DEPARTMENT OF THE AIR FORCE
COMMANDANT OF CADETS
US AIR FORCE ACADEMY

DEVELOPING AN UNMANNED AIRCRAFT SYSTEM FOR INTELLIGENCE, SURVEILLANCE AND RECONNAISSACE (ISR) MISSIONS

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Executive Summary

This paper describes the control, sensing, and communication capabilities of an unmanned aircraft system developed at the U.S. Air Force Academy during the 2009/2010 academic year. Particular emphasis is placed on finding targets autonomously and relaying the target information to operators through a user friendly graphical interface. The goal of the unmanned system is to fly autonomously over a mission area, find ground targets semi-autonomously, and report the locations of detected targets. The ground targets are made of plywood with a number of distinct polygonal shapes and two different sizes (4ft by 4ft and 8ft by 8ft). Each target is visually distinguishable by a color and an alphabetic character drawn on the target surface. The system contains two essential subsystems: the ground station and the aircraft. The ground station controls and monitors the aircraft during the mission. The ground station also includes a target recognition system, which is used to analyze telemetry data and images produced by a sensor module onboard the aircraft. The aircraft subsystem carries a control module, a communication module, a sensor module, and payload batteries to complete ISR missions, which last no more than 30 minutes each. We conducted multiple flight tests and successfully verified the capabilities of our system.

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1. Introduction

We have developed an unmanned aircraft system based on the requirements published by the AUVSI (See page 20 for a list of abbreviations) organization for the Annual Student Unmanned Air Systems (UAS) Competition. This paper describes the one semester long effort to design, develop, flight test, and analyze an unmanned aircraft system by cadets at the US Air Force Academy as part of the course work in System Engineering 460 (SE 460). The paper is organized as follows. In this section, we present the overall mission requirements and a brief description of how we developed our UAS to meet those requirements. In Section 2, the processes we used to select payload and aircraft are outlined followed by subsystem descriptions in Sections 3 and 4. Section 5 is allocated to show the safety precautions we use, and Section 6 shows the results and procedures associated with our lab and flight tests. Finally, Section 7 concludes the paper with a few summary remarks.

1.1 Mission Requirements

The AUVSI organization lays out specific competition rules which were used by our team to systematically develop the best fit unmanned aerial system based on system engineering concepts. The competition requires that the aircraft take off and follow a path to a designated search area. The search area contains a number of different targets. The team must be able to report information on these targets, such as the latitude, longitude, color, shape, orientation, and alphabetic designator. Our system also should be able to cover a pop up search area in order to find additional targets effectively. An additional constraint to be considered is designing an aircraft capable of autonomous flight, including takeoff and landing. Finally, having an autonomous target recognition system is desired for efficient, real-time reporting, which is essential for today’s military capability.

1.2 Mission Analysis

Each competition requirement must be analyzed by prioritizing desired functionalities against system capabilities. Appendix I shows the priorities that we have outlined from the mission requirements. Our team rated safety, communication, and autonomous flight as the top three priorities for the mission requirements. The other categories that have placed closely behind the first three are target recognition, cost, and weight. All of these are shown in the decision matrix in Appendix I.

1.3 System Overview

Our complete system has two subsystems, which contain modules, which will be discussed in further detail in Sections 3 and 4. The first main subsystem is the aircraft. We have two different types of airframes: the Kadet Senior and the Rascal. These are both marketed RC aircraft that we have revamped into our own systems. The airframe has a payload that consists of a camera, an autopilot, a laser altimeter, and a power system. The camera and the autopilot, with the laser altimeter being connected to the autopilot, transmit real-time information back down to the ground. The second subsystem, the ground station, is made of two main components, the autopilot interface and the target recognition system. The autopilot interface provides a user with the capability to control airspeed and elevation of a UAS. The target recognition system is designed to provide a user with target information. The target recognition system captures images, performs image processing algorithms, and sends resulting target information to an operator.

2. Subsystem Selection

In order to determine the best payload/ airframe selection, members of the SE 460-Unmanned Aerial Systems class reviewed the AUVSI competition rules and requirements. This group, which is made up of cadets with various backgrounds, used a combination of new research and 2009 competition results to determine the best system for the given mission. The main method, however, for selecting our airframe and payload was the use of systems engineering-based feasibility analyses.

2.1 Payload Selection

Our team developed two different payloads: Payload A and Payload B, seen in Table 1 and Appendix I. Based on the AUVSI competition guidelines and rules, our design team determined that the following requirement families should be analyzed for each option: Sensors, Communications, Power, Safety, Control, Weight, and Simplicity. Although each of these requirement families were determined to be very important, our team felt that the payload sensing, communications, and simplicity were the most important factors and these were weighted at 0.25, 0.2, and 0.25, respectively, out of combined weight of 1. In the sensing category, Payload A, was a clear winner due to its ability to support fully autonomous target recognition, output images in JPEG format, and take digital pictures which provide clearer images compared to the ones generated by the analog camera in Payload B. Next, in the communications category, Payload A was once again the winner. Despite the fact that Payload A uses an Ethernet signal which must be converted to a wireless signal, increasing time delay, Payload B—based on test flights—has an issue with consistently transmitting clean signals. Due to the trouble Payload B has with transmitting clean signals, the team decided that Payload A should be rated higher even with the small time delay. Last, but not least, is the simplicity category. With the belief that fewer interfaces between subsystems on our UAS are more reliable, our team decided that Payload B was the simpler system. This was determined because Payload B has no onboard computer which will eliminate data connections between its autopilot and onboard computer, camera and computer, and computer and wireless transmission unit. Additionally, Payload B will make the system analysis easier because there are fewer components to interface, ultimately making the system easier to use, maintain, and train operators in the long run. As seen in Table 1, Payload B was chosen as the better option.

2.2 Airframe Selection

The primary means of selecting our aircraft was based on the correct wing sizing. Wing sizing is determined by looking at the mass to wing area ratios of different components of the aircraft and then deriving the appropriate wing area. The derivation begins with realizing the total mass is the sum of masses of the aircraft sub-components. For simplicity and ease of measurement, the airframe and motor masses were combined as shown below.

Since we are not dealing with known values of wing area, it is more appropriate to look at the ratio of mass to areas. This is done by dividing all the masses by the wing area.

By performing some simple rearrangement of the equation, we can isolate the payload ratio, as shown below.

Now we can solve for the wing area from the payload mass-to-area ratio.

Property:		Field of View	Image size	Weight	Range	Number of Batteries	
Weight:		0.15	0.15	0.40	0.25	0.05	
Normalizing Rule:		#/Highest	#/Highest	Lowest/#	Highest/#	Lowest/#	
Candidate	Ratings						Totals
Payload A	Raw Score	"+/-70 pan +/-52 tilt"	640x480	2064.00	1 mile	3.00	**0.88**
	(Normalized)	(1.00)	(1.00)	(0.70)	(1.00)	(1.00)	
Payload B	Raw Score	"+/- 45 pan +/- 45 tilt"	640x480	1444.00	1 mile	3.00	**0.95**
	(Normalized)	(0.64)	(1.00)	(1.00)	(1.00)	(1.00)	

Table 1 Payload Evaluation Table

The mass of the payload can be easily measured and the mass-to-area ratios of the total airframe plus motor can be also found with a simple calculation of the weight divided by a reference wing area. The battery ratio is slightly more complicated and involves such factors as mission duration, charge density, and efficiencies.

Figure 1 Kadet-Senior Unmanned Aircraft System

By measuring the masses and areas of our components, we were able to find the values and ratios needed to solve the equation. The value used for the wing area was taken from an average of the three models, seen below in Table 2.

	Alpha 60	Rascal	Kadet Senior	Average
$m_{Aircraft/Motor}$ (kg)	2.880	4.706	2.795	-
$m_{Payload}$ (kg)	1.586	1.586	1.586	1.586
m_{Total} (kg)	6.852	8.678	6.023	-
S (m^2)	0.604	0.928	0.440	0.657
$m_{Aircraft/Motor}/S$ (kg/m^2)	4.768	5.071	6.352	5.397
m_{Total}/S (kg/m^2)	11.344	9.351	13.689	11.461

Table 2 Aircraft Performance

Based on our mission and available components, we were able to choose values to estimate our battery ratio, as shown in Table 3.

Mission Average Velocity	11.1 m/s
Mission Duration	40 min
Aircraft Lift-to-Drag Ratio	8
Battery Charge Density	163 W-hr/kg
Motor Efficiency	0.9
Propeller Efficiency	0.85

Table 3 Motor Selection Parameters

With all the values of the sizing equation known, we were able to determine the proper wing area for our aircraft, shown below.

Three airframes, shown in Table 2, were investigated for the aircraft selection. All have a wing area greater than that which would be ideal. We, therefore, chose the Kadet Senior, seen in Figure 1, because it had the smallest wing area, closest to the computed value. The Kadet Senior should prove to be an aircraft capable of meeting all the needs of our mission without unnecessary weight or size.

3. Airborne System

The airborne payload system is comprised of two main components, each with their own power system. The first main component is the autopilot, which is manufactured by CloudCap Technology, Inc. The second component is the camera used for the image processing system, which captures digital pictures.

3.1 Autopilot

The team chose to use the Cloud Cap Piccolo autopilot system for autonomous flight control. The Piccolo was an easy choice because it has been used in many of the US military’s operational UAVs and it has the capability to integrate with other software. The ability to integrate custom made software is important because the camera gimbal must interact with the autopilot to orient itself appropriately within the plane. The Piccolo system, shown in Figure 2, is broken down into three main parts, the on board autopilot, the Piccolo ground station, and the Piccolo Command Center software.

