for more complexity in the design itself.

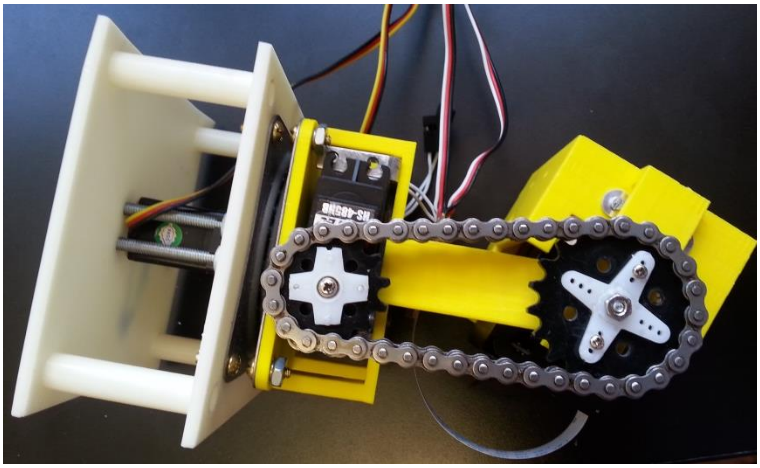


Figure 2-5

2.4.1. Gimbal Lock

Although gimbal-lock is present in the design, the overall performance and space needed to be used for the gimbal was better and smaller than a gimbal without gimbal-lock. To avoid potential problems during flight testing, we keep the gimbal tilted upward to give more immediate vision to the port and starboard sides of the air vehicle. If it is decided that gimbal lock along the roll axis is too much of a problem during later test flights, we can rotate the lower half of the gimbal by 90° by merely unscrewing four bolts.

2.4.2. Camera

The gimbal was originally designed for a Sony FCB EX 980-S optical video camera, but due to hardware zoom problems the team decided to switch to the FM36X700, a similar but lighter version of the Sony OEM camera. The FM36X700 weighs half as much as its predecessor and has a 36x optical zoom, which will be critical in the identification stage of the competition, along with its 700 TV lines video resolution, which is close to that of the old camera. On top of that, both cameras have infrared technology, which will allow us to use them for future competitions too.

3. Data Processing

3.1. Overview of Data Processing Systems

The Data Processing team is tasked with automatic image detection and recognition, connecting to the SRIC, and transmitting a GPS feed to both the judge’s computer and the computer with the live image feed.

3.2. Image Detection

The image detection is run on a secondary ground station computer in C/C++, using the OpenCV library. It works by converting incoming images to grayscale, then using Canny Edge Detection to find edges. Once the edges are found, another OpenCV method finds possible polygons. Finally, our program converts those polygons to shapes. Once a shape is found, the program looks for edges inside of the shape with a bounding box and matches them to a particular letter given particular characteristics, such as vertices and angles. Once found, the program then uses the original image to determine the closest approximate color for both shape and letter. To avoid finding the same target twice, the combination is stored for comparison to future targets. If the same target is found again, it is thrown out.

Once finding a unique shape and letter combination, the GPS feed from the primary computer is read and interpreted to determine GPS location. If the GPS location is too similar to a previous target, the target is flagged as a possible duplicate for further review. This would also mean that the target had been incorrectly detected in one of the two instances.

Although the opportunity to apply this code while flying has not yet surfaced, it shows promise when run on previously captured video feed:

Detection Rate: 60% (out of total possible targets)

False Alarm Rate: 20% (out of total targets found)

Incorrect Detection Rate: 25% (out of total targets found)

Difficult Shapes: Crosses (Difficult to turn into polygon), Parallelograms (Mistaken for squares), Circles (Mistaken for Octagons).

Difficult Alphanumerics: 2/5/S, Y/T, A/V, M/W, 8/B

The main issues with this method are reliance upon a low number of heavy shadows and the necessity to fly almost directly over the target. Both of these can be corrected given more time and experience, but as of right now the code is limited.

