The University of Texas at Arlington
Autonomous Vehicles Laboratory

2007 AUVSI Student UAS Competition

Student Team

Amen Omoragbon
Enrico G. Pianori
Brandon Watters
Dustin Kerr
Deene Ogden
Andrey Belchev

Faculty

Dr. Atilla Dogan - Mechanical and Aerospace Engineering
Dr. Arthur A. Reyes - Computer Science and Engineering
Dr. Brian Huff - Industrial & Manufacturing Systems Engineering
Dr. Kamesh Subbarao - Mechanical and Aerospace Engineering

ABSTRACT

This paper describes a system to perform autonomous reconnaissance for the AUVSI 2007 Student UAS Competition. An aircraft autonomously takes off and navigates to specific GPS waypoints within a predetermined, confined search area. While in flight, Targets are located and identified by image operators operating two payloads. One payload is a fixed, wide-angle camera for image search. The other payload is a high-resolution camera mounted on a pan-tilt-zoom platform. Once the aerial overview is obtained, a series of targets are manually assessed and categorized. The success of this project relies on the use, implementation and integration of commercial off-the-shelf (COTS) components to create a reliable autonomous reconnaissance system. Specifically, success depends on proficiently controlling mission elements including; autonomous takeoff and landing, autonomous control, waypoint navigation, mission flexibility (the ability to change missions before and during flight), and target interpretation. Discussed in this text are the rationales, architectures, components, and processes involved in achieving this goal. Additionally, Safety features such as structural reinforcements, the ability to switch to manual control at anytime during the flight, and safety-specific engineering processes are addressed.

TABLE OF CONTENTS

NOMENCLATURE

Abbreviation	*Definition*
AGL	Above Ground Level
AMA	Academy of Model Aeronautics
ARF	Almost Ready to Fly
COTS	Commercial Off the Shelf
GCS	Ground Control Station
GPS	Global Positioning System
GUI	Graphical User Interface
IPD	Intelligent Pulse Decoding
MP	MicroPilot autopilot system
PID	Proportional, Integral, Derivative (control loops)
R/C	Radio control
RX	Receiver
TX	Transmitter
UAV	Unmanned Aerial Vehicle

INTRODUCTION

Ever since man first experienced the thrill of flight, he has relentlessly devised ways to improve the efficiency of aircraft and maximize their capabilities. A century after man's first powered flight, a new era of unmanned automated aviation has emerged. One in which pilots have been removed from the cockpit, thereby eliminating the limitations imposed by the human physique. We now live in a new aviation era, the era of the Unmanned Aerial Vehicle. UAVs have opened a new world of possibilities. They give the ability to gather information and data without risk to human life and the need for constant human control. These platforms provide a functionality limited only by the capabilities of the specific airframe, control system, payload, and our imagination. This technology has widespread military and commercial applications; and the 5th Annual AUVSI Student UAS Competition gives students the chance to work in this frontier. The UAV under consideration is required to be capable of autonomous flight, reconnaissance, and performance under a time constraint. This paper describes the University of Texas at Arlington's development of a fully-functional system that meets these requirements.

MISSION REQUIREMENTS

The mission has five major parts which are stated below.

Autonomy

The aircraft is required to autonomously navigate through a specified GPS corridor to an area where it searches for targets. Extra credit is awarded for autonomous take off and landing but neither is required.

Target Location

The target locations are required within 250 ft of true position and recorded in 'ddd.mm.ss.ssss' format. Extra credit is awarded if targets are located with 50 feet of true position.

Imagery

In addition to the target location, the aircraft must identify at least two target parameters selected from the following list (extra credit is awarded for identifying more).

- Background Shape
- Background Color
- Orientation
- Alphanumeric Character (Number or letter)
- Alphanumeric Colors

Mission Time

The entire mission is required to be performed in 40 minutes.

Dynamic Re-Tasking

The aircraft is required to have the ability to change at least one waypoint altitude and location in flight. The ultimate goal of this requirement is the ability to dynamically change the search area.

DESIGN DESCRIPTION

Design Rationale:

In order to succeed in the mission, each mission requirement must be met. To do so components capable of the tasks must be selected and properly integrated. A stable, fast and easy-to-control aircraft should be selected to meet time requirements. A proven automatic flight controller which allows in-flight re-tasking is necessary to meet the autonomy and dynamic re-tasking mission elements. Two cameras are also needed; one, low resolution with telemetry (GPS and Orientation) overlay from the auto controller, for obtaining target location and orientation. The other, a high resolution camera, is for identifying other target parameters.

System Overview

A stable fixed-wing R/C aircraft controlled by an auto controller carries two imaging payloads. One payload comprises of a fixed, wide-angle camera, a video overlay board, and a video transmitter. The other payload consists of a high-resolution camera mounted on a pan-tilt-zoom platform, an R/C receiver and a video transmitter. On the ground, there is a pilot station, a ground control station, and two imaging stations. The fist imaging station receives video from payload 1 for target searching. The other receives video from payload 2 and controls the pan-tilt-zoom platform for target identification. There is also a team liaison that coordinates information between all the stations and the judges. A system diagram of this design is shown below.

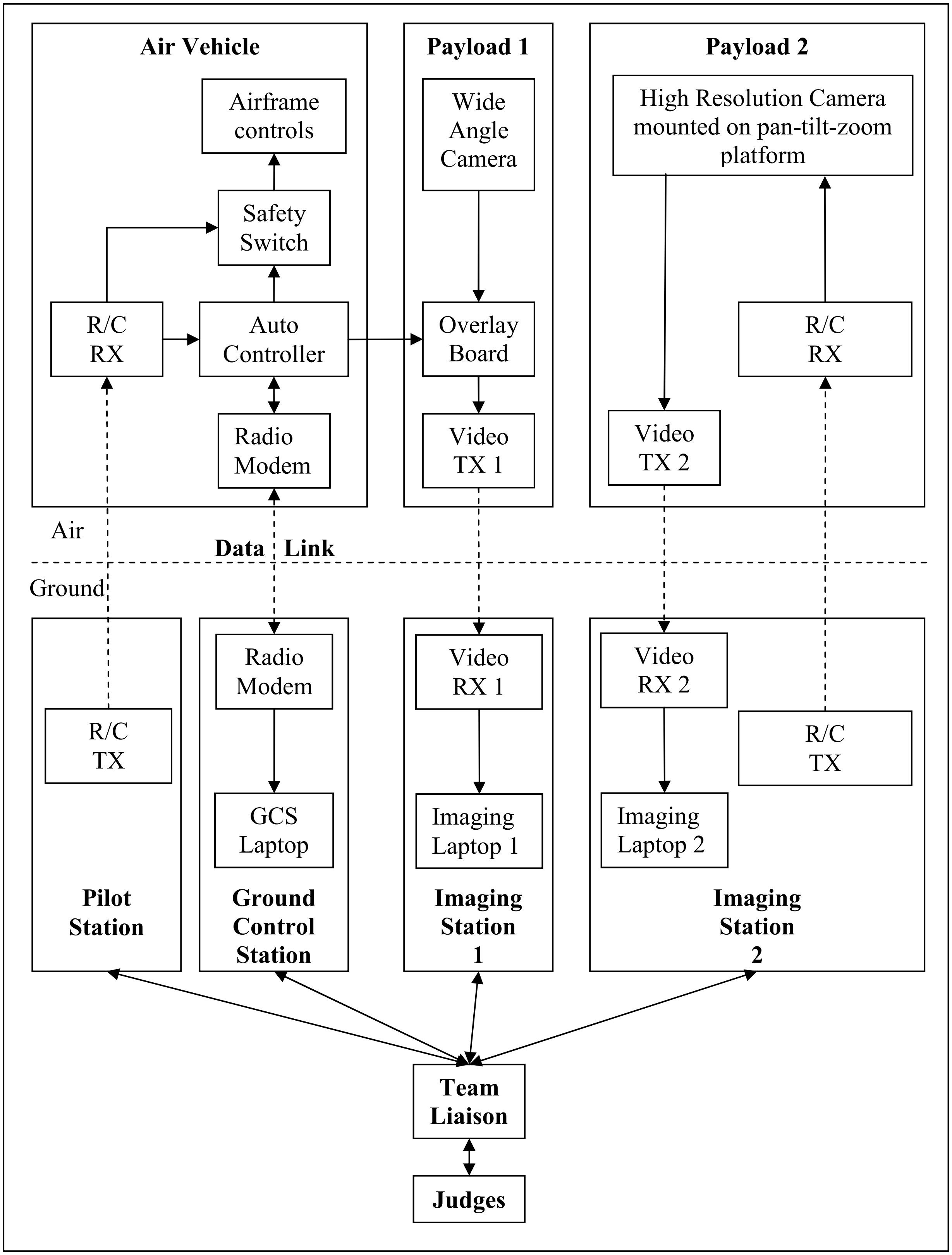


Figure 1: System block diagram

System Components

Air Vehicle

<u>*Rationale:*</u> This is an autonomous vehicle competition therefore; the focus should be on autonomy and reconnaissance rather than developing a new kind of aircraft. This means a stable R/C airplane with sufficient power, a short build time and enough internal room for the payload should be selected. Along with a stable airframe, an auto controller capable of meeting mission specs should be chosen. There is also need for a safety bypass to the servos should the auto controller fail.