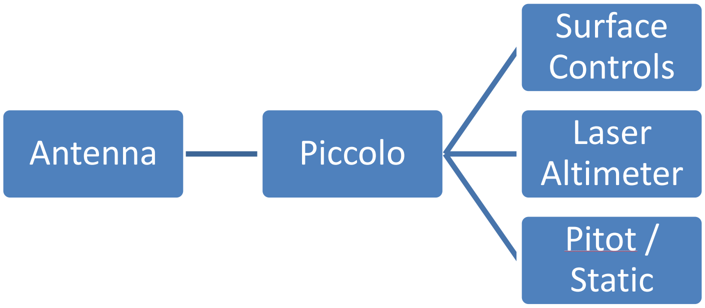

Figure 2 Piccolo Autopilot Diagram

Figure 3 Piccolo Onboard System (www.cloudcaptech.com)

A photo of the onboard Piccolo is shown in Figure 3. The onboard Piccolo has inputs for a pitot tube and static tube. These inputs are used by the autopilot to calculate the speed of the aircraft using differential pressures. The autopilot has a connection for a GPS antenna, which is used to determine the exact location of the aircraft at all times. Also, the Piccolo has internal accelerometers to determine the pitch, roll, and yaw angles of the aircraft. Finally, the onboard autopilot generates aircraft control surface signals that are routed via a wiring harness to provide servo inputs to control the aircraft. This allows the Piccolo to control all aspects of flight with little or no human interaction.

3.2 Camera Payload

Our system utilizes an Axis 212 PTZ Network Camera with a resolution range of 160 x 90 to 640 x 480 pixels that is capable of streaming up to 30 frames per second in either MPEG-4 format or Motion JPEG format. The camera is capable of zooming; however, our team desired a constant field of view and therefore the function is not utilized. The camera mount was constructed by USAFA Training Devices in conjunction with the Engineering Mechanics Department and is our in-house design. The camera, coupled with the Ubiquiti Ethernet-to-Wireless communication system transmits one 480 x 360 image per second to the target recognition system in the ground station.

4. Ground Station

The ground station consists of three main modules: the autopilot interface, the target recognition system, and the communication system. The autopilot is the interface that a user can control to fly the UAS, the target recognition system provides the user with target information, and the communication system links the ground station with the aircraft in order for information to be passed between the two.

4.1 Autopilot Interface

The Piccolo ground station, shown in Figure 4, is a graphical user interface that allows the user to control the aircraft. The program is capable of recognizing multiple Piccolo autopilots on different aircraft.

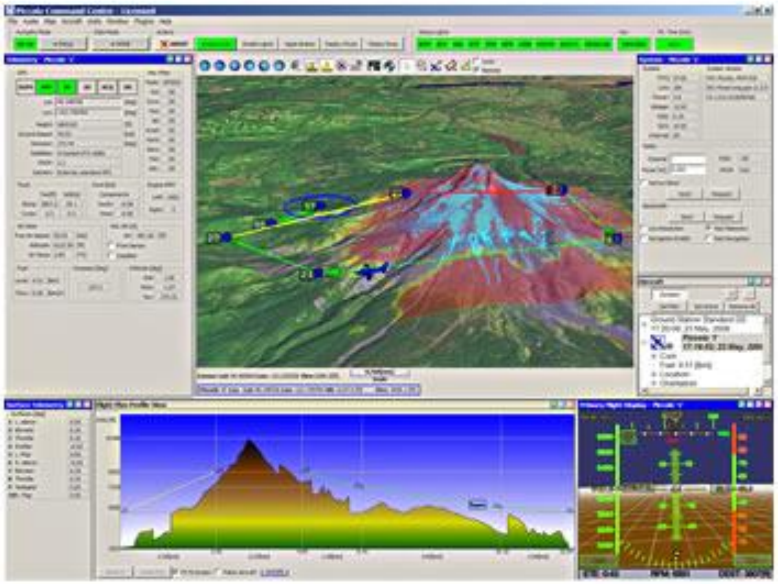

Figure 4 Ground Station Display (www.cloudcaptech.com)

The program allows you to create, delete, or modify a set of waypoints or individual waypoints. Modifications include changing locations of waypoints by clicking and dragging waypoints on the displayed map, adjusting altitude, speed, or direction of an aircraft by opening the waypoint settings page. Creating a set of waypoints is as easy as clicking on the displayed map at the desired location of each waypoint, entering the altitude, and naming the set of waypoints.

The Piccolo ground station also allows you to monitor every aspect of the aircraft, as well as set specific operational limits. It provides a type of “Heads Up Display” which shows the aircraft's attitude, altitude, airspeed, and heading. It also has windows that monitor bank angle, GPS position, servo inputs, altitude (AGL and MSL using a laser altimeter and GPS), as well as setting limits such as maximum bank angle, climb rate, airspeed, and glide slope angle.