We also plan to detect images manually through the use of the secondary computer for snapshotting images and saving them with the GPS location. This is run in tandem with the actual image detection in the same program, with the image files being saved to another folder. This provides a fallback plan for if the automatic detection underperforms.

3.3. WiFi Handling

Kratos carries a small onboard Linux-based computer, a BeagleBoard, for WiFi purposes. It has a 2.4 GHz b/g/n wireless adapter connected to it. To connect to the SRIC, the BeagleBoard runs a Python script that automatically searches for and downloads the file required. It then connects to a router at the ground station which is connected to the secondary computer. The file is then downloaded by a script running on the secondary computer. The process takes a minute overall in testing. Once downloaded, the file can be easily opened and read from the desktop of the ground station computer.

3.4. GPS Feed

Mission Planner has built-in functionality for the live streaming of GPS information. We have set up Mission Planner on the primary computer so that it is constantly outputting a GPS feed to the USB com port. We then have built a splitter that sends the information to both the secondary computer and the judge's computer. This information is then used to find target locations and track the air vehicle live on Google Earth.

3.5. Testing Processes

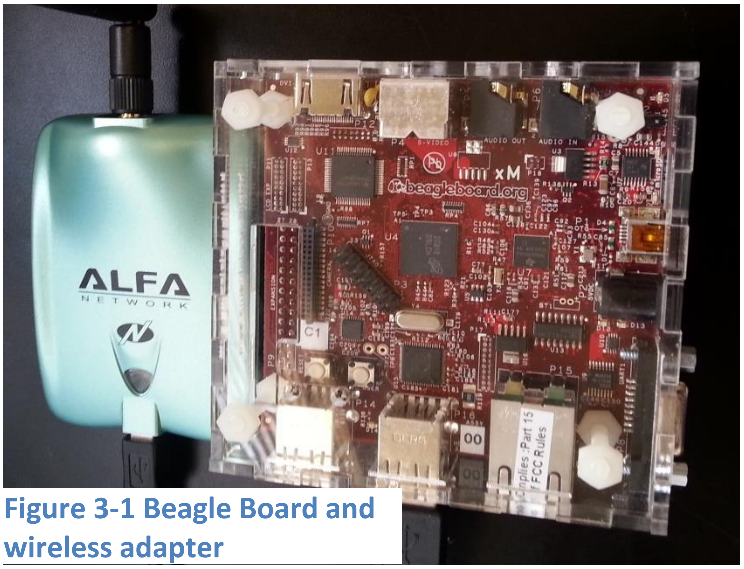


Figure 3-1 Beagle Board and wireless adapter

Testing for image recognition was primarily performed through video captured during flight and then read into the program at the lab as if it were a live video feed. This allowed for more time to debug and find errors while still using real-world video. The WiFi is easily tested in the lab by using the configuration shown in Figure 2-6 and the ground station equipment. Finally, the GPS feed is tested by using a student laptop with Google Earth, the primary computer, the secondary computer, and a simulation setup of the Ardupilot Mega system. We have yet to test either of the last two in actual flight. However, they are relatively autonomous and should not pose much difficulty.

4. Conceptual Operations

4.1. Overview of Mission Operations

Waypoints are drawn so that the path does not overlap during the search in order to save time. In addition, to prevent the aircraft from going out of bounds, a geofence is drawn with a rally point. The aircraft will be at an altitude between 250 feet to 750 feet from the ground. The aircraft will start at a higher altitude to allow the camera to cover more area at the expense of image quality. The aircraft will then decrease in altitude and commence with the more accurate search of the targets. Once a target has been detected, the ground crew will make note of the location and continue flying over other areas. The GPS data is constantly being sent to the imaging laptop and that of the competition judge's in NMEA format.

4.2. Ground Station

Ground station monitors the aircraft during flight through live GPS and video feed. A data log of the location of the aircraft is also recorded in Mission Planner during each flight. Conceptual Operations makes sure that the aircraft stays in the mission area and monitors battery consumption. The secondary computer is hooked up to a wireless router to receive the SRIC message from the air vehicle.

4.3. Ground Crew

The ground crew includes a Safety Pilot, a Flight-Line Assistant, a Mission Planner Pilot, an Image Recognition Operator, and a Mission Director.