Airframe

The R/C aircraft chosen is a SIG Kadet Senior ARF (Almost Ready to Fly) fit with an OS FX .91 in^3 engine. The Kadet Senior is a stable fixed-wing airplane with a large wing area and sufficient payload space. Additionally, since it is an ARF it has a short build time. The OS FX .91 in^3 is a powerful, reliable and easy-to-maintain engine with a top output of 2.8 hp. The airframe is also equipped with HS-311 HI-tech servos for the control surfaces and an HS-81 micro servo for the throttle, all of which are very durable and reliable. Additionally, a few modifications were made to make the airframe more ergonomic. Modifications such as

- Reinforcement of the firewall to withstand stresses from the more powerful engine.
- Relocation of the throttle, rudder and elevator servos to increase payload space.
- Creation of panel hatches for easy access to the batteries, payload and servos.
- Replacement of stock main landing gear with composite to improve take-off and landing stability. The main landing gear strut was moved aft one inch from the ARF's out-of-the-box configuration to allow more room for the Target Identification Payload.

Safety Switch

The safety switch is a custom-built device created by Reactive Technologies[10] in collaboration with NCSU[11]. Its inputs are from the R/C receiver and the auto controller and it outputs to the servos. It selects which input signal is sent to the aircraft servos and it operates both manually and automatically. The pilot can manually bypass the auto controller during emergencies by sending a signal through the receiver. In a case where the aircraft losses signal from the pilot's transmitter, the switch automatically turns control to the R/C receiver which is preprogrammed to initiate a cut-throttle-spiral-to-the ground maneuver. This is a fail-safe maneuver implemented in compliance with the AUVSI competition rules.

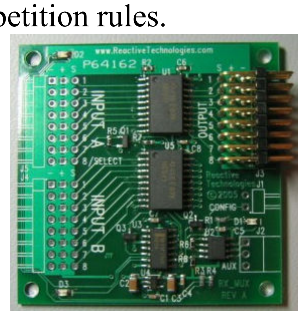


Figure 2: Safety Switch

R/C Receiver

The purpose of this receiver is to allow the pilot to control the aircraft. It relays the signals from the pilot's transmitter to the aircraft. It is connected to both the auto controller and the safety switch. Under normal conditions, the pilot can fly the aircraft through the auto controller via the receiver. However in an emergency, the pilot can take direct control of the aircraft by sending a signal to the safety switch. The R/C receiver selected for this UAV is a synthesized Multiplex IPD 9 channel RX. This receiver was chosen because it is synthesized and can run on almost any R/C frequency. Additionally it can be programmed to initiate a fail-safe maneuver if the aircraft losses signal from the pilot's transmitter.

Figure 3: R/C Receiver

Auto Controller

<u>Rationale:</u> The auto controller is the backbone of the system's autonomy. It should be capable of navigating and piloting the aircraft safely and accurately. It also should allow for dynamic re-tasking in to meet mission requirements. It has to be compact and lightweight so that there is more room for the payload. It also needs to produce reliable telemetry data for use by both the ground station and the imaging station 1 which requires it.

Method of Autonomy

The auto controller chosen is the MicroPilot MP2028^{g} autopilot. It was chosen because team is familiar with the system and knows it meets design requirements. It is capable of altitude hold, airspeed hold, coordinated turns and GPS navigation as well as autonomous take-off and landing. It also produces sufficient telemetry data which can be transmitted via a modem link or overlaid unto a video as needed.

MP2028^{g} uses rate gyros and accelerometers, GPS data, ultrasonic and pressure altimeters, and an airspeed pressure sensor to determine the aircraft's attitude, position, and velocity in flight. From these sensor data, it determines the required line of action in order to achieve a desired flight condition. The actual magnitude of the commands MP2028^{g} issues to the aircraft servos are governed Proportional-Integral-Derivative (PID) control loops which are tuned to the specific airframe. It uses 12 PID loops which are:

1. Aileron from Desired Roll
2. Elevator from Desired Pitch
3. Rudder from Y-accelerometer
4. Rudder from Heading
5. Throttle from Speed
6. Throttle from Glide Slope
7. Pitch from Altitude
8. Pitch from AGL Altitude
9. Pitch from Airspeed Altitude
10. Roll from Heading

11. Heading from Cross Track
12. Pitch from Descend

Auto controller components

1. *MP2028^g Control board:*

The MP2028^g weighs only 1 oz and measures 3.9 inch by 1.5 inch. It comes equipped with two pressure transducers, X-Y-Z gyros and accelerometers and a GPS unit. One pressure transducer is connected the Pitot tube for airspeed measurements while the other is open to ambient air for altitude measurements. This board is the base of the auto controller. It is where all the flight parameters are stored including airplane characteristics and the current flight plan. It also does all the calculations required for flight. A layout of the board is shown below.

