Development of a Fixed-Wing Autonomous Aerial Vehicle at Virginia Tech

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Abstract

The Autonomous Aerial Vehicle Team (AAVT) at Virginia Tech has constructed a fixed-wing autonomous aircraft named Pandora to enter into the 4th Annual Student Unmanned Aerial Vehicle (UAV) Competition. The purpose of the competition is to challenge undergraduate engineering students to design and produce unmanned systems and to establish ties in the UAV industry. For the competition, the vehicle must complete a reconnaissance mission autonomously, identifying and locating targets in a designated search area. The AAVT submitted their first entry, named Xavier, into the 2005 competition and Pandora's design began where Xavier's left off. This paper describes the competition requirements and how Pandora will meet those requirements. Included in this paper is a description of Pandora's overall system design and a summary of the design steps that have taken place in the past year, including vehicle modifications, autonomous testing, vision system development, and design for safety.

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Introduction

The Autonomous Aerial Vehicle Team at Virginia Tech was created in 2004 and made its first entry of a fixed-wing autonomous vehicle, Xavier, into the 3rd Annual Student Unmanned Aerial Vehicle (UAV) Competition in the summer of 2005. The current fixed-wing portion of the AAVT is composed of nine senior mechanical engineering students completing their Capstone Senior Design Project in addition to a freshman volunteer and a graduate student advisor. The fixed wing vehicle is an evolution of the Xavier design, which has been named Pandora. The team is entering Pandora into the 4th Annual Student UAV competition in the summer of 2006.

The objective of the Student UAV competition is to develop an autonomous aircraft to complete three requirements. The first is to demonstrate autonomous flight control where altitude and heading can be changed by commands from a Ground Control Station (GCS). The second is to demonstrate the ability to autonomously navigate through Global Positioning System (GPS) waypoints. The third requirement is to fly over a designated search area on which targets have been placed, and report back the number of targets observed, the location of the targets and their orientation. During the trial run, the aircraft must stay inside a safety boundary and complete its mission within a forty-minute time limit. The aircraft also needs to meet certain safety requirements including a fail-safe measure to automatically crash the plane if radio contact is lost and an Emergency-Stop to manually cut the engine in an emergency. The fail-safe measure is designed to orient the ailerons and the elevator in a position that will cause the plane to spiral toward the ground.

Pandora was built from a SIG Kadet Senior and uses a nitro methane-fueled engine for propulsion. The landing gear has been converted from the stock tricycle gear to a tail-dragger configuration for a number of reasons discussed below. Other mechanical modifications have been made to solve various design issues resulting from increased weight and the requirements of the mission. Autonomous flight is achieved using a MicroPilot MP 2028g autopilot. The reconnaissance system uses a BlackWidow AV analog camera and an Olympus digital camera. The MicroPilot, cameras, transmitters, and batteries are all contained inside an aluminum "black box" onboard the aircraft. This box is intended to protect the electronic components in the event of a crash and is where Pandora takes her name: Pandora's box. The analog camera transmits a live feed to the computer at the Ground Control Station (GCS) where LabVIEW software performs automated image analysis to identify targets and, combined with telemetry data from the MicroPilot, calculate their GPS locations.

The next three sections of this paper describe Pandora's essential systems: the airframe and mechanical components, the method of autonomous flight, and the vision system. Following those sections, the overall strategy for completing the mission within the allotted forty minutes—including collecting, analyzing and reporting reconnaissance data—is discussed. Next, a section discussing safety concerns and features of Pandora is included. Finally, the paper closes with conclusions drawn from the team's design process and a discussion of further uses of Autonomous aircraft being pursued at Virginia Tech.

Airframe

The SIG Kadet Senior is the airplane that the team is using as the base vehicle. This aircraft was chosen for a variety of reasons. The main reason that this craft was chosen was because it was one of the more cost effective options that provided enough payload capacity to fit all of the instrumentation. The cost of the plane that is chosen is important because it was necessary to buy backup planes in the event of a crash. The cost is also important, in this case, because this system has the potential to become a consumer/military product. Another advantage of the Kadet is its quick and easy assembly which is important for rapid turn-around time and obtaining flight experience.

Tail-Dragger Conversion. The stock Kadet that was ordered initially came with a tricycle landing gear. With this configuration there is one front wheel attached to the firewall and two others fixed to the underside of the fuselage. The front landing gear attached to the firewall is shown in Figure 1. The front wheel posed a problem while landing. During numerous test flights, the front wheel would hit the ground and bend, adding stresses to the firewall and deforming the gear itself. A possible scenario resulting from this condition would be for the firewall to completely break away from the plane. The solution to this problem was to convert the tricycle gear to a more conventional tail-dragger setup. This configuration is advantageous because it takes away any extra forces that may be applied to the firewall during a landing. The rear landing gear would also deflect under the weight of the plane. The conversion to the tail-dragger also required more robust landing gear which helped solve the problem presented by the tricycle configuration. Another reason the plane was converted to a tail-dragger was to make room for the electronic components that went into the plane.

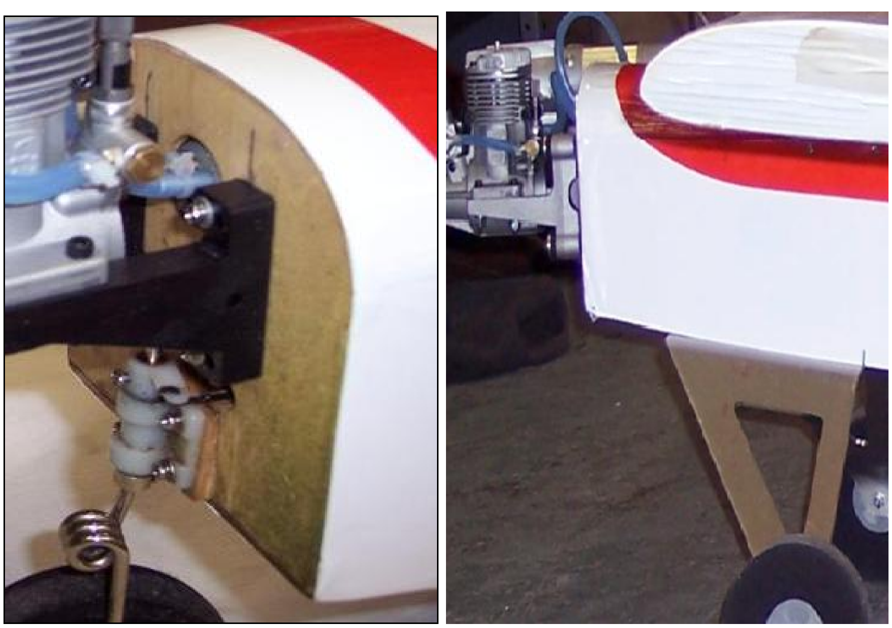

Figure 1. The firewall and original landing gear(left), the new tail dragger gear(right)

The conversion to the tail-dragger was completed by removing the old tricycle wheels and replacing them with a large aluminum front gear and a smaller tail wheel. This large aluminum gear was considerably heavier than the previous landing gear because it was made out of 1/8” thick aluminum. Three holes were machined in the new front gear—as seen in Figure 2—to reduce the weight while maintaining functionality and stability.

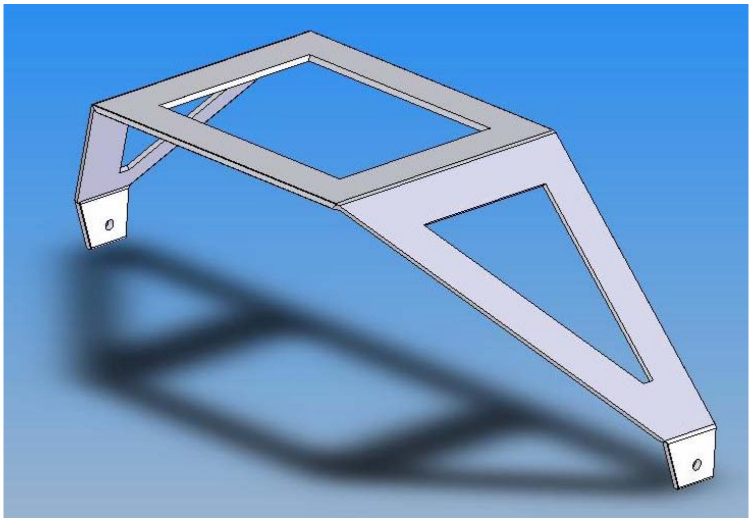

Figure 2. The front landing gear for the taildragger conversion

Another modification that was performed was the shelling out of the fuselage to maximize the space available for the black box. This was done by cutting out the balsa wood cross pieces that housed the main servos, creating the need to move the current servos. The servos that controlled the elevator and rudder/tail wheel were moved to the back of the fuselage. The control rod that operated the front wheel of the tricycle gear would have interfered with the open space that the team needed to create. The throttle servo moved to the front of the plane and is now fixed to the vibration damping mounts.

Black Box. In order to protect the fragile electrical components that are needed for autonomous flight, the team designed and manufactured a black box. The box is used to house the MicroPilot, an analog and a digital camera, the AGL (above ground-level sensor), a digital compass, two data transmitters, a servo board, and batteries. The box is made out of 0.032” thick aluminum Alloy 1100.

The team manufactured one prototype with aluminum that was slightly thinner in an attempt to reduce weight. The result was not rigid enough to provide the impact protection that was desired and so.032” was settled upon as an appropriate balance of weight and strength.