Mission Director	The Mission Director is responsible for the overall success of the mission. The Mission Director maintains communication with the judges and decides when to move on to the next task.
Safety Pilot	The Safety Pilot stands on the flight-line and watches the aircraft to ensure it is always under control. If the Safety Pilot sees the aircraft begin to perform an unsafe maneuver, he will take control with the RC.
Mission Planner Pilot	The Mission Planner Pilot is responsible for the flight path of the air vehicle, as well as the geofencing and GPS data transfer. He controls the air vehicle from takeoff to landing, assuming no problems arise. During flight, the Mission Planner Pilot must be in contact with the Flight-Line Assistant at all times.
Image Recognition Op.	The Image Recognition Operator is responsible for target detection and SRIC connection. He also controls the camera when necessary.
Flight-Line Assistant	The Flight-Line Assistant maintains radio contact with the Mission Planner Pilot and relays information between the ground station and Safety Pilot. This allows the Safety Pilot to maintain full attention on the aircraft.

4.4. Flight Procedures

An abbreviated list of Flight Procedures is as follows:

Pre-flight

1) Aircraft is assembled and made ready for system testing.
2) Mission Planner Pilot begins inputting waypoints and setting up geofences.
3) Avionics and Propulsion batteries are connected, avionics is turned on. Mission Planner is connected to the air vehicle and the Mission Planner Pilot uploads waypoints.
4) Full System Test, including RC range test, stabilization test, and propulsion test. Once finished, Mission Director notifies the judge.
5) When the judge is ready, the Safety Pilot taxis the air vehicle to the runway.
6) When cleared by the judge, the Mission Director alerts the Safety Pilot to turn on the propulsion system. The Mission Planner and Safety Pilots both notify the Mission Director when they are ready for takeoff.
7) The Mission Director gives the order to commence flight.

In-flight

8) The air vehicle follows the waypoints as directed in the Autonomous Flight Task.
9) The Mission Planner Pilot alerts the Image Recognition Operator when he needs to look for the Off-Axis Target. The Image Recognition Operator maintains vision of the target with the camera while the Mission Planner Pilot writes down the target information.
10) Once in the Search Area, the Mission Planner Pilot will maintain focus on the air vehicle’s position to maximize search effectiveness and minimize the chance of crossing the No-Fly-Zone Boundary.
11) The Image Recognition Operator maintains control of the camera and takes pictures of targets he sees. The Mission Director records the information of any targets he cannot. The image recognition code should be running in the background as well.
12) When the SRIC text file is downloaded, the Image Recognition Operator alerts the Mission Director to what it says. The Mission Director then decides whether to continue the Search task or attempt the task defined by the message.
13) Once the Mission Director believes that the team has achieved all it can, he alerts the Mission Planner Pilot to return to landing.
14) The Safety Pilot is notified and maintains vigilance in case of poor landing conditions or an autopilot malfunction.

15) Upon landing, the air vehicle is taxied off the runway and propulsion system is powered down.

Post-flight

16) The Mission Director gives the okay to power down the avionics systems when both the Image Recognition Operator and Mission Planner Pilot are ready.
17) The Image Recognition Operator saves to a flash drive all targets he recorded, as well as those recorded by the image recognition software. He hands the flash drive to the Mission Director and then attempts to solve the anagram created by the targets.
18) The air vehicle is taken off the runway and the batteries are placed in the battery box by the Flight-Line Assistant.
19) When either the mission time is running low or the Image Recognition Operator has solved the anagram, the Mission Director notifies the judge of mission completion.

4.5. Mission Planner

Mission Planner was selected as the autopilot because it is open source, is well documented, allows external functions to be programmed through python, is compatible with RC radios, and outputs GPS coordinates in NMEA format. Other benefits to using Mission Planner with APM 2.5 over systems such as Paparazzi include cost (Paparazzi costs four times as much as Ardupilot Mega) and ease of programming the board itself, which was required to make the failsafe work properly.

Mission Planner is well suited to the mission since waypoints and geofences can be easily drawn up and sent to the aircraft, even during flight. Geofences are useful when creating boundaries over which the aircraft may not cross.

4.6. Search Trajectory

As the Kratos aircraft enters the search area, trajectory are utilize within the no-fly-zone boundaries at altitudes of 200 and 750 feet MSL. While there are many trajectory plans to conduct surveillance, conditions were analyzed to finalize the flight navigations: wind, target recognition time, banking angles and overlapping. Table 1 shows the trajectory plans under consideration.

Conceptual Operations: Flight Paths			
Description/Title:	Loop and zig-zag	8-shape	Alternating boxes
Starting point:	Corner	Corner	Corner
Benefits:	Covers all area (1 time)	No overlap	Small number of turns
Costs:	Overlapping	Potential high banking	Overlapping at edges
Other factors:	Different starting position (wind)	Different starting position (wind)	Different starting position (wind)

Table 1: Flight Navigation Plans

The trajectory plans were constructed using a set of waypoints on Mission Planner. An example is shown in Figure 1, where the flight goes counter-clockwise. The trajectories were simulated on X-Plane 9 and operated in flight testing for analysis from the observation of overlapping, banking angles and wind effects.

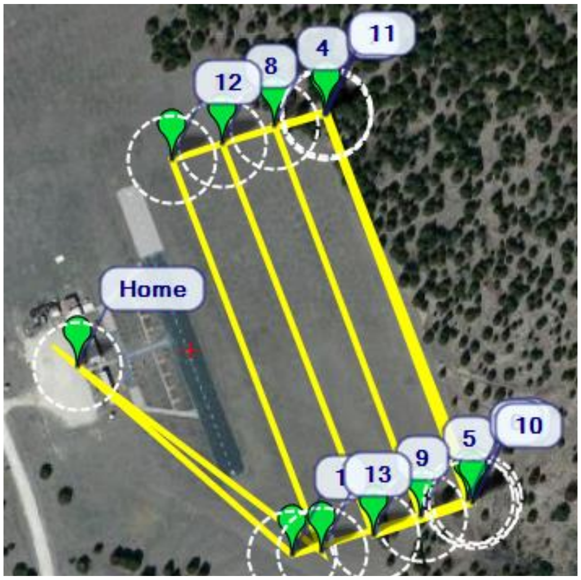


Figure 2-6 Alternating box flight path on Mission Planner

When accounting for wind in the analysis, the speed and direction of the aircraft are affected. Tailwinds add to the aircraft's speed, while headwinds slow down the aircraft. Thus these conditions affect the amount of time the camera can recognize a target. Cross-winds change the direction of navigation, which must be taken into account in the flight trajectory to maintain the desired direction of aircraft. Using a simulation, Kratos performed better in an alternate box path with head winds because of the decrease in airspeed that maximize target recognition time. Under cross-wind conditions of 5-10 knots, all of the paths had difficulty staying along the flight route. The consideration was to minimize cross-winds along a flight path.

Banking angles are another consideration that affects navigation. High banking angles causes the stall speed to increase and creates high stress on the wing. During a flight test, Kratos' left wing broke due to high banking angles of 45°. This changes the paths to contain turns of 30° or less for safety concerns. Overlapping was predominating in most flight paths. In figure 1, the aircraft passed the top, right and bottom edges several times. The conclusion was to allow one edge to be outside of the search area but inside the no-fly zone. With the same example in figure 1, the right edge would have this condition of placing it outside the search area to minimize the overlapping of the top and bottom edges.

5. Conclusion and Acknowledgements

No matter the outcome of the competition, the UT UAV Team will consider this year a success. The amount of learning and experience imparted to its members will prove to be invaluable later on in the careers of many; moreover, the newfound love of RC flight which the program has sparked in me in others on the team could be considered to be worth the work alone.

As with all projects, this could not have been accomplished without the help of individuals outside of the team itself. The UT UAV Team would like to recognize and thank the following individuals for their help with the project:

- Dr. Billy H. Wood
- Joe Silverthorne
- David Taken
- Michael "Miki" Szmuk
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