Finally, the Piccolo system is capable of auto takeoff and auto landing with the use of a laser altimeter. It is capable of creating a standard landing pattern, calculating altitudes based on mean sea level and the desired glide slope, as well as executing an abort if the aircraft falls outside of set conditions, such as too far from the runway, or too high when it reaches the landing point.

4.2 Target Recognition System

To accurately detect and locate ground targets, the team designed and built an image processing system consisting of three parts. The first component is a telemetry console written in C++, the second component is a database written in SQL, and the third is a target recognition program written in MATLAB. Each of the subsystems contributes to the operation of the autonomous target recognition and location system. All three subsystems are located on the target recognition system laptop the team uses as part of the Ground Station. The telemetry console queries the Piccolo autopilot once per second for the most recent telemetry data for the aircraft and also requests an image from the Axis digital camera once per second. The telemetry console also displays current telemetry and imagery to the team's sensor operator. Once both the telemetry from the autopilot and an image from the camera are received, the telemetry console pairs the telemetry data and the image with a time stamp. The telemetry console writes the telemetry data, including the aircraft's latitude, longitude, altitude, heading, and speed, to the database while also writing the name of the associated image to the same row in the database. At the same time, the telemetry console writes the image in JPEG format to a file on the image processing laptop's hard drive. After the telemetry and image name have been written to the database and the JPEG image has been written to the hard drive, the MATLAB program queries the database for the most recent database entry. Once MATLAB recognizes a new entry to the database, it reads the JPEG image from the hard drive associated with the most recent database entry. MATLAB then searches the image for possible targets and displays the results of the search to the user. Figure 5 depicts the Image Processing/Target Recognition system.

The search process consists of multiple steps. MATLAB first reads the most recent JPEG image from the hard drive. Next the program converts the image from the Red, Green, Blue (RGB) spectrum into the Hue, Saturation, Value (HSV) spectrum. This facilitates the next step in the process, which is to isolate the hue values for each pixel in the image. Once only hue values exist in the image, the program converts the hue image into a black and white image based on a threshold pre-established for each color. Once only certain colors remain in the image, the program identifies objects larger than a pre-determined number of pixels and evaluates those objects based on their characteristics. If an object meets the physical characteristics of a target, MATLAB marks the object as a possible target and displays the result to the user. Figure 6 provides a flowchart of the target recognition process.

MATLAB also calculates the GPS coordinates of the target based on the calculated coordinates of the center of the image. The team developed an algorithm to calculate the actual GPS coordinates of the target assuming that the telemetry information for the image provided the correct latitude and longitude for the center of the image. This algorithm introduces some error to the estimation of the target's actual location, but tests verified, under the normal conditions for the competition, the algorithm to be accurate within 15 feet, given the correct latitude and longitude coordinates for the center of the image. If no targets are found in the image, the program displays “No Targets Found” to the sensor operator. Figure 7 illustrates the processes that take place when the MATLAB target recognition program is executed for real targets.

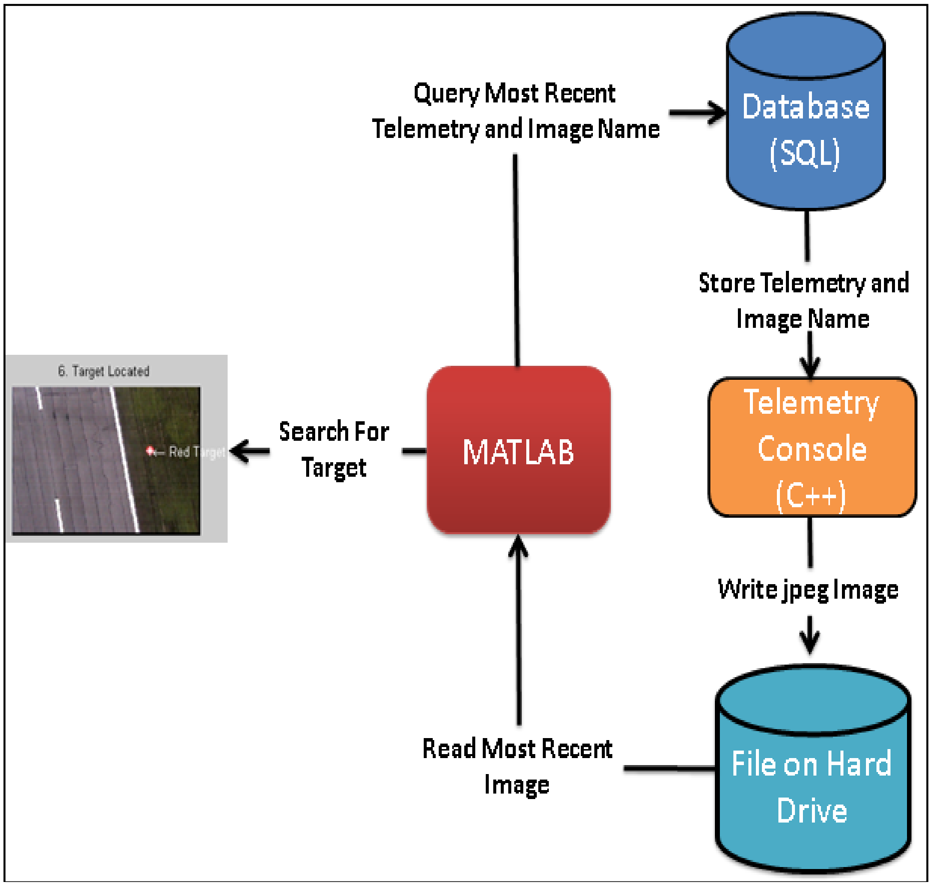

Figure 5. Image Processing/Target Recognition System

4.3 Communications

Our aircraft uses the UBIQUITI BULLET M2-HP equipped with an omni-directional antenna to send images captured by our AXIS 212 PTZ Network Camera. The images are transmitted at 2.4GHz from the transmitter to receiver. The UAS is also equipped with the Piccolo Plus autopilot system by CloudCap Technology. This system operates on the 900 MHz unlicensed ISM radio frequency, as is our ground station transmitter so that the two can communicate with minimum adjacent channel interference.

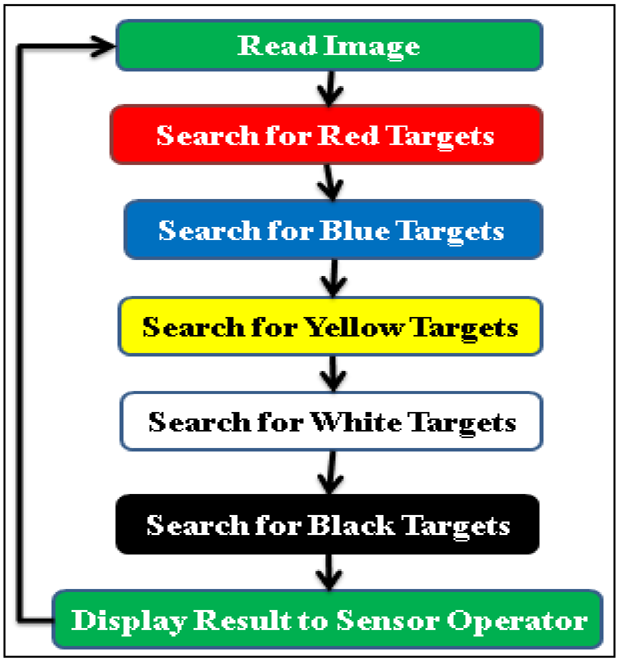

Figure 6. Target Recognition Flowchart

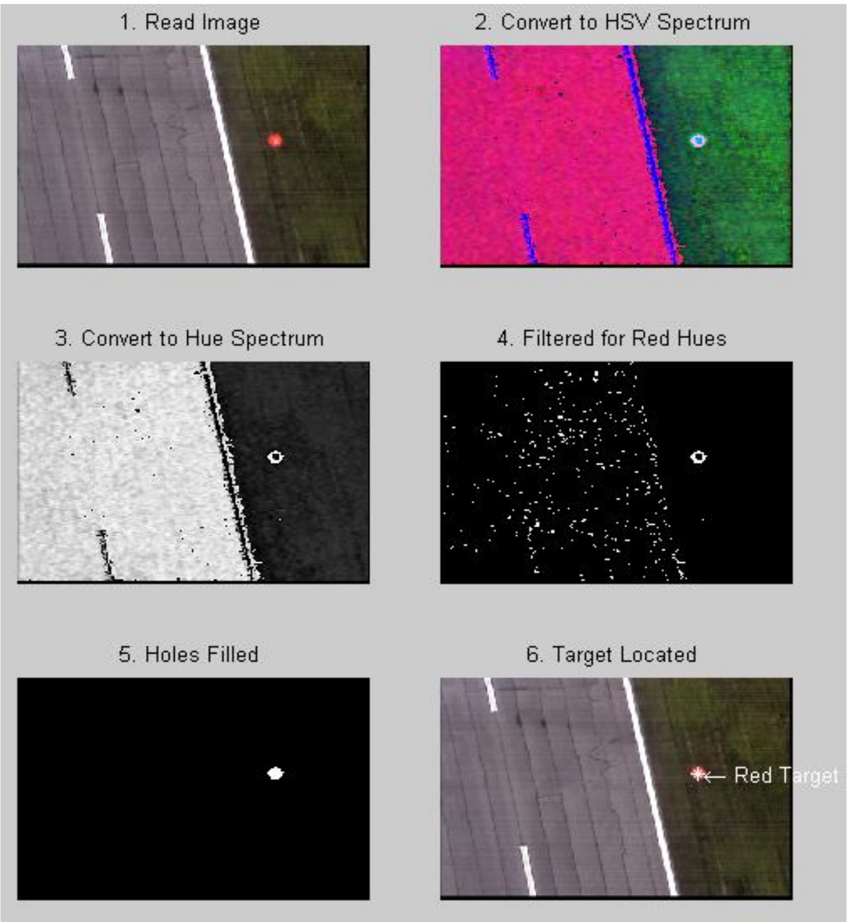

Figure 7. Target Recognition Procedure

5. Safety

The USAFA AUVSI Team implemented four different safety systems. We have the aircraft programmed for a series of safety options using the autopilot to include a lost communications waypoint. This prevents the aircraft from flying away from a mission area when a communication link is lost. Next we have a safety printed circuit board onboard the aircraft, which automatically allows the pilot in command to take complete control of the aircraft in case of emergency. We clear each flight through our local aircraft controller and have an approval from the FAA to fly our UAS in the local Class D airspace. This airspace is also watched with spotters from our team to make sure there are eyes on the aircraft at all times. Along with the safety measures that we take for each flight, we are serious about checklists that are followed in order to ensure each flight is conducted safely.

5.1 Piccolo Safety Systems

The first safety method uses the options available to us in the Piccolo autopilot programs, the most prominent being a lost communication waypoint. The lost communication waypoint is a preset location in the Piccolo Command Center. If the UAS loses communication with the ground station for more the two seconds, the UAS will automatically start flying toward the lost communication waypoint until communication is reestablished with the ground station. Also if communication is not regained within a predetermined time, the UAS will go into a controlled crash by putting the plane into a spin. If the aircraft goes outside of any mission limits, we are given a visual warning through the ground station interface. Also we are warned by the autopilot when the aircraft losses communication with the ground station.

5.2 Safety Boards

The second safety system used is a safety printed circuit board, seen in Figure 8. The safety board gives a human pilot on the ground the ability to take control of the aircraft at anytime using a regular 72 MHz RC controller. If the UAS is not performing as it should, the safety pilot can take control of the UAS and fly it like a regular remote control plane. Also, the safety board will automatically give control to the pilot if the battery for the Piccolo fails. The safety board is designed and built by the Electrical and Computer Engineering Department at the United States Air Force Academy.

5.3 FAA Coordination/Spotters

In order to ensure that there will be no mishaps with local air traffic, we coordinate all of our flights with the air traffic controller at the USAFA airfield. We notify the Air Traffic Controller (ATC) before we take off and after we land. This provides the ATC with situational awareness of the traffic in their airspace so they are able to divert any traffic away from us. We have an approval from the FAA to fly our system in the local airspace for testing, provided we have spotters and met other documented safety requirements. For each flight we keep eyes on the aircraft with our spotters. The spotters keep the operational crew aware of local air traffic, birds in the area, and the whereabouts of the aircraft.

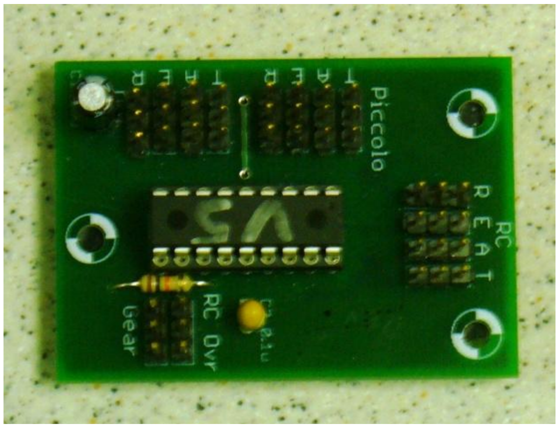

Figure 8 Safety Printed Circuit Board

5.4 Checklist Discipline

The checklists are developed from the lab simulations for test flights and supplemented, by additions from lessons learned from our test flights. A copy of the checklist that we use for each flight is seen in Appendix II.

6. Testing/ Mission Results

Mission testing of our system is a very essential component in order to be truly prepared for the competition. One of the methods that we use to test our system in the lab is the hardware-in-the-loop test, which is always conducted before any flight test. This subsection describes the hardware-in-the-loop setup and our test results.

6.1 Hardware-in-the-Loop

The hardware-in-the- loop is the name for the simulations that we run in our laboratory. It is a key component to our overall success because it allows us to simulate flying without actually putting the aircraft in flight. The basic components of the hardware in the loop system are the airframe with its own Piccolo, communication module, batteries, and the ground control station. While the hardware-in-the-loop simulation is going, the airframe’s batteries, communication, and Piccolo autopilot are all running as if they were in flight. There is a Piccolo simulator program that is plugged into the Piccolo on the aircraft which simulates inputs from the flight such as air speed, GPS location, UAV orientation, direction, and altitude. The Piccolo ground control station serves as an interface between the aircraft and the ground station. The Piccolo ground control station receives data from the Piccolo simulator on the aircraft and using the MATLAB program, it searches for targets.

The hardware-in-the-loop simulation shows us very similar results to what would happen in flight. Mainly, it shows how imagery is displayed to the sensor operator, and it allows us to modify the communication link, camera settings, and airframe to get accurate results on how the modifications will perform in actual flight. These simulations play a critical part in our development. Any new modifications must pass this simulation before being tested on the flight line.

6.2 Flight Tests

The team has accomplished several flight tests to create the best possible system and to prepare for any problems that may arise during competition. Initially, the tests were done using one of the aircraft with different test payloads, Payload A and Payload B seen in Appendix I. Among the new systems tested are the laser altimeter and digital cameras. Several problems initially occurred with these systems that the team was able to discover, thanks to the flight tests. By testing the laser altimeter, we ensured that it worked properly to keep the plane at designated altitudes. This was accomplished by knowing the field elevation and estimating the correct altitude based on observations during the test flights. The digital camera could have introduced many new issues. Among those issues are the clarity of images and range of transmission to the ground station. By testing the camera in the air prior to competition, the team verified that the range and functional capabilities meet competition requirements.

By combining all available data with countless hours of simulations and real-world testing, our team has brought together a complete platform capable of achieving desired results. Since January of this year each of our main subsystems (aircraft, payload, and ground control) has undergone simulation tests in our lab at least three days a week; all exceeding thirty hours of simulations since completion. The primary flight control and aircraft have been tested in real world scenarios and at our local high altitude twice weekly since mid-April. We utilized an agile engineering process in conjunction with a previously developed system to allow us to demonstrate results and perform tests at frequent intervals along the design process. This agile process allowed us to make changes continuously as needed during the integration process.

Each of our subsystem specialists were able to get several hours of testing completed with multiple versions of their systems. The sensor team tested both analog and digital packages including several different cameras, camera arrays, transmitters, receivers, and processing software. Our flight team has evaluated several aircraft ranging from our Kadet Senior and Rascal models to the Scan Eagle, Predator, and Reaper used in active combat by the US Air Force and US Army.

Once fully integrated, our system was able to consistently achieve successful image collection and evaluation of targets. The live video feed provides an uninterrupted view of the target area and the automatically collected images are undistorted and of high quality. Our aircraft has been tested in the air for power needed for the duration of the competition and communication capability. The image processing software can detect a target automatically and display its location to the operator within an average of 50ft from its true location. All image and location data from our flight are processed into Google Earth immediately, following the completion of the mission. Currently, this post mission analysis using the Google Earth map can locate a target with less than 20 ft errors.

7. Conclusion

Using a systems engineering approach, the requirements to participate successfully at the 2010 AUVSI competition were analyzed. We prioritized the requirements of the competition and performed a feasibility analysis. Our team evaluated two separate payloads and compared their components against the mission requirements.

Our system consists of an aircraft and a ground system. The airborne subsystem is comprised of an autopilot and an image capture system, which send telemetry and images down to the ground station. The ground station receives the information and synchronizes the telemetry of the aircraft and images to find ground targets.

The system has gone through a substantial amount of testing with an extensive safety procedure implemented. As a result, we made several minor changes to our system throughout the semester, which improved the overall performance of our system. The team is ready to compete in this year's competition and we are very confident of the capabilities of our system.

Appendix I Payload Decision Matrix

					Candidate			
					Payload A		**Payload B**	
Requirement Family	**Property**	**Weight**	**Property Weight**	**Normalizing Rule:**	**Raw Score**	**(Normalized)**	**Raw Score**	**(Normalize)**
Weight/size		**0.1**						
	Battery Weight		0.2	Lowest/#	528 g	1	528 g	1
	Autopilot Weight		0.2	Lowest/#	212 g	1	212 g	1
	Battery Size		0.15	Lowest/#	647680 mm^3	1	647680 mm^3	1
	Autopilot Size		0.15	Lowest/#	404984 mm^3	1	404984 mm^3	1
	Additional Weight		0.15	Lowest/#	820 g	0.304878049	250 g	1
	Camera Weight		0.15	Lowest/#	504 g	0.900793651	454 g	1
	Total		**1**			**0.880850755**		**1**
Target Recognition		**0.15**						
	Field Of View		0.3	#/Highest	140 degrees	1	25 degrees	0.178571429
	Gimbal Pan		0.2	#/Highest	70 degrees	1	45 degrees	0.642857143
	Gimbal Tilt		0.2	#/Highest	52 degrees	1	45 degrees	0.865384615
	Camera Zoom		0.1	#/Highest	3 x	0.1	30 x	1
	Image Size		0.15	#/Highest	640 x 480	1	640 x 480	1
	Image Capture rate		0.05	#/Highest	30 fps	1	30 fps	1
	Total		**1**			**0.91**		**0.65521978**
Autonomous flight		**0.2**						
	Way point Navigation		0.5	Yes=1,No =0	Yes	1	yes	1
	Flight Duration		0.5	Lowest/#	30 min	1	30 min	1
	Total		**1**			**1**		**1**
Communication		**0.2**						
	Range		0.7	#/Highest	1 mile	1	1 mile	1
	Bandwidth		0.3	#/Highest	20 MHz	1	20 MHz	1
	Total		**1**			**1**		**1**
Safety		**0.2**						
	Servo Switch Board		0.25	Yes=1,No =0	yes	1	yes	1
	RC control		0.25	Yes=1,No =0	yes	1	yes	1
	Lost Comm. Waypoint		0.25	Yes=1,No =0	yes	1	yes	1
	Transponder		0.25	Yes=1,No =0	yes	1	no	0
	Total		**1**			**1**		**0.75**
Cost		**0.1**						
	Camera Cost		0.25	Lowest/#	$618.95	0.644559334	$398.95	1
	Autopilot		0.25	Lowest/#	$7,500.00	1	$7,500.00	1
	Battery Cost		0.25	Lowest/#	$1,245.88	1	$1,245.88	1
	On board Computer Cost		0.25	Lowest/#	$323.00	0	$0.00	1
	Total		**1**			**0.661139834**		**1**
Simplicity		**0.05**						
	set up time		1	Lowest/#	30 minutes	1	30 minutes	1
	Total		**1**			**1**		**1**

Appendix II- Challenge/ Response Preflight Checklist

1. Piccolo Ground Station .... set up
    a. Ensure serial cable in Link 1 .... check
    b. Ensure UHF antenna in Link 1 .... check
2. Piccolo Ground Station .... power on
3. PCC laptop .... power on
4. PCC software .... start
5. Video Capture System .... set up
6. Rascal propeller .... install
7. Rascal main LiPo batteries .... connect
8. Rascal Piccolo batteries .... connect
9. Install wing and struts .... check
10. CG .... check
11. R/C transmitter .... power on
12. Rascal servos .... power on
13. R/C only control surfaces .... check
14. Rascal Piccolo Autopilot .... power on
    a. PCC autopilot reset report .... check
15. Kill engine using PCC .... engine off
16. Piccolo switch to manual .... check
17. Piccolo manual control surfaces .... check
18. Piccolo switch to autopilot .... check
19. Preflight Window: Piccolo autopilot control surfaces .... check
20. PFD: Pitch, Bank, Yaw angles .... check
21. PFD: Check airspeed .... blow in pitot
22. Piccolo System Window .... open
    a. Voltage > 11 Volts .... check
    b. Channel = 1 and power = 1 .... request and check
    c. Fast Telemetry .... send
    d. RSSI is near -71 .... check
    e. Link is 100 .... check
23. Piccolo Mission Limits Window .... open
    a. Lost comm waypoint set to 99 .... set
    b. Autoland waypoint set to 90 .... check
    c. Comm. timeout set to 2.0 seconds .... check
    d. Flight termination If Lost GPS and Comm. .... check
    e. Close throttle on flight termination .... check
24. Telemetry Window: GPS 3D and PDOP < 3.0 .... check
25. Preflight Window: GPS field elevation .... enter
    a. Cover pitot, Zero air data .... check
26. Rascal Camera Batteries .... connect
27. Receiving Video and Telemetry in Image Capture System .... check
28. Focus Camera at 250 ft .... check
29. Enable engine using PCC .... engine on
30. R/C only throttle operation .... check
31. Piccolo manual throttle operation .... check
32. Airspace operations and permission .... clear
33. Call airspeed and altitude .... during climb out
34. Call GPS/INS and autopilot enable .... when GPS/INS green

List of Abbreviations

ISR – Intelligence, Surveillance, Reconnaissance
GPS – Global Positioning System
AUVSI – Association for Unmanned Vehicle Systems International
RC – Radio Control
UAS – Unmanned Aircraft System
SE – Systems Engineering
JPEG – method of lossy compression for photographic images
MPEG-4 – collection of methods defining compression of audio and visual (AV) digital data
USAFA – United States Air Force Academy
AGL – Above Ground Level
MSL – Mean Sea Level
SQL – Structured Query Language
RGB – Red, Green, Blue
HSV – Hue, Saturation, Value
ISM – Industrial, Scientific and Medical
FAA – Federal Aviation Administration
ATC – Air Traffic Control
GCS – Ground Control Station
PCC – Piccolo Command Center
LiPo – Lithium Polymer
CG – Center of Gravity
PFD – Primary Flight Display
INS – Inertial Navigation System