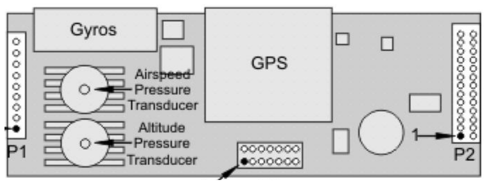


Figure 4: MP2028^g Layout

2. *Acoustic Altimeter:*

The acoustic altimeter gives high-resolution altitude measurements up to 15 feet. It mostly used by the auto controller in landing the aircraft. The setup comprises of an AGL (Above Ground Level) board and an ultrasonic transducer. The AGL board is a 2.23 by 1.78 inch PCB board unit and is the interface between the ultrasonic transducer and the MP2028. The ultrasonic transducer is 0.6 oz., 1.7 inch diameter and is mounted on wing pointing downward. A picture of these devices is shown below.

Figure 5: Acoustic Altimeter

3. *GPS Module and antenna:*

The MP2028g comes standard with a Trimble Lassen® SQ GPS module. The unit has 8 channels and an update rate of 1 Hz. The module is used in conjunction with a San Jose Navigation Inc. MK-4 Mini GPS antenna that provides a standard 24 dB overall gain. Pictures of the module and the antenna are shown below.

Figure 6: GPS antenna

4. *Servo Board:*

The servo control board is the interface between MicroPilot board and the servos. The controller sends multiplexed signals to the board which then distributes these signals to the appropriate servos. This board is connected to the bypass switch for controlling the aircraft. A diagram of board is shown below.

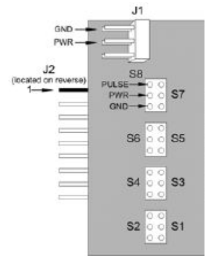


Figure 7: Servo Board Diagram

Onboard Radio Modem

The onboard radio modem is the means by which the auto controller communicates with Ground Control Station. It allows two-way interactions between both systems. The radio modem chosen for this UAV are a 900 Hz MaxStream Xtend Radio modem. It was chosen because of its long range (up to 20 mi) and auto controller manufacturer recommendations.

Payload 1: Target Search

<u>*Rationale:*</u> The mission requires the UAV to search for targets on the ground and give their locations an orientation. This can be done by having a fixed video camera, with a wide Horizontal Field Of View (HFOV), pointing downwards. This camera will view targets along the path of the aircraft and it can be transmitter via a video TX. If the orientation and the GPS location of the aircraft are known then the orientation and location of the target can be approximated. For quick target location it will be beneficial to obtain this information in real-time. A video overlay board compatible with the auto controller's telemetry is an efficient way of accomplishing this task.

Wide-angle Camera

The wide-angle camera selected for this UAV is the RHPC 2000 CCD camera fit with a wide-angle lens. This camera-lens combination was chosen because it is compact, light weight and meets the requirements. The CCD camera is 22mm by 26mm and weighs 10g. It has a decent resolution and with the lens gives a HFOV of approximately 60 degrees on either side.

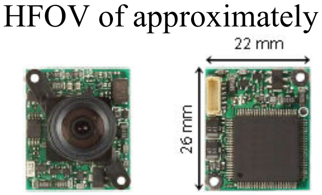


Figure 8: Wide-Angle Camera (front & back)

Video Overlay Board

The video overlay board used is a BOB-3 videotext overlay module. It is compatible with the auto controller and can display telemetry texts at specified locations on the screen. The video from the wide-angle camera into the board, it overlays the specified data and sends it to the video transmitter for viewing. A picture of the card is shown below.

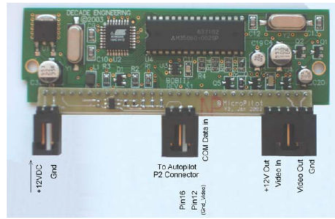


Figure 9: Video Overlay Board

Video Transmitter 1

The selection of a video transmitter is a critical part of the design. Its range could determine the range of the vehicle itself. The transmitter chosen for this UAV is a 2.4 GHz Black Widow A/V TX. It can operate on 8 channels and has an output power of 1Watt.

Figure 10: Video Transmitter 1

Payload 2: Target Identification

<u>Rationale:</u> Images from the fixed, wide-angle camera may not be clear enough to identify target parameters such as shape, alphanumeric character and color. A high-resolution camera with ability to pan, tilt, & zoom will give a better chance of identifying these parameters.

High-Resolution Camera

The high-resolution camera used is the SANYO VPC-HD1A Camera. It is mounted on a custom-built pan-tilt-zoom platform made from carbon fiber. The camera is a 5 megapixel camera with 10x optical zoom. It is light weight and has an anti-shake image stabilizer which is perfect for this application. The platform, which was designed by a student of the team, is lightweight and gives about 100 degrees of motion both horizontally and vertically. It has two metal geared servos to control motion pan and tilt and it has a micro servo for controlling zoom.

Figure 11: High-Resolution Camera on the pan-tilt-zoom-platform

R/C Receiver

The R/C receiver in this payload is also a synthesized Multiplex IPD 9 channel RX. It has the same capabilities of the Air vehicle's receiver; however, it is used solely for manually controlling the pan-tilt-zoom platform.

Video Transmitter 2

The transmitter chosen for this payload is also a 2.4 GHz Black Widow A/V TX. It can operate on 8 channels and has an output power of 1Watt.

Pilot Station

Rationale: In the most autonomous scenario, there will be no need for a pilot or a pilot station. However, since safety is paramount and mishap is a possibility, a pilot is necessary for this system.

Roles of a pilot:

- Ensure the auto controller flies the aircraft in a regular manner.
- Update the team and the liaison on any irregularities during the course of the mission
- Take control of the aircraft if there is a major malfunction

Pilot's R/C Transmitter

The pilot's transmitter is the means by which the pilot can control the airplane. This transmitter sends signals to the air vehicle's receiver, allowing the pilot to fly either via the auto controller or directly through the safety switch. The transmitter chosen is a Multiplex Royal EVO 9 channel TX equipped with a frequency scanner. It is reliable, durable and versatile. It is versatile in the sense that it allows the pilot to assign any of its switches to any of its channels. The frequency scanner allows the transmitter to check for dirty or in-use R/C frequencies. This gives added safety because the transmitter will be inactive if a channel is dirty and the UAV will not fly if the transmitter is inactive (see safety switch).

Figure 12: R/C Transmitter

Ground Control Station

Rationale: The ground control station is the center for all information related to autonomy. It is the primary mode of communication with the air vehicle and auto controller. It should allow easy display of telemetry such as aircraft altitude, attitude, airspeed and location. A modem with a reliable link, a laptop for mobility and user-friendly GCS software recommended for this subsystem.

GCS Laptop and Software

The GCS laptop accepts information from the radio modem and displays it. The Laptop chosen is a Dell XPS Gen 2 and it is loaded with GCS software from the auto controller manufacturer called HORIZON^{mp}. The laptop has a 17" screen and enough memory and speed for viewing the telemetry GUI. Horizon displays the information in a GUI shown below and allows the operator to monitor as well as dynamically change flight parameters. It is also used to upload aircraft parameters and flight plans to the auto controller. There is also a log viewer for examining flight logs.

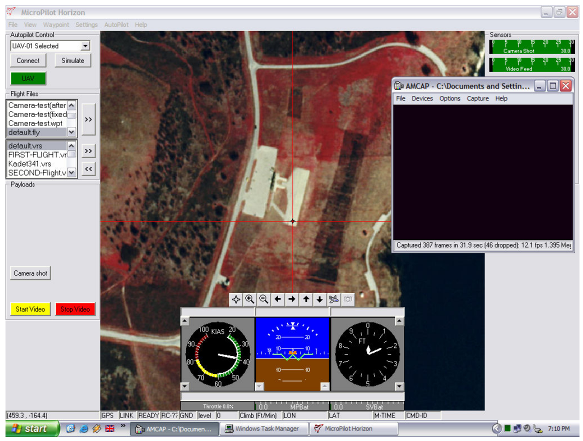


Figure 13: GCS HORIZON Software display

On-ground Radio modem

The on-ground radio modem is the second half of the data link with the auto controller. It receives telemetry from the onboard modem and sends out commands from the GCS laptop. The radio modem chosen for this UAV is a 900 Hz MaxStream Xtend Radio modem. It was chosen because of its long range (up to 20 mi) and auto controller manufacturer's recommendations. A picture of the modem is shown below.

Figure 14: Radio Modem Transceiver (Ground)

Imaging Station 1: Target Search

Rationale: There has to be a means of viewing video from the target search payload. Additionally, the exact positions in the video streams have to be recorded so targets can be viewed again. The setup requires a high quality video receiver connected to a laptop equipped with video book marking software.

Video Receiver 1

A receiver with good range and good video quality is required for effective target search. The video receiver selected is a 2.4 GHz Black Widow A/V diversity receiver. Unlike regular receivers, the diversity receiver has 2 antennae inputs and it automatically switches between the inputs to get the best reception. This switch is instantaneous and it allows for various antennae combinations such as short-mid or long-mid range setups. A 14 db long-range antenna and an 8 db mid-range antenna combination was selected and tested to give a rage up to a mile on ground.

Figure 15: Video Receiver

Imaging Laptop 1

The imaging laptop for target search is a Compaq R2000 laptop with an outdoor screen. It gets the video feed from the transmitter via an Avert Media video card. The video is viewed with a VLC media player. This player enables the operator to record live feed in any format, make book marks on parts of it, take snapshots and stream the images in real-time.

Imaging Station 2: Target Identification

<u>*Rationale:*</u> The target identification station needs a means of viewing targets & book marking them. There should also be a way of manually controlling the pan-tilt-zoom platform to get a better view of the targets. A similar setup to that of the target search station with an R/C transmitter is sufficient for the task.

Video Receiver 2

A receiver with good range and good video quality is required for effective target identification. The video receiver selected is a 2.4 GHz Black Widow A/V diversity receiver (see Video receiver 1 for a picture and description).

Imaging Laptop 2

A laptop similar to the target identification laptop was chosen with the same interface and structure.

R/C Transmitter

The R/C selected for controlling the pan-tilt-zoom platform is a Multiplex Royal EVO 7 channel TX. With it the operator is able to move the onboard platform and zoom in and out on the camera for a better view of targets.

Figure 16: R/C Transmitter

Team liaison

<u>Rationale:</u> There is a need for a means of controlling the flow of information, such as target reports and mission re-tasking request, between the team stations and the judges. A person with good communication skills is best suited for the job.

<u>Roles of a team liaison:</u>
The team liaison will communicate mission information from the judges to the team stations. Information such as

- Mission characteristics such as the location of boundaries, entry corridor, search area etc.
- Start and end of the mission
- Mission changes and new tasks

The liaison update judges on team decision, results and other related information such as:

- Team decision to terminate the mission
- Actionable intelligence
- Target report

System Integration

Testing

Components

Testing of the aircraft continuously evolves as new features are brought online. The aircraft's main control surfaces and sensors were tested in parts: on the bench, and during piloted, semi-autonomous, and autonomous flight. The bench testing ensures that each control is actuated properly, and has a proper range of deflection to accomplish the task in flight.

Appendix IV provides a sampling of errors encountered during systems testing, their possible causes, and solutions. These and many other issues had to be addressed prior to attaining radio controlled and fully autonomous flight. Though some problems stood out more than others, all had to be approached with equal care and methodology so that the next problem could be remedied.

Autonomy

Autonomy was first achieved about two years ago on April 8, 2005. After our successful participation at the 2005 AUVSI student competition we sought to further improve autonomy from takeoff to aerial navigation to landing. Even though the airframe was reasonably tuned, we decided to further fine-tune each feedback loop to an even higher degree of accuracy so that if desired we could consistently achieve autonomous landings at every unmanned flight.

Gradually, the project progressed to more sophisticated command programming and tasking. Later, additional systems were incorporated such as the photogrammetric system. As of this submission, more than 180 autonomous flights have been achieved including 30 autonomous takeoffs and 15 autonomous landings.

Component Placement

After bench testing and component verification, all the subsystems were integrated in a methodical fashion. All the critical boards were grouped based on function (i.e. MP board with servo board) and mounted in grounded modular boxes. The placement of these modules was decided from a weight-moment balance spread sheet. This eliminated the need of ballasts to balance the airframe at the manufacturer recommended center of gravity location. Pictures of the modules are shown below.

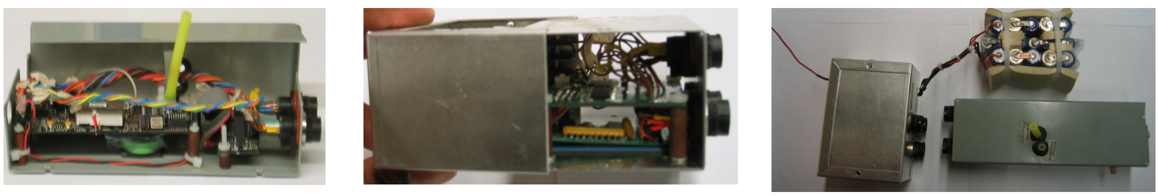


Figure 17: Pictures of modules

Component Connectivity

The modules created are connected via durable, multi-pinned Alden pulse lock connectors. These connectors help in both functionality and ascetics. The connections are secure and each component is easily accessed. It also makes a cleaner wiring.

SAFETY

Safety is an important part of engineering design. A lot of thought and planning has to go into safety ensuring that personnel, equipment, and software are well-protected before, during and after the missions. In this project, safety was stressed from the beginning and was emphasized through the daily operation of the equipment in the Autonomous Vehicles Laboratory.

It was standard practice to use of checklists and other means in order to prevent or minimize chance of injury. These SOP for safety is characterized below under Procedures for Accident Avoidance and Hardware Handling.

Procedures for Accident Avoidance

The general operation guidelines are:

- The airplane must be de-fueled after each flight.

- Two team members are involved in the starting of the airplane's engine. One secures the plane while the other starts the engine.
- Prior to each flight, the transmitter and receiver range check is performed according to the manufacturer's suggested procedure.
- All flights are conducted using a skilled pilot covered by AMA insurance.
- No spectators or operators are allowed to stand in front or to the side of a rotating propeller. All team members must remain behind the airplane while the engine is in motion.
- All autonomous fine-tuning flights are conducted at a minimum altitude of 500 ft. This altitude is to provide enough time to safely transition from autonomous to manual flight in case of an emergency. Also, in the event of an engine failure, the conservative altitude provides the pilot with a better chance of safely landing the aircraft.

Hardware Handling

- The tips of the propeller are painted white so that its boundary is visible at all times while in rotation.
- All battery charging ports and switches are placed either under or on the side of the fuselage opposite to the engine's exhaust in order to prevent possible short-circuiting due to fuel or oil ingestion.
- The Lithium-Polymer battery charging port is marked in order to distinguish it from the other battery ports. This is done in order to prevent improper charging which could result in fire or a possible explosion.
- The fuel is stored in a fireproof cabinet and never left unattended under the direct heat of the sun.
- All batteries onboard the aircraft are checked for proper charge prior to each takeoff in order to prevent loss of control or communication during flight due to insufficient battery charge.
- A redundant voltage monitoring LED indicator switch is installed on the battery supply of the MicroPilot board.
- All software files and programs pertinent to the autonomous project including the operating system of the ground station are backed up and saved. This gives the ability to retrieve the information in case of loss or damage of the original one.

CONCLUSION

Many considerations must go into the design of an autonomous aerial vehicle program, from aerodynamics and structures to electronics and communications. This paper has briefly described the University of Texas at Arlington's Autonomous Vehicle Lab's UAV. It made familiar the process by which the air vehicle was selected, the suite of electronics chosen to be integrated, the tuning of the autonomous system and the modifications that took place on the airframe in preparation for the AUVSI 2007 Student UAS Competition. Brief rationales for each subsystem's choice as well as the method of their implementation to the UAV were also discussed. Safety was also paramount to this project. The participating students had to become familiar and fully aware to the associated risks of dealing with flammables, internal combustion engines and propellers. Safety compliance was addressed with checklists and constant reinforcement of situation awareness. From content of this document, the UTA AVL is confident that its UAV is capable of achieving the performance goals of the 5th AUVSI Student UAV Competition.

ACKNOWLEDGEMENTS

Special appreciation goes to our primary sponsor, Bell Helicopter Textron, for their generous financial sponsorship. We also thank the MicroPilot Company for their technical contributions and discounts used on the project. Also to Reflex XTR for donating a computer R/C flight simulator to use for pilot training. Additional thanks goes to Multiplex for giving the team great deals on their radios and other electronics. Special thanks go to Jay Francis from Reactive Technologies for developing and donating two of his bypass boards to the AVL. The UTA AVL also appreciates ALDEN's donation of pulse lock connectors.

REFERENCES

1. MicroPilot, "MP2028g - Autopilot."2005, http://www.micropilot.com/Manual-MP2028.pdf
2. MicroPilot, "HORIZONmp User Guide."2004.
3. MicroPilot, "Working with radio modems." 2005.
4. MaxStream, "Xtend Wireless OEM RF Module." 2006. http://maxstream.net/products/xtend/product-manual_XTend_PKG-R_rs-232-rs-485-RF-Modem.pdf.
5. O.S. Engines, "61FX Owner's Instruction Manual." 2001.
6. SIG, "Kadet Senior ARF Assembly Manual." 2002.
7. Multiplex, "Royal EVO Instructions." 2002.
8. Multiplex, "Operating Instructions RX-9 / RX-12 SYNTH DS IPD receivers."
9. Ublox TIM-LP Product Summary http://www.u-blox.com/products/Product_Summaries/TIM-LP_Prod_Summary(GPS.G3-MS3-02028).pdf
10. Reactive Technologies- James T. Francis.
11. North Carolina State University- Dan Edwards.
12. EMS Jomar, http://www.emsjomar.com/SearchResult.aspx?CategoryID=4 , 2006

APPENDICES

Appendix I: Airframe Characteristics

Aircraft Parameters

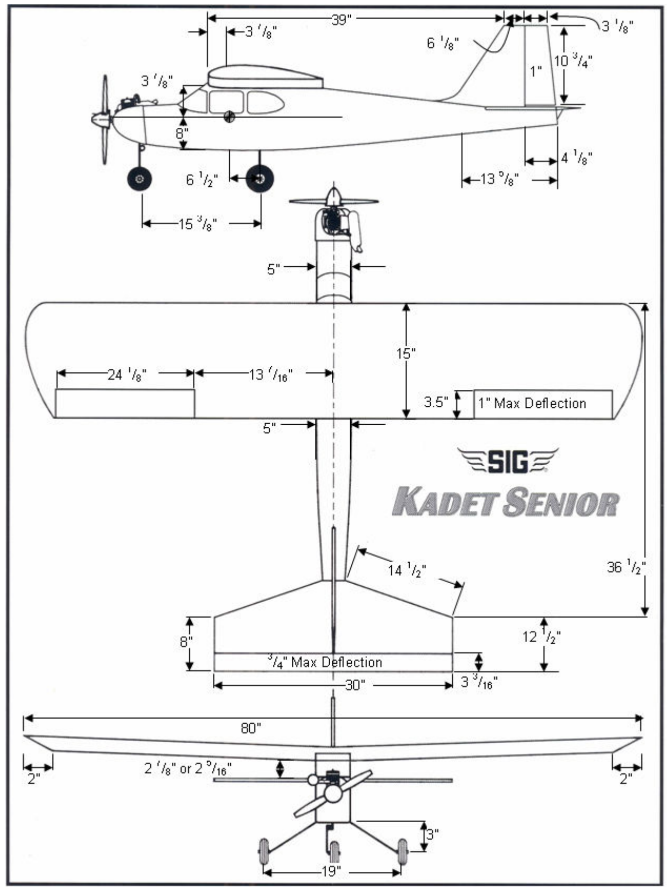
Aspect Ratio	5.07
Wing Area (ft^2)	7.92
Wing Span (ft)	6.33
W/S (lb/ft^2)	0.66
Fuselage Length (ft)	5.33
Fuselage Width (ft)	0.42
Weight Take-Off (lbs)	12
Weight Landing (lbs)	11.5

Engine Specifications

Engine Model	.91 FX (OSMG0591)
Displacement (cu in)	0.912
Bore (in)	1.091
Stroke (in)	0.976
RPM	2,000 -16,000
Output (hp @ rpm)	2.80 @ 15,000
Weight (oz)	19.3
Recommended Props	13x8, 13x9

Flight Characteristics of UAV

Cruise Speed (mph)	40
Max Speed (mph)	70
Cruise Altitude (ft)	250
Max TO Weight (lbs)	14
Empty Weight (lbs)	10.5
Range (mi)	20
TO Distance (ft)	60
Landing Distance (ft)	60
Wing Loading (lbs/ft^2)	1.768



Appendix Ii: Hardware Characteristics

Radio Communications Equipment Specifications

Model	Multiplex Evo 9 	Multiplex Synthesized Receiver 	MaxStream XTend Radio Modem 	Black Widow 2.4Ghz 1000mW Transmitter 	Black Widow 2.4Ghz 1000mW Receiver 	San Jose Navigation Inc. MK-4 
Type	Transmitter	Dual Conversion Receiver	Transmitter and Receiver	Video Transmitter	Video Receiver	Mini GPS Receiver
Channels	9	9	7	8	8	4
Frequency	72 MHz	72 MHz	900 MHz	2.4 GHz	2.4 GHz	2 GHz
Range	1.5 mi	1.5 mi	Up to 20 mi.	-	-	-
Operating Voltage	DC 8.2V	DC 4/6V	DC 8.7V	DC 12V	DC 12V	-
Connection Hardware	PC Interface Cable	Servo Control Wires	RS-232 PC Serial Interface Board	RCA F-type Wire Connectors	RCA F-type Wire Connectors	Coaxial cable

Camera

Model	RHPC-2000 	Sanyo VPC-HD1A 
Signal format	NTSC	NTSC
Resolution	768 x 494 pixels	640 x 480 pixels
Operating Voltage	12V, 130mA	3.7 V
Lens	1.9 mm wide-angle lens	6.3mm – 63.0mm Optical 10x zoom lens
Battery:	11.1 V LiPo	3.7 V Li-ion

Appendix Iii: Troubleshooting

Sample Troubleshooting Chart

Problem	Possible Cause(s)	Solution
Positive pitching moment	Negative thrust angle	Change the thrust angle to 0 deg
Radio frequency interference	GPS signal is causing an interference	Locate the GPS receiver away from the MicroPilot in a position in which its wires do not cross the MicroPilot or servos.
	Radio waves emitted from wires are causing interference.	Shield wires with copper tape with gap in the shielding and connect all the negatives to a common ground.
	Radio frequencies from the modem are causing interference.	The same as GPS signal interference. Separate main power source cables away from signal cables
Malfunctioning MicroPilot.	Radio frequency interference.	Cover micro pilot with 1mm thick copper box to isolate MicroPilot from frequencies and follow above solutions.
	Vibration from the engine is causing an interference	Mount the engine on vibration reduction mounds. Replace the engine to a less vibrating one.
Malfunctioning Radio Transmitter.	Transmitter is out of tune.	Send to the manufacturer for oscilloscope tuning.
Airplane making shallow bank turns.	The PID term “roll from heading” for is lower than required.	Increase PID term in order to get required bank angle.