Team BYU
AUVSI 2007 Student UAS Competition
Journal Paper

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ABSTRACT

Team BYU consists of students who participated in a university sponsored UAS competition during BYU's 2007 Winter semester. Members of Team BYU were selected from each of the different teams to bring together the best ideas to create this year's entry. BYU's entry into the 2007 Student UAS Competition uses innovative technologies and inexpensive components. The airframe is a lightweight foam flying wing similar to a standard electric flying wing RC kit. The aircraft is equipped with a Kestrel Autopilot from Procerus Technologies, a UBlox GPS, two video transmitters, and two cameras (one with a wide angle lens, the other with a narrow angle lens which is mounted on a gimbal). Onboard the aircraft is a safety switch wired into an RC receiver which allows the safety pilot to override the autopilot and take control of the aircraft at any time. Because the aircraft weighs a mere 3 lbs 14 ounces (1.8 kg), it is able to withstand crashes that would have otherwise destroyed a balsawood plane. The five members of the team each have their own specific responsibility: navigation control, target spotting, target geolocation, target identification, and safety pilot. Custom software has been designed to allow individual team members to focus on these tasks while facilitating collaboration. BYU's lightweight and inexpensive UAS provides a practical solution for many applications in both military and civilian use.

1. INTRODUCTION

The AUVSI 2007 Student UAS Competition outlines critical objectives necessary for completion of the mission. The competition objectives are to fly autonomously as well as be able to view and identify targets. In addition to these needs, search areas must be able to be updated while in-flight and target identification must be made quickly and accurately.

Team BYU is made up of two mechanical engineers and three electrical engineers. All students participated in a senior project where four teams competed in building UASs from off-the-shelf components to perform geolocating missions. Though the goals of the senior project were slightly different then that of AUVSI, all members of the 2007 BYU AUVSI team, (most of whom came from different senior project teams), proved themselves as innovative. Team BYU's entry into this year's AUVSI competition is a culmination of that innovation.

As the use of UASs increases in both military and civilian applications, new and innovative ways of accomplishing tasks are being developed. This paper seeks to illustrate the rationale behind Team BYU's choices of system components and present the innovations that facilitate completing the mission objectives. These decisions are especially important as UASs are being entrusted with diverse responsibilities including military surveillance and reconnaissance, civilian search and rescue, and police force assistance; each UAS requires different system requirements.

Each component of the system was chosen to provide a safe, lightweight, and low cost solution. This paper will begin by describing the hardware and software and how it helps the system achieve its goals, followed by a discussion of how the goals are achieved. Finally, we will show results up to this point and provide thorough discussion of the safety of the system.

The goal of team BYU is to develop an inexpensive, robust UAS that can easily and accurately detect and identify a wide range of ground targets. This identification process is designed to be done in real-time providing up-to-date intelligence. With these goals in mind BYU students have developed a system that

1. Flies autonomously
2. Finds and geolocates targets through vision
3. Identifies and determines target orientation
4. Perform all tasks safely and in a controlled manner

2. SYSTEM OVERVIEW

2.1 COMMAND STRUCTURE

The vehicle system uses a compact and sturdy airframe which is designed to be fully autonomous and carry video and navigation systems. The vehicle transmits video and wireless radio through separate channels and is laid out to minimize interference between the signals. The autopilot has onboard gyros and accelerometers to provide estimates of all attitude angles and rates which allows for reliable navigation. Users at the ground station use vector path planning to define paths for waypoint navigation. The ground station relays important telemetry data to the operators and gives them all complete control over the autopilot configuration in order to successfully complete the mission. Video, telemetry, and navigational information are at the user's fingertips. To provide stability and safety, failsafes are in place in the event of low battery voltage, loss of communication, or loss of GPS.

2.2 AIRFRAME

The final airframe design is based upon a custom flying wing configuration which BYU has designed and built to hold avionics and video equipment. The airframe is made from expanded polypropylene (EPP) foam which was cut using a CNC foam cutter at BYU facilities. The EPP foam was chosen over other constructions, (i.e. balsa kits, custom composite designs, etc.), due to its ability to withstand severe impacts with minimal damage and because our anticipated payload was such that we did not require a wide wing span. The EPP foam is reinforced with carbon fiber spars for structural support and a layer of fiber tape for rigidity. The airframe and all RC components weigh 2 lbs 14 ounces while the video components and hardware required for autonomous flight add 12 ounces of additional payload. The aircraft has a wingspan of 54 inches, consisting of 24 inch wings and a 6 inch center pod that holds electrical and autonomous components. Two servos are located at about quarter wing and two video transmitters at opposite wingtips.

The airframe has many distinct advantages over it's larger and heavier counterparts. First and foremost is its compact and lightweight design. These two properties can only increase the potential uses of a heavier-than-air vehicle. The choice to use impact resistant EPP foam has thoroughly proven its worth as it not only absorbs impact in the event of catastrophic failure but also provides several inches of protective cushion for the sensitive electrical and optical equipment onboard the airplane. Even in the event of catastrophic failures which have resulted in the plane dropping from the sky, the airframe has proven that it will protect the vital hardware components of the system. This has allowed for more time to be spent testing, debugging, and adding features and less time in the lab rebuilding. Rebuilding with foam is made easy as foam provides a large mating surface with which an airframe can be glued back together with basic epoxy or foam glue. Another vital feature of this aircraft is that it is hand-launchable and does not require any special equipment to get airborne, nor does it require runways for either takeoff or landing. It can be launched away from runways and only requires a relatively soft piece of ground on which to land.

2.3 ONBOARD HARDWARE

For safety reasons the airplane was set up so that it can be controlled autonomously via computer software and autopilot, or manually via Radio Control (RC). This means that all the hardware required for safe radio controlled flight are required on top of the hardware already needed for the aircraft to fly autonomously. A picture of the electrical components in the center pod of the plane can be seen in figure 1.

The plane uses two lithium polymer batteries as its power source which are rated to provide 12.6 volts of DC power at a rate of 2000 milliamp hours each. These have proven to provide a continuous flight time of about 30 minutes. For radio control the airplane is equipped with a dual conversion, narrow band, RC receiver. The receiver antenna is buried in the left wing and runs from the center pod and out the end of the wing.

When the aircraft has several electrical components running at full power, the range of the RC receiver is considerably decreased. The electronic speed control (ESC) sees severe fluctuations in amperage which may cause it to deprive the RC receiver of sufficient power. In order to solve this problem a 5 volt regulator was connected directly from the batteries to the receiver instead of being powered by the ESC.

Figure 1 – Top View of Hardware

The aircraft is propelled by a 1500 Kv brushless motor made by MEGA Motors, which spins a 7" Graupner propeller with 4 degrees of pitch. This motor/prop combo was chosen because its efficiency reduces power consumption and increases flight time. This combination provides sufficient power to avoid unexpected flight situations such as wingtip stalls, power on stalls, spins, etc. The motor is powered by a 35 Amp ECS made by Castle Creations which is equipped with programmable failsafes for situations such as low battery voltage, too many amps being drawn, prop strike, etc. A diagram of the aircraft hardware can be seen in figure 2.

Because the airplane is a flying wing its only control surfaces are elevons. These control surfaces control pitch and roll; the plane is not equipped with yaw control. The two servos controlling the elevons and the motor signal connection plug into a safety switch onboard the plane that is used to transfer control between the autopilot and the safety pilot. This safety switch is also connected to the signal leads of the receiver and the command ports of the autopilot in order to be able to relay signals to the servos and ESC. A diagram of the safety switch is shown in the appendix. A toggle switch on the safety pilot's RC transmitter communicates with the safety switch. At any point during a flight the safety pilot can easily take control of the aircraft or give control to the autopilot.

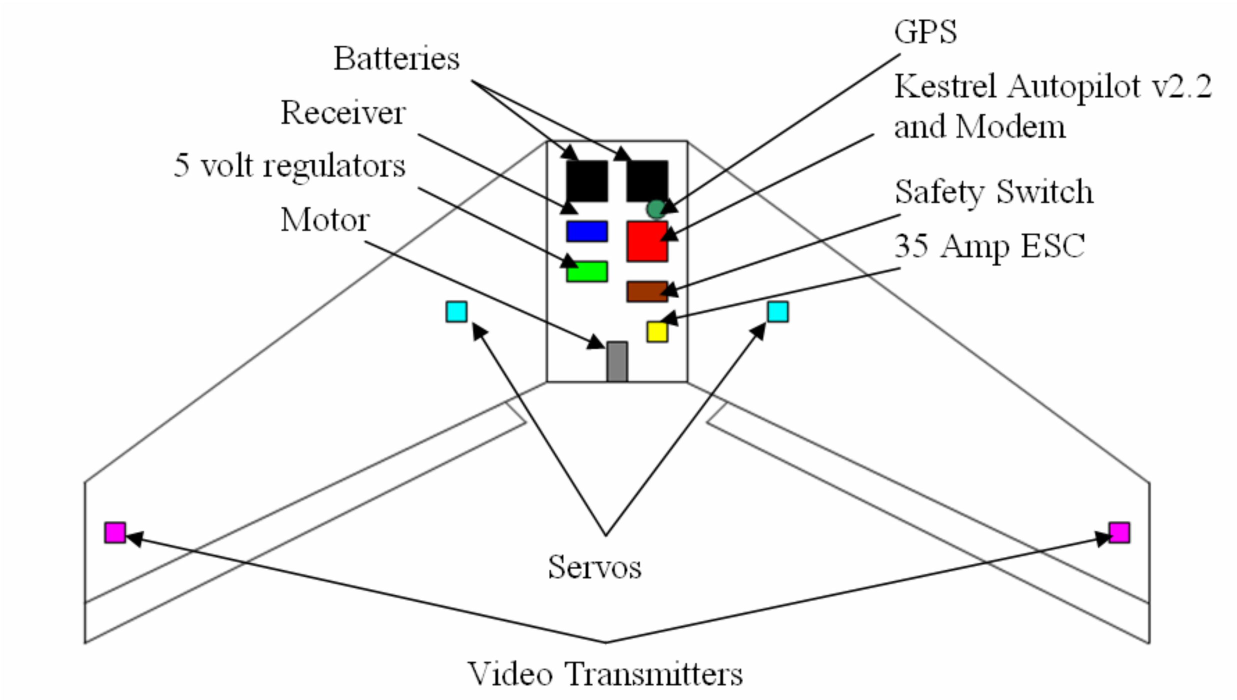


Figure 2 – Airframe Layout

In addition to the 5 volt regulator that powers the RC receiver, there is a second 5 volt regulator powered directly from the batteries that provides electrical power to the two onboard cameras and their respective video transmitters. The first camera is forward looking pointed down at a 60 degree angle from the horizon. The second camera is mounted on a 2-axis gimbal which can control both the azimuth and elevation of the camera. Video from these two cameras is taken and transmitted to the ground via video transmitters. The two 500 milliwatt video transmitters are mounted at opposite wingtips in order to minimize the interference that could occur amongst the transmitters or with other electrical components. A tabular listing of the aircraft components can be found in the appendix.

2.3.1 KESTREL AUTOPILOT ™

AUTOPILOT HARDWARE

The aircraft is equipped with the 2.2 version of the Kestrel Autopilot manufactured by Procerus Technologies, which weighs just 16.65 grams and measures 2 x 1.37 x 0.47 inches (5.1 x 3.5 x 1.2 cm). The Procerus Kestrel Autopilot, as seen in figure 3, is small, light, and robust. The Kestrel Autopilot contains a central processing unit, avionics sensors, and input/output ports. The autopilot system uses a Rabbit Semiconductor RCM 3400 microprocessor which can be programmed using Dynamic C (a variant of ANSI C programming with special operators that take advantage of the Rabbit microprocessor's abilities).

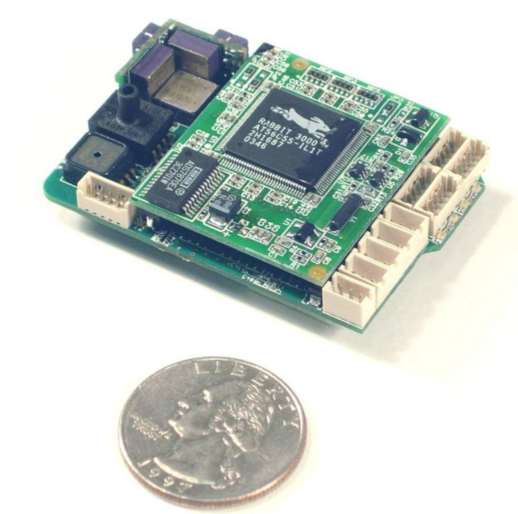


Figure 3 – Kestrel Autopilot™ v2.2

The Kestrel motherboard houses the Rabbit RCM 3400 microprocessor which monitors all of the sensors and communication with the ground station. The RCM 3400 runs at 29 Mhz and has 175 kilobytes of memory. Onboard the autopilot there is a barometric sensor calibrated to the takeoff altitude which monitors the UAS's height relative to home. The autopilot also uses a differential pressure sensor in conjunction with the barometric sensor to calculate airspeed.

The autopilot houses a six degree-of-freedom (6-DOF) inertial navigation unit with 3-axis solid-state rate gyros that calculate roll, pitch ,and yaw rates and direction of flight accelerometers that provide information about the roll, pitch, and yaw angles. The rate gyros double as temperature measuring sensors, and all accelerometers and gyros use temperature-compensation to account for nonlinearities in measurements. The GPS unit connects via one of four available serial ports. An analog input port is also available for sensor reading.

Because the autopilot has been developed into a commercial product, it is user-friendly and can reliably maintain autonomy. Because of its small size and the fact that its sensors are self-contained, it was easily integrated into the UAS. Due to BYU's proximity to Procerus Technologies and the working relation BYU has with Procerus Technologies, there is easy access to experienced individuals for troubleshooting and support.

Method of Autonomy

The autopilot uses proportional-integral-derivative (PID) control with successive loop closure to ensure stable flight. The operator has the ability to control the type of PID loop selection from the ground station and can alter PID gain values in order to suit the airframe and flying conditions. Typically, the airplane is flown under full autonomy, meaning that pitch, pitch rate, roll, roll rate, and altitude are all controlled onboard the autopilot. The autopilot flies paths based on user input from the ground station and uses GPS as its primary navigation method. Knowing its current location and where it needs to go, it can either choose the shortest distance to the waypoint or it can join a path between waypoints. Its behavior in joining the path is based upon its distance from the path. As it approaches the path, its trajectory becomes more parallel to it, thus easing the transition onto the path.

2.3.2 GPS

The UAS uses a UBlox GPS unit which gives updates at 4 Hz and is accurate to within 5 m. The autopilot and its accompanying software requires a minimum of 4 satellite uplinks in order to safely fly without activating predetermined failsafes.

2.3.3 Video

The UAS uses two color CCD cameras which capture 30 frames per second of 640x480 interlaced color video. Clear video is vital for the success of any mission requiring target imaging. Due to continual motion of the UAS, interlacing causes degradation of the video. The ground station software de-interlaces the video stream by taking one field of the interlaced video and interpolating to generate the second field.

Figure 4 – Forward Looking and Gimbaled Cameras

To send and receive the video streams, Team BYU uses two 500 mW transmitters which transmit at 2.4 GHz. The forward looking camera has a 60 degree field of view (FOV) lens, while the gimbaled camera has a narrower 17 degree FOV lens. The 17 degree FOV camera is installed in a custom built gimbal which can travel 135 degrees in azimuth and 100 degrees in elevation. These can be seen in figure 4. As targets are identified using the forward looking wide angle lens camera, the user clicks on the target on the computer screen and the gimbaled narrow angle lens camera autonomously reorients itself so that it is pointing to the location on the ground that the user identified as a target By using one wide angle lens and one narrow angle lens, broad search patterns can be conducted quickly while maintaining the ability to examine targets more closely without introducing the complication of zoom. This set up allows for identification and localization of potential targets to be done in a rapid and efficient manner.

2.3.4 Data Link

As weight and size are common constraints on a UAS, Team BYU decided to use the 900 Mhz XTend RF MaxStream modem to pass telemetry to and receive commands from the ground station. The 900 Mhz XTend RF MaxStream modem is capable of continuous transmission for up to 25 miles. Its power output is customizable for power consumption or interference compliance. The modem is connected directly to the autopilot via a daughter board. The ground station communicates with the plane via a ground based communication box which also uses a MaxStream Xtend modem to communicate with the plane. The comm box passes the UAS waypoint information and receives information about the orientation and behavior of the UAS. The communication box connects to the computer through an RS-232 Serial Port.

2.4 Ground Station

2.4.1 Video

The video at the ground station consists of 2 video receivers each equipped with an omni-directional antenna. The incoming video signals are routed through dual frame grabbers into one computer where it is integrated with telemetry and processed using the OpenCV vision library. By using omni-directional antennas, the video signals maintain their fidelity without requiring an extra team member to keep the antennae properly oriented.

2.4.2 Computer Setup

The ground hardware consists of 4 laptop computers linked together via Ethernet. The computers will share information including telemetry data and video footage. One computer will be dedicated to maintaining the UAS's flight pattern. It will be tasked with observing the UAS in relation to the no-fly zones and updating waypoints when needed. Another computer will parse the telemetry from the first computer and link it to its respective video frame that was captured while in flight. The operator of this computer will also flag possible targets for examination by the other two team members. The two remaining computers will be tasked to geolocate the targets and examine the pictures taken with the narrow FOV camera for target identification purposes.

2.4.3 Virtual Cockpit

The Virtual Cockpit (VC) software package from Procerus interfaces directly with and gives direct control over the Kestrel Autopilot. It includes a number of features which give the operator the ability to perform all tasks necessary to maintaining a UAS in flight. Figure 5 shows a Map Screen for inputting flight paths and observing relative flight behavior, a Gain Tuning Screen for initial and subsequent tuning of the autopilot PID loops, and several other features which give the ability to manage autopilot and sensor behavior as well as collecting flight data. Virtual Cockpit is a tested, commercial product that has been integrated into the BYU system to safely interface with the autopilot and monitor aircraft behavior.

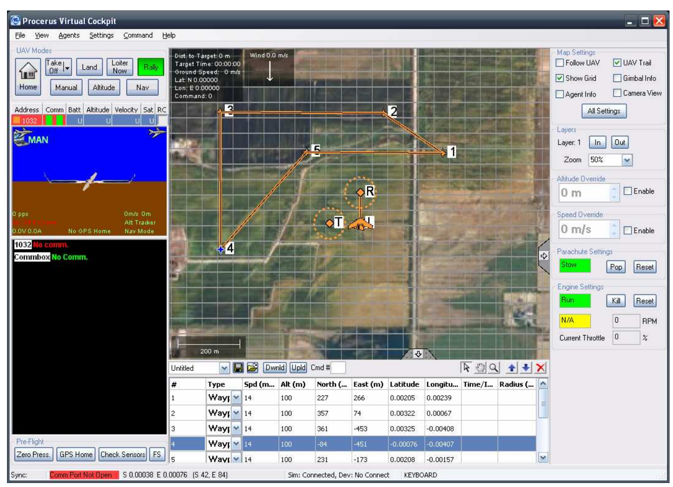


Figure 5 – Virtual Cockpit

2.4.4 Custom Apps

A custom application written by BYU Team members interfaces directly with Virtual Cockpit and stores video frames and their corresponding telemetry packets to a location accessible on the network. This application also updates an image of a map with the location of the plane in relation to the no fly zones with every telemetry packet so that each member of the team can be aware of the orientation and location of the plane. This image is automatically updated and redisplayed to each team member once per second. This enables each team member be responsible for the safety of the plane without diverting them from their assigned tasks. The geolocation and identification software accesses the video and telemetry data from the network to achieve their assignments.

3. Team Roles

Our team consists of 5 individuals each with specific responsibilities. These individuals' responsibilities are as follows:

1. Autonomous Control/Safety Pilot
2. Navigation
3. Preliminary Identification
4. Target Geolocation
5. Target Identification

The flow of data through the system is illustrated in figure 6. The description of individual tasks in the system follows.

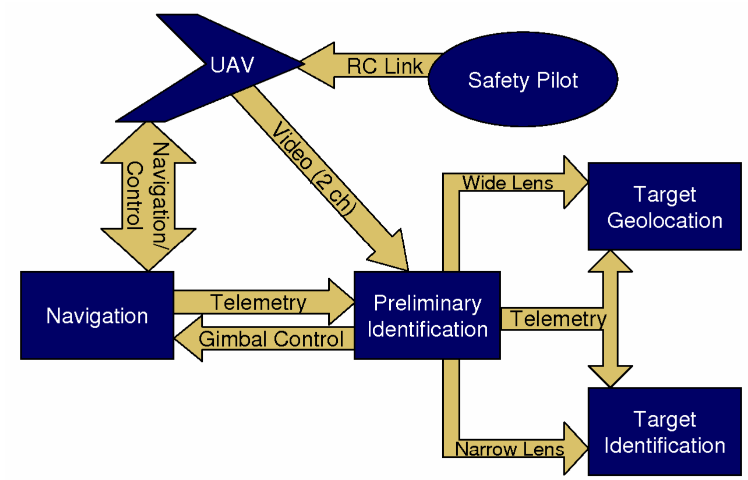


Figure 6 – Data Flow

3.1 Autonomy Control/Safety Pilot

The autopilot controls the plane and is interfaced in two ways, pilot-in-control (PIC) and computer-in-control (CIC). PIC means that the pilot has control of the plane and CIC means that the autopilot has control of stability and navigation. The safety pilot always has the capability of override the autopilot if anomalous behavior should occur or if manual landing is required. Virtual Cockpit is equipped with both 'Take Off Mode' and 'Landing Mode' so the safety pilot is not required to fly the airplane up to altitude before switching controls over to the autopilot, nor is he/she required to manually land the airplane in a normal flight without complication.

3.2 Navigation

As mentioned previously, the autopilot uses a series of PID loops to control its heading, roll and pitch. The operator uses Virtual Cockpit to give the UAS a series of GPS waypoints by which to fly. The team member responsible for navigation uses Virtual Cockpit to plan paths and monitor mission status. Because of the reliability of the system, the navigation operator can mainly focus on directing the UAS in specific search patterns and not be overly concerned with its detailed behavior. This leads to better control of a search mission and a higher likelihood of target detection and identification.

3.3 Preliminary Identification

While the plane is in flight, the individual in charge of preliminary identification views the video feed from the wide angle camera. This camera is facing slightly forward to give the operator a view of terrain the UAS is about to pass over. When the operator sees a potential target, he/she clicks in the video feed which will orient the gimbaled camera so that the potential target is in the narrow FOV. Using software, the frame is flagged and the target is tracked in the frame by one of two methods. One method is by using a series of optical flow and template matching so that the gimbal follows the target for as long as it is in the FOV of the wide angle lens camera. The other method is to track the target using a GPS coordinate and have the onboard autopilot calculate the continuously changing orientation for the gimbaled camera. Telemetry data is also recorded and linked with the corresponding video frame for geolocation. The data recorded is then processed by other members of the team. This allows for one individual to focus entirely on watching for new targets. The use of two cameras provides the advantages of being able to see a large area in front of the UAS while still being able to get clear close up shots from which the target can be easily identified.

3.4 Target Geolocation

The geolocation method is a straightforward ray-plane implementation for geolocation. The orientation of the aircraft is rotated using a series of matrices to be in a "world" frame. A ray is computed based upon the azimuth and elevation of the camera. The location where the ray intersects the ground plane is the geolocated point. The preliminary identifier will flag possible targets as the aircraft flies its search pattern. A second operator will search through the flagged images and calculate the geolocation of the suspected targets. The geolocater then establishes a listing of targets for identification and passes it on to the identifier.

3.5 Target Identification

The method of target identification used by Team BYU is a manual process with computer aided enhancements. Previously, no extra enhancements were used and identification was simply based on the captured video frames. However, because of unsatisfactory results, new identification tools have been implemented. Two enhancements in use are color and edge enhancement. To demonstrate, an image is shown in figure 7. The color enhancement helps to clearly identify the target background and lettering color by 'washing out' the colors most prominent in the video feed and leaving new or rarely seen colors bright. This principle can be seen in figure 8. The edge enhancement gives the ability to see shapes clearly and identifiably. This is done by identifying edges using a canny edge detector, isolating detected edges and displaying them (as shown in figure 9). By using computer aided enhancements, the ability to accurately identify targets increases and false identifications decrease. The source of the images used by the target identifier is the narrow FOV camera which provides the best view of the target for the identification process.

Figure 7 – Original Image

Figure 8 – Color Enhancement

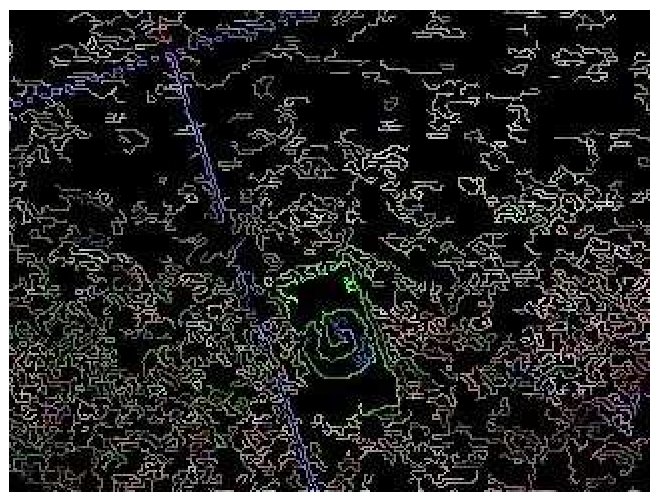


Figure 9 – Line Detection

4. Flight Results

Simulation results, though helpful in developing software, did not reflect actual system ability. Consequently, a series of practice runs were performed in an effort to simulate the situations found in the competition. Targets unknown to the search team whose sizes ranged from 2 to 8 feet were randomly placed within a given search area. These targets were also of unknown color and shape. Team BYU's current results are found in table 1.

Table 1 – Flight Results

	Possible	Result
Targets found	7	7
Targets identified	7	2
Average geolocation distance	0 m	12.12 m

The results thus far are promising and have provided valuable information for developing new tools to help achieve competition objectives. Though all the targets were found, they were not all clearly identified with color, shape and letter. Several of the targets were spotted from a far off distance and no easy way existed for transferring the geolocation information into a new search pattern which would help more clearly identify the targets. Also, because Team BYU was unable to get consistently clear pictures of the targets, our geolocation data suffered. These results were obtained on a day when wind gusts exceeded 10 m/s. With experience and new tools, identification of the targets should increase dramatically.

5. SAFETY

Safety is a principal concern of any flight. The onboard autopilot software has preprogrammed failsafes that immediately take effect under potentially hazardous conditions. In preparation of possible incidents requiring safety pilot intervention, a safety switch was designed to allow the safety pilot to remotely override autopilot control and pilot the plane through RC. The safety switch consists of a PIC microcontroller and a signal multiplexer (MUX). The PIC receives and processes a signal from the RC transmitter which it then uses to control the control input source through a MUX. A diagram of the safety switch can be found in the appendix.

There are many circumstances which could inhibit the safety of a flight. The circumstances can be classified as either flight recoverable or flight unrecoverable. Flight recoverable (see table 2) implies that the stage 1 response to the failsafe condition could lead to the problem being fixed while in flight in which case the flight would continue. Flight unrecoverable (see table 3) implies that the flight must be discontinued and the plane must land in order to fix the failsafe condition. Flight unrecoverable implies only that the flight is unrecoverable, not the mission. Several situations, such as low battery, allow the flight to resume shortly after landing. Stage 2 response is only necessary if the failsafe condition still exists after the stage 1 response has been activated.

Table 2 – Flight Recoverable Failsafe Conditions

Failsafe Condition	Stage 1 Response	Stage 2 Response
Loss of Communication with ground	Fly Home, wait to reestablish communication	After 3 minutes, Land Now
No GPS	20 degree fixed roll at current location, wait to reestablish	After 1 minute, Land Now
Low Airspeed	Audible Warning Plane decreases pitch to gain airspeed	Safety Pilot takes over
Abnormal Navigation	Verify flight path	Safety Pilot takes over
Minimum Height Above Ground	Audible Warning Climb from X alt to Y alt	Safety Pilot takes over
Airplane Stalls	Autopilot attempts to regain control	Safety Pilot takes over

Table 3 – Flight Unrecoverable Failsafe Conditions

Failsafe Condition	Stage 1 Response	Stage 2 Response
Erratic flight behavior • gyro, accelerometer failure • servo failure • loss of control surface	Safety Pilot takes over	
Loss of thrust • loss of motor • loss of speed control • loss of prop	Send Land Now command from ground station	Safety Pilot takes over
Safety pilot loses control of aircraft	Result: Crash Landing	
Low battery voltage	Audible Warning	After 1 minute sustained low battery, Fly Home
Critical low battery voltage	Land Now	
Complete loss of battery power	Result: Crash Landing	
Airframe failure	Result: Crash Landing	
Loss of airspeed sensor • malfunction • plugged	Safety pilot takes over	

In order to ensure a safe flight every flight, a preflight checklist is followed prior to every launch. This checklist is based on industry recommendations and team experience and can be found in the appendix.

6. CONCLUSION

The AUVSI 2007 UAS Student Competition presents the opportunity for students to learn and enhance their skills. Brigham Young University has developed tools in areas necessary to succeed at completing the objectives outlined for this competition. Team BYU's system allows for complete autonomy, with user input given through a map interface allowing for quick waypoint manipulation and accurate placement. The live video information with associated telemetry is collected, flagged, and disseminated for quick identification and geolocation of targets. By focusing on simple yet innovative design features and overall system safety, Team BYU's entry distinguishes itself as a viable candidate to complete all previously outlined mission requirements in an effective and cost efficient manner.

Appendix

Preflight Checklist

Things to Bring List

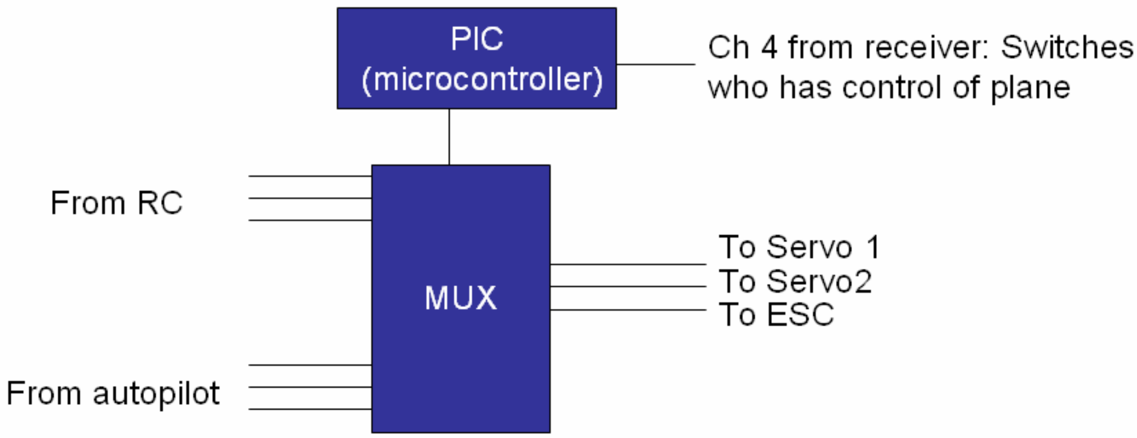
- ☐ Airplane
- ☐ Laptop (charged)
- ☐ 2 Batteries (charged)
- ☐ DC/AC inverter
- ☐ Table and Chairs
- ☐ Toolbox
    - ☐ Comm box (charged)
    - ☐ Comm box antenna
    - ☐ 2 Video Receiver
    - ☐ 2 Video Receiver Cable (Frame Grabber)
    - ☐ 2 Video Receiver Power Cable
    - ☐ RC Transmitter (charged)
    - ☐ Tape

Preflight Check

- ☐ Computer On
- ☐ Airplane On
- ☐ RC Trimmed
- ☐ Up is Up and Down is Down (RC)
- ☐ Virtual Cockpit Opened
- ☐ Communication Established
- ☐ GPS Verified (Do we have satellites?)
- ☐ Video Software Opened
- ☐ Video Verified
- ☐ Video in Focus
- ☐ Waypoints Uploaded
- ☐ Pressure Zeroed
- ☐ Autopilot Trimmed
- ☐ Up is Up and Down is Down (Autopilot)

--Ready For Launch!!

Safety Switch



COMPONENT OVERVIEW

System Components	Specification	Function
Airframe		
- Span	54 inches	
- Material	EPP foam with carbon spars	Robust design
Communication		
- Transmitter and Receiver	900 Mhz XTend RF MaxStream modem	Relay information between ground station and autopilot
Autopilot	Kestrel Autopilot v2.2	Control the UAS's yaw, pitch, and roll to traverse a waypoint path
Video		
- Cameras	2 - 480 line resolution CCD cameras	Capture high quality video
- Transmitters	2 - 2.4 GHz 500 mW	Transmit high quality video streams
- Receivers	2 - 2.4 GHz receivers	Receive high quality video
- Frame Grabber	2 - KWorld USB frame grabbers	Record high quality streams
Safety		
- Safety switch		Give the pilot the manual override ability

COMPONENT LAYOUT