Figure 3 shows the box, which is 7 inches tall, 4 inches wide and 10 inches long and was designed to fit inside the fuselage. In designing the box, the team also wanted it to have the ability to be removed from the plane easily. Its main purpose is to protect all of the electrical components within the plane in the event of a crash. One of the major advantages of the black box is that it can be transferred from one plane to another if there is a crash or some other problem with the plane being used. Three holes were cut out of the sides of the box to allow access to different parts of the contents of the box. One of the holes is used to allow easy access to a switch panel that is used to turn on the many components within the black box, including:

the MicroPilot, analog video camera, two transmitters, and the Emergency stop servo. Another hole in the side of the box is used for two transmitting antennae to protrude. The last hole lines up with plastic side scoops that are mounted on the exterior of the plane to provide forced convection cooling of the electronics within the box.

Figure 3. Black box, constructed of aluminum alloy.

To save weight, all the electronics have been removed from their original casings. Unfortunately the casing often also serves as a heat sink, and so cooling the circuit boards was a crucial design issue. The plastic side scoops allow outside air to blow directly on the MicroPilot—the component that generated the most concern for overheating. The resulting airflow inside the box is believed to be enough to provide a cool interior for all the electronics to function properly. There has not been a problem with the electronics overheating during any of our trial runs with the system.

The lid to the box is held on by a hinge on the front edge and a removable screw on the back of the box allowing access to the internal components. Two square holes and a slot are cut out of the bottom of the box and another in the lid. The holes in the bottom are shown in Figure 4. The slot is cut to fit over a wooden piece in the bottom of the plane that is used for structural stability of the frame of the plane. The smaller square hole is cut to permit a small analog camera a full range of vision so that its field of view is not impeded by any part of the box. The larger square hole is for the larger digital camera. Both holes provide for unobstructed vision from the airplane. The hole in the top of the box is for the aileron wires, the AGL wire, and the Pitot tube to pass through.

Figure 4. Photo of the cuts from the box

One of the main goals in the creation of the autonomous system was to keep it as light as possible so it would be fuel efficient and thus capable of remaining in flight for the longest time possible. All of the components in the plane were weighed and their weights are shown in Appendix A. In addition to the weights of all of the components, the plane itself was weighed to determine the fraction of the total weight that was produced by the internal components. From early calculations, it was found that the SIG Kadet Senior aircraft would not be able to carry much more than five pounds of payload which was the main constraint that had to be considered when components were being purchased. The total weight of the plane and all the components is approximately 11.09 pounds, and the payload weight is about 3.5 pounds. The heaviest components include the black box itself, a bass wood skeleton (with all the components), and the fuel within the tank. Also, the batteries that power all of the components within the plane are relatively heavy.

There are two 4.8 volt batteries and one 11.1 volt battery. The 11.1 volt battery is rated at 1500 milliamp hours and powers the Micropilot, the transmitters for the MicroPilot, and the analog camera within the black box. The rest of the components on board are powered by the 4.8 volt batteries, which are rated at 2000 milliamp hours. The original fuel tank (10.8 ounces) has been replaced with a tank that can hold approximately 20 ounces. This new tank allows the plane to fly for approximately 40 minutes.

MicroPilot

The plane requires a controller to obtain the autonomous flight needed for the competition. MicroPilot is the autopilot being used due to its light weight and high functionality. It allows the plane to navigate waypoints through the desired search area while allowing the user real-time dynamic control of flight characteristics.

Components. The autopilot has many components that combine functions to allow the plane to accomplish its tasks. The board is equipped with 3-axis gyros and accelerometers that take measurements to control the roll, pitch, and yaw of the aircraft through PID control loops. A GPS unit is attached to the board and a satellite signal is received through the antenna mounted on top of the wing. A static pressure sensor allows the autopilot to know the current above ground altitude and GPS is used to determine the above sea level altitude. A Pitot pressure sensor is used to track the airspeed of the aircraft. The Pitot tube is mounted under the port-side wing away from the fuselage in order to obtain accurate airflow readings. Excess fuel tubing connects the Pitot tube to the Pitot pressure sensor.

Additional components were added to the MicroPilot to increase its functionality and obtain additional data to aid in the reconnaissance mission. The compass module was added to allow the autopilot to read the true heading of the aircraft, not just the GPS heading of the aircraft. This is important for dealing with windy flying conditions. The combination of GPS heading, compass heading, GPS speed, and airspeed allow the autopilot to calculate wind velocity and direction. This results in more precise control of navigation and allows the team to accurately determine the orientation of the cameras onboard.

An AGL (above ground level) sensor was added to allow for autonomous take-off and landing. This sensor uses an ultrasonic transducer mounted on the bottom side of the port-side wing to accurately determine distances within 16 feet of the ground. The sensor is connected via a shielded coaxial cable. An ADC (analog to digital converter) was added to allow for additional parameters to be monitored. A liquid-level sensor was mounted to the fuel tank and the signal is processed by the ADC to allow the GCS (Ground Control Station) to know when the level of fuel is getting low. Currently, the fuel sensor gives approximately a three-minute warning.

All control surfaces are controlled by the autopilot. The signals for the servos pass through a servo board. Passing signals through a separate board allows the power supply to the servos to be independent of that powering the MicroPilot. Since servos can have high current draw, the power source could see high fluctuations in voltage—which could result in resetting of the autopilot during flight—if the servos were not independent of the MicroPilot. The servo board also controls the infrared trigger for the onboard digital camera, which acts as a payload in MicroPilot.

The plane can be controlled manually via a 72MHz RC transmitter. The receiver on the aircraft has its signal passing through the autopilot board. Control is transferred to and from the autopilot by a switch on the RC transmitter. When in manual mode, the signal simply passes through the autopilot to the servo board.

Control Methods. MicroPilot uses PID (Proportional, Integral, and Derivative) control loops to control flight performance. The loops can be adjusted using the GCS software. The PID loops consist of:

Aileron from Desired Roll
Elevator from Desired Pitch
Rudder from Y-accelerometer
Rudder from Heading
Throttle from Speed
Throttle from Glide Slope
Pitch from Altitude
Pitch from AGL Altitude
Pitch from Airspeed Altitude
Roll from Heading
Heading from Cross Track.

Only some of the loops are in use at any particular moment depending on the command state the autopilot is in. Each loop controls a different aspect of the performance of the plane and, collectively, controls the aircraft. The gains were tuned in this order as recommended by MicroPilot. The final product of the airframe did need precise tuning because of the weight of the payload.

Ground Control Station. The GCS consists of a laptop running Horizon: MicroPilot's interface software. The aircraft communicates with the GCS by the use of a 900MHz radio modem allowing real-time monitoring and control of nearly all aspects of the flight. Figure 5 shows the path of data between the GCS and the final control surfaces of the aircraft. Black arrows show a wired connection while red shows wireless. Blue boxes show autopilot functions and yellow boxes show RC override control. Flight files, which contain waypoints, can be modified and uploaded during flight. Horizon was programmed to read the output of the ADC and displays when the plane is low on fuel. Other items that were programmed to show on the Horizon interface are GPS speed, airspeed, altitude, compass heading, and GPS heading. The data received by Horizon passes through LabVIEW first so that the vision system can collect telemetry data, as explained in the following section.

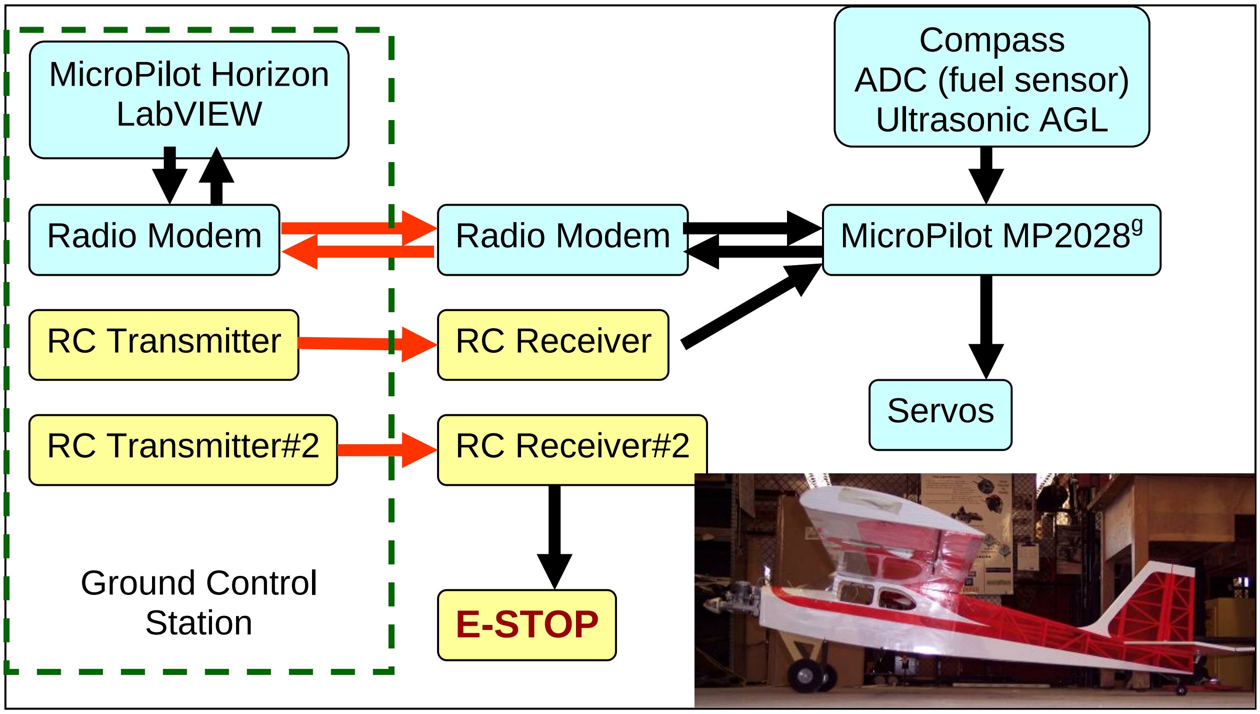

Figure 5. Diagram of autopilot data and control.

Vision System

The team intends to identify targets on the ground using visual data obtained from cameras. Visual data is a very practical way to detect ground features from an aircraft. A vision system in a UAV can be used in a wide variety of applications, some of which will be discussed in the conclusion of this paper. Pandora uses two cameras to collect aerial images and LabVIEW software to analyze those images. This section describes the hardware that makes up Pandora's vision system, the method of acquiring images, and the method of processing images to identify and locate targets.

Hardware. There are two cameras onboard the plane, an analog video camera, and a digital still camera. The primary imaging device is the analog camera, a Black Widow AV KX141 High Resolution Color CCD Camera, shown in Figure 6. This camera has multiple lenses that can be attached to create 19, 30, 64, and 90 degree fields of view. The optimal lens selection will result in the largest area of view yet still allows the target to be read from the image. Experimentation is still being performed to determine the best lens for use in competition; preliminarily, the 30 deg lens appears to work well. The analog camera does not store any data onboard the plane. Instead, it is connected directly to a wireless data transmitter. The signal is received, saved, and processed at the ground station.

Figure 6. Black Widow AV KX141 High Resolution Color CCD Camera

The other imaging device we are using is an Olympus Stylus 500 5MP Digital Camera, Figure 7. This camera is also located onboard the plane. The digital camera is equipped with a 1-Gb storage card. When images are taken they are stored on the card. The images taken by the digital camera cannot be viewed until the plane is back on the ground. For this reason the digital camera is a backup and should only be needed in the event that video signal from the analog is lost.

Figure 7. Olympus Stylus 500 Digital Camera

Image Acquisition. Image acquisition during the competition poses several challenges. First, the Stylus 500 is a standard digital camera and therefore was designed for casual picture taking. The challenge with the Stylus, involved finding a method to trigger the device while being mounted onboard an autonomous airplane. There are currently two methods for recording an image with the camera mounted in the plane. One method uses an IR-trigger that we have mounted to the front of the camera. This method uses the IR port on the camera—normally used for remote triggering—to eliminate any vibration resulting from mechanical triggering of the camera. However, this technique resulted in a time delay that made the IR trigger impractical. The method currently employed uses a servo to turn the camera on as well as to take pictures. The servo method appears to be consistent and has a short delay between triggering the camera and capturing the image. The camera is mounted securely enough to the bass wood frame, along with the servo motor that triggers it, that no vibration has been noticed in the resulting images.

The other challenge involves the analog camera. The analog image is continuously broadcast to the ground via a wireless transmitter. On the ground, a receiver converts the image into an RCA component format. The challenge is to get that video feed into the computer. For the competition a PCMCIA capture card is being used. The card we are using is a VCE-PRO capture card. This card was chosen because of its easy compatibility with LabVIEW. With this device analog video streams are pulled into the computer in a digital format. The video can then be saved as an Audio Video Interleave file (.avi) or, in this case; the live video stream is run through LabVIEW.

Image Processing. The image processing for the competition will be done in a custom program written in National Instrument's visual programming environment: LabVIEW. This program consists of two inputs; the video feed from the plane and live telemetry data from the MicroPilot. The program will output multiple picture files that have the telemetry data at the instant the images were taken. The images will then be used to determine the number of targets at competition, what the character on the targets is, the orientation of the target, and the location of the targets.

The LabVIEW application has multiple stages. The application is running live video along with a live data feed. The application then pulls the latest frame from the video and associates the latest telemetry data with that image. The image is then processed by extracting the red color plane and using a threshold to identify any areas that could be identified as a target. The altitude and the camera lens being used are both factored into calculating the area of any potential targets. If the image does not contain any objects that could be a target, LabVIEW starts the process of pulling in a new frame and new telemetry data. If the processing shows that a target might appear in the current frame, the image and telemetry data are sent on to the next stage.

The second stage reorients the image to the ground coordinates. To perform this process, the image is corrected for the roll and pitch of the plane and then rotated so that "up" is aligned to north. The corrected GPS coordinates of any point in the image can then be determined, including a point identified as a target. The processed images are saved with all of the MicroPilot data in a folder on the desktop and can be viewed at any time during or after flight. A general overview of the process can be seen in Figure 8.

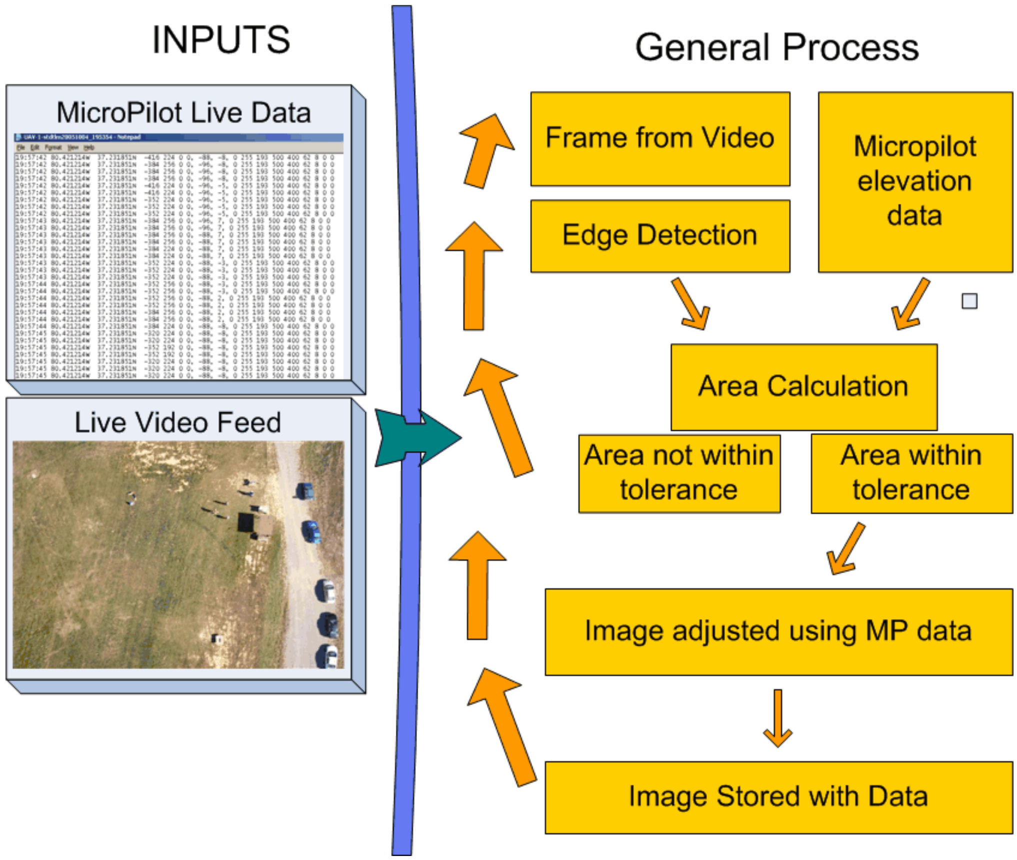

Figure 8. Image Processing in LabVIEW

Mission Strategy

In order to achieve the optimum competition run, a mission strategy requiring four people will be employed so that chaos and stress will be minimized during each flight. The strategy begins in the preflight phase of the missions, and continues through the flight and the final delivery of materials. Each person involved is given specific tasks so that when the timer begins, no necessary tasks are unknowingly skipped or repeated.

Preflight Procedures. Prior to the mission, batteries are hooked to the components and the wooden support frame is placed securely in the black box. Once closed, the team will place the black box inside the body of the aircraft and secure the wings to the plane. The black box has been wired so that the plugs are routed out of the box to allow for quick hook-up, and switches are easily accessible from outside the plane body to apply power. This setup will allow the team to power up the various components and connect the antennas and servo lines as quickly as possible without having to drain the batteries while waiting between missions.

While the plane is being powered and connected, the computer will be started and begin running both LabView and MicroPilot's Horizon. At this point, a range check will be performed, the gyros will stabilize, and the GPS will connect to its satellites. The range check is preformed in order to ensure proper radio communication, and is preformed by taking the radio controller, with antenna retracted, 50 yards from the plane. If proper control is maintained at that distance, then radio contact with the plane, with the radio antenna raised, should be maintained throughout the flight.

Taking Off. Once the MicroPilot has initialized and the vision system is running, the plane's engine is started. When cranking the engine, each of the four flight team members has specific tasks; the first is responsible for physically starting the engine using a powered starter, the second for holding the plane steady while it is being started, the third for managing the radio transmitter to control the throttle, and the fourth for controlling and monitoring the MicroPilot. Once the engine is running, the plane is moved to the runway for takeoff. At this point, autonomous mode is engaged and the plane begins its preset takeoff flight program.

In-flight Mission and Data Collection. Before embarking on its pre-established search mission, the MicroPilot and plane are to be controlled according to the judges' requests. This includes demonstrating dynamic control, such as changing altitude and airspeed, and waypoint navigation through a series of GPS locations. When the plane proceeds to the search area, vision data will be recorded and analyzed as previously discussed in the vision section. The team's software will constantly store the targets it has located, as well as the corresponding GPS coordinates of those targets. Thus, even while in the air, or while the plane is landing, the results from the mission can be documented and prepared. During the reconnaissance portion of the mission the plane will follow a strategic search pattern, which is discussed below.

Landing and Data Submission. The end of the searching mission will direct the plane to land on the designated runway. By accessing the stored files containing the photos and MicroPilot log, the team will prepare the required list for the judges containing all the necessary data about the targets. This list will include the total number of targets, the GPS location of each target, and the orientation of each target. At this point, high-resolution digital photographs can also be retrieved from the digital still camera installed within the plane. These pictures can be used to compliment those taken from the analog camera if the analog pictures are inadequate or lost. While team members one and two retrieve the plane and the digital camera within, team members three and four can create the spreadsheet for the final judging using the analog camera pictures and MicroPilot data.

Search Patterns. The total mission time for competition is forty minutes, which includes preflight, takeoff, searching, landing, and processing. As a result, the search pattern that is used when locating targets must be highly efficient, so the maximum ground area can be covered in the least amount of time. Several search patterns have been investigated to determine the most practical pattern. Figure 10 shows several patterns that are commonly used in search-and-rescue missions for missing persons as recommended by the United States Coast Guard.

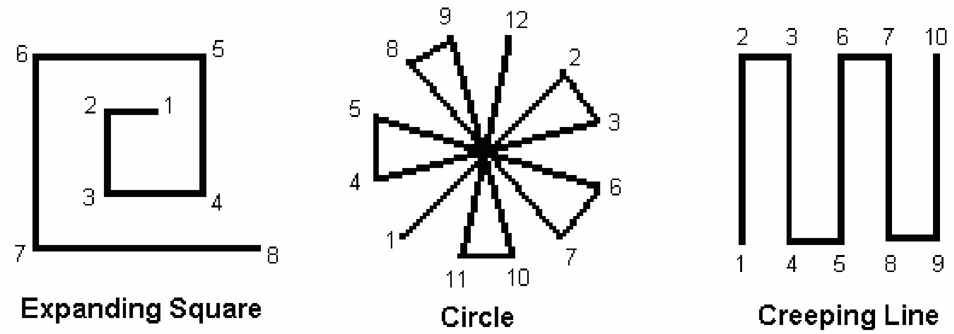

Figure 9. Traditional search-and-rescue mission flight patterns used for missing persons searches. [Coast Guard Boat Crew Seamanship Manual. 27 Feb 1998]

Each pattern has its advantages under various circumstances, and the advantages and disadvantages of each pattern were examined in order to select the most appropriate pattern. For example, the expanding square search is used when the last known position of the search object has a high degree of accuracy, the search area is small, and a concentrated search is desirable. However, each area is only passed over once, so objects undetected in the first past are never passed over again. The circle search is also used when the last known position has a high degree of accuracy, but the search object is difficult to detect. Thus, the search unit passes through the center several times, each time increasing the chances of finding the search object.

One aspect of the team's mission that differs from that of the Coast Guard is that the team will have no idea where the targets are mostly like to be located. The targets will be distributed at random, and even the total number of targets will not be known to the team. Thus, the search cannot be focused on any particular section of the search area, but must be distributed over the entire area. The creeping line pattern, also called the parallel track pattern, is especially useful when the search object could be anywhere in the search area because it provides uniform coverage of the area.

In addition, the parallel tracks are the simplest flight patterns to use in MicroPilot. Through the bulk of the area, the plane will maintain level, straight flight, with turns occurring only at the edges of the area. Keeping a level flight path will be a great advantage for the video and still photo collection because there will be less distortion of the photographs due to angled shots of the ground. Furthermore, straight, parallel paths ensure that the orientation of the targets will be easily assessed. Overall, the creeping line pattern allows the team to maintain a simple flight path that will ease the collection and identification of ground targets.

Safety

While the team hopes to successfully complete the given mission objectives, a high level of safety is required to be even partially successful. Safety precautions must be executed during the operation of an RC aerial vehicle and even more so if the vehicle is to fly in autonomous modes. There are various factors that can cause a malfunction of the vehicle during operation. Some of these factors include low power levels, radio interference, gyro malfunctions, and erroneous sensor data. While through our design and testing we hope to have reduced the risk of these malfunctions, it is impossible to eliminate that risk entirely. Because of the possibility of system failure, many safety precautions have been designed and built into the vehicle to protect our team and spectators. These precautions include:

- The ability to switch from autonomous to manual flight at any time. The safety pilot can use the transmitter to switch from CIC (Computer in Control) to PIC (Pilot in Control) at anytime necessary. Doing so would end our run in the competition but safety is more important than winning.
- An automatic fail-safe spin maneuver, required by the competition rules, which is triggered in the event that transmission is lost or the safety pilot selects the fail-safe. When the fail-safe is triggered, the ailerons are deflected to roll the plane to starboard, the elevator pulls the nose up, and the throttle is closed to stop the engine. The net effect is a terminal spin that will quickly bring the plane to the ground, ensuring that it will not travel far from the competition area out of human control.
- Constant monitoring of battery levels by the MicroPilot. If battery levels are low, the safety pilot can take over and land immediately.
- An emergency-stop servo operated on a separate frequency that will disconnect the fuel line from the engine. More efficient fuel cutting valves are currently being tested to replace the servo as the emergency-stop.
- A strobe light and audible pulse emitter being tested for use as indicators of autonomous modes. These would ensure that spectators are aware that a computer, and not a human, is piloting the vehicle. The strobe and audible pulse emitter can also be used as beacons in the event of a crash to aid the team in finding the vehicle.

Safety is a major element of the design process for this vehicle. The safety features are tested just like any other component that is used to achieve the mission goal. The integration of these safety features help to minimize the risk of operating an autonomous aerial vehicle and also contribute to a successful design.

Conclusion

The AAVT has improved upon the design from last year to produce Pandora, a fixed-wing autonomous aerial platform capable of performing reconnaissance of ground targets. From the outlined criteria presented in this paper, the AAVT is confident that Pandora will be capable of successfully completing the mission specified by the Student UAV Competition rules.

Unmanned Aerial Vehicles have a wide range of potential uses, in both the military and civilian sectors. While our design team has been primarily focused on producing a vehicle that will perform well at competition, we have noticed considerable interest in UAV research from the Virginia Tech College of Agriculture. Much of the world's agricultural production is still harvested manually by laborers, picking produce by hand. The development of a fully mechanical harvesting system has been in existence for the last two decades. A major dilemma facing the mechanical harvesting of commercial produce is that an automated harvester must be able to accurately select the ripe fruit or vegetables without disturbing the rest of the population. Engineers have developed and launched satellites capable of detecting crop type, crop height, and other crop characteristics. These satellites use radiation to determine image divergence in vegetation patches. These images can help detect crop maturity and aid in tabulating a date to optimize harvest. However, these satellites cost millions of dollars, and the resolution of the images is poor. The relatively low resolution is due to radiation scattering as the waves enter the

Earth's atmosphere. Therefore the reliability of the images gathered from the satellites is weather dependent. An unmanned aerial vehicle could provide visual data of crops at a significantly higher resolution and a much lower cost.

Another potential use of UAVs is the detection of early signs of crop infestation. The quicker that damaged crops are identified, the quicker the problem can be contained, resulting in a higher yielding harvest.

UAVs are also being developed at Virginia Tech for the study of airborne pathogens. Professors of the toxicology department are interested in using UAVs to collect airborne microbes at various altitudes in the atmosphere to study the transport of airborne disease. Similar experiments have been conducted using RC planes, like Pandora, with one major difference. The planes used in these studies were operated under manual control. Our team believes that an autonomous platform would be capable of more accurately collecting samples at specific altitudes and locations.

The field of UAV research is very exciting and the members of the AAVT at Virginia Tech are proud to participate in this project. Pandora should prove to be a valuable contribution to the industry and good step forward for the team.

Appendix A: Vehicle Weight by Components

COMPONENT	WEIGHT (lb.)	TOTAL (lb)
Plane w/engine and tail drag gear	5.420	11.09
Wings	2.187	
Fuel	0.639	
Camera Servo	0.095	
Wing Servo Harness	0.033	
Wing Nuts	0.007	
Servo Battery	0.300	
Receiver	0.093	
MP antenna	0.042	
tail dragger gear	0.648	
MP Battery Harness	0.009	
MP Battery	0.269	
estop battery	0.300	
estop receiver	0.093	
BlackWidow Data Transmitter	0.115	
BlackWidow Camera	0.064	
Black Box (Empty)	0.825	
Wooden Skeleton w/components	0.875	

Appendix B: Electrical Power Usage

	Component	Current Draw (mA)	Operating Voltage (Volts)	Outboard Switching	Battery Type
Battery 1					FMA/Kokam Lipo 11.1 volt 1500mAh
	MicroPilot	200	11.1	Switch 1, RS-232	
	Transmitting	240	11.1	Switch 2	
	Video Transmission	450	11.1	Switch 2	
	RC Rx	16	4.8	Through MicroPilot	
	AGL			Through MicroPilot	
	Compass			Through MicroPilot	
	ADC			Through MicroPilot	
Battery 2					Hydrimax NiMH 4.8 volt 2000mAh
	Blackwidow camera	120	4.8	Switch 3	
	E_Stop Rx	16	4.8	Switch 4	
	Fuel Sensor	15	4.8	Switch 4	
Battery 3					Hydrixax NiMH 4.8 volt 2000mAh
	Servos (6)	400	4.8	Switch 5	
Other					
	Lights, beacon, etc				
	Digital Camera				