Mississippi State University's Entry for the 2005 AUVSI Undergraduate Student Competition

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1.0 Abstract

Team Xipiter is Mississippi State University's entry into the Association for Unmanned Vehicle Systems International (AUVSI) Undergraduate Student Unmanned Aerial Vehicle (UAV) Competition. Xipiter, a modification of the Latin term for hawk, is a short-range, heavy duty UAV designed to perform autonomous flight via GPS coordinates, provide real time flight imagery, and return high-resolution photographs of any target designated during the time of flight. The approach is to use a student designed and fabricated UAV to perform an Intelligence, Surveillance, and Reconnaissance (ISR) mission. The design is built to carry a 10-15lb payload that is insensitive to vibrations and heat. The payload consists of two digital cameras (one low resolution video camera and one high resolution still camera), a Micropilot 2028g autopilot, high and low bandwidth wireless transmission capabilities, and a small form factor PC for programming communications. Many of the electronic components are commercial off the shelf (COTS) parts to allow for simple software modification in the event a component goes bad, or an upgrade is needed. A student-designed power supply unit (PSU) is utilized to power all of the onboard electronic components using an engine-driven AC generator. A backup battery supply is provided in the event of engine failure, along with voltage monitoring of each component.

2.0 Introduction

Team Xipiter is a multidisciplinary team composed of 15 undergraduate students from Aerospace Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Computer Science and Engineering and 2 high school students from the surrounding area. The team was formed to provide undergraduate students with experience in UAVs and to serve as a foundation for UAV research at Mississippi State University. The 2005 AUVSI Undergraduate Student UAV Competition features both autonomous flight and visual reconnaissance. These fields are crucial for both civilian and military applications alike for numerous reasons. By holding this competition, AUVSI allows undergraduate students to gain experience with new technology in both aircraft and electronics, develop new applications for existing equipment, and acquire hands-on experience; three things important to all aspects of engineering.

Per competition rules, Xipiter is designed to perform fully autonomous flight, including take-off and landing, fly at low altitudes and within GPS marked boundaries, and provide visual reconnaissance of short-time framed pre-determined data. While in flight, Xipiter can provide both low resolution video and high resolution still imagery on demand, and is capable of being dynamically re-tasked. Xipiter is able to perform such operations through custom-built and COTS equipment and software. Components include:

- Nikon Coolpix 4100 4MP Digital Camera
- TrendNET Internet Webcam
- 2.4 GHz Linksys Wireless Router
- 900 MHz MHX-910 Radio Modem
- Aaeon Gene-6350 Micro PC
- Micropilot 2028g Autopilot
- Custom-built DC Power supply
- Back-up batter supply

The airframe is a nearly all composite structure, made from fiberglass, carbon, plywood, and balsa. By competition rules, the plane cannot weigh more than 55lbs, as such the aircraft has been built to be durable, handle the weight of the components, and remain under this limit. Its simple design allows for easy construction in the event of catastrophic failure. The 2-stroke engine provides excellent power for the custom power supply while giving the airplane enough power to perform the mission. Airframe components include:

- Foam Core/Fiberglass Shell Wings
- Heavy Duty Fiberglass Fuselage
- Balsa/Carbon Tail
- Carbon Wing Spar
- Plywood Electronics Runners and Firewall
- Carbon Landing Gear
- 2-Stroke BT-64 Engine
- Brushless DC Motor for power supply
- High-torque servos and PCM Controller

Using this configuration, Xipiter will transmit in real-time to the ground station all GPS coordinates, airspeed, height, and bank and pitch angles along with high resolution still images of targets and low-resolution real-time video. The MP2028g software, Horizon MP, controls all avionics, while custom-built Labview software controls image display and data gathering. Open source software has been implemented into the 2.4GHz wireless routers to extend the range. In addition, all ground station antennas have been mounted to a custom-built stand to provide better range.

3.0 System Overview

The Xipiter UAV System consists of four electrical areas: avionics, reconnaissance, transmission, and power and the airframe. Below is an overall schematic of the Xipiter UAV System (Figure 3.1).

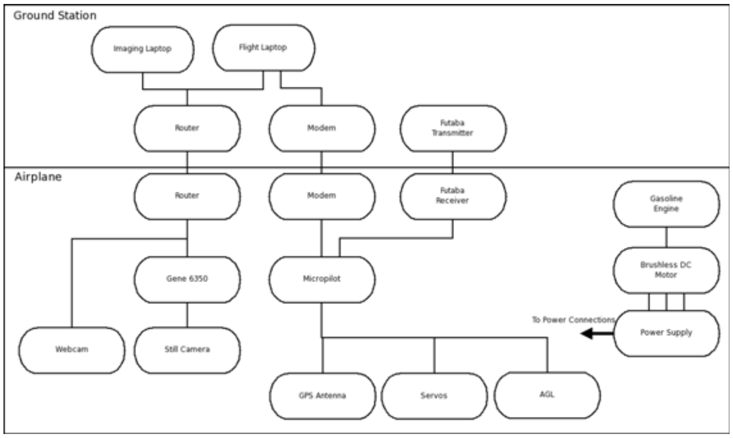


Figure 3.1: Xipiter UAV System

3.1 Avionics:

Micropilot 2028g

Xipiter is flown completely autonomous through the use of the Micropilot 2028g miniature autopilot system. This system is ideal for a UAV of Xipiter's size due to its small footprint and weight and its ability to coordinate with a standard R/C aircraft setup. The MP2028g includes onboard controls for all servos in the Xipiter, airspeed and altitude pressure transducers, and a standard serial connection for easy transmission of data. The MP2028g includes the ability to take-off and land using the associated AGL sensor. The MP2028g also allows for in-air re-tasking when FIXED commands are used. The Micropilot 2028g is shown in Figure 3.2 below.

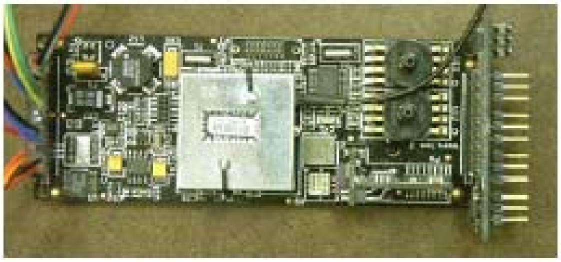


Figure 3.2: Micropilot 2028g Autopilot

R/C Control

R/C Aircraft (Manual Control) is performed via Futaba 9C Radio System which includes the Futaba transmitter and 9-channel receiver. This system also includes HiTech high torque servos. By using standard R/C control, manual flight can take place in the event of autopilot failure. Also, it provides a good control platform for testing autopilot and reconnaissance controls.

Reconnaissance:

Cameras

Xipiter must be able to provide visual reconnaissance of any unknown target at any time. The targets may have assigned GPS coordinates along the flight line, or within a diameter given by GPS coordinates. Due to these circumstances, prior knowledge of any target becomes nearly impossible, and initial recognition is easiest when done visually. To accomplish visual confirmation of targets, a simple internet camera has been located in the fuselage. This camera can transmit at 20+ frames per second (about that of a standard television) and has slightly better resolution than a normal television. In addition to providing target visuals, the camera also serves as an in-plane monitor to determine if the aircraft is responding as programmed. The internet camera may be seen in Figure 3.3.

Figure 3.3: Internet camera

Once Xipiter has located a given target, image quality becomes crucial to the mission. Civilian bandwidth limitations prohibit a high resolution camera from constantly recording. To overcome this limitation, a 4 megapixel Nikon Coolpix 4100 (Figure 3.4) still camera is used in conjunction with the internet camera. When a target is visually located, a command is given to the airplane via the ground control station to capture an image. This high resolution image is then transmitted to the ground station and processed to provide a superior image to that of the standard internet camera. The still camera provides an ideal solution for conducting detailed visual reconnaissance of given targets.

Figure 3.4: Nikon Coolpix 4100

Controllers

The center of reconnaissance control on Xipiter is the Gene-6350 Single Board Computer (SBC). In recent years, SBCs have become a cost effective solution for communicating to electronics in small areas. The Gene-6350 features a 600 MHz Intel Celeron processor with 4 USB 2.0 Ports and a boot ready compact flash drive. By using USB 2.0, the high-resolution camera communicates to its controller with one of the fastest forms of communication on the civilian market today. This insures as little latency as possible when trying to capture target images. The GENE-6350 communicates to its transmitter through a standard CAT 5 100Mbit/s Ethernet controller.

Transmission:

Wireless Network Communications

In order to receive real-time video from the Xipiter, we needed an antenna that would cover the greatest area and that was reliable. There are several types that fit this category, but after doing research and comparison on them, we decided that an omni-direction tripod mounted antenna would be the most reliable communication device. This is mainly because of the range and our vision will be obscured by a 6 foot wall (except for Mark, our 6’11” pilot). The tripod itself is 12 feet tall and is used in order to maximize the area covered by the antenna. The tripod is made from three telescoping painter poles, a fabricated antenna mount, and aluminum structural braces. The approximate maximum range of the mission is no more than an estimated 2500 feet and maximum ceiling of 500 feet. Using these numbers, a 10 dB (decibel) omni-directional antenna was determined to suit the mission needs. It has an isotropic transmit/receive coverage area.

An Omni-directional Antenna Beamwidth Analysis program was used to calculate the approximate “antenna to Earth” distance. With the center of the 10 dB omni-directional antenna located 14 feet above the ground, a 14 degree vertical 3 dB beamwidth, and the effective Earth radius K factor of 1.33, the range of the antenna was calculated to be 5.471 miles. Although this figure is based upon perfect communication parameters and the Xipiter will not fly at this range, the calculated range is well within the acceptable range. However, since all things are not perfect, a 1-watt amplifier is included as an additional safety margin.

A 2.4 GHz 802.11 b/g 1 watt amplifier was added in order to improve the ability of the antenna to transmit and receive. According to the Federal Communications Commission (FCC) regulations for “Wireless Power and Antenna Height Limitations”, chapter I, part 27, section 27.50, subsections a-h, with 1 watt of power output the system is still within civilian transmission limitations. This amplifier has a built in low noise receiver pre-amp with an 18 dB gain. This feature will amplify any incoming and outgoing signal while reducing any noise traveling on the carrier wave.

As noted this communication link is for real-time video transmission. The video is taken from a Trendnet network camera that is focused to infinity at 320x240 in order to get the best video possible when in flight. This network camera transfers real-time video via standard category 5e Ethernet cable through a 2.4 GHz Linksys Wireless Router with an inboard speed booster, and to the ground station’s video monitoring PC using the wireless link, where on command a picture can be taken of any target. The still picture will be taken by a digital Nikon Coolpix 4100**,** sent via USB 2.0 to the Gene-6350 for processing, and then sent to the ground station via the wireless link in order for the team to give orientations and descriptions of the targets.

Power:

Power System

The aircraft's electrical system had several requirements for its design. First, the system had to have a long endurance. The limiting factor for aircraft endurance could not be electrical power. Secondly, the system had to have a relatively high current output. The electronic components, especially the on board computer, had relatively high current requirements. Thirdly, the system had to have several different voltage outputs. The electronic components operate on five different voltages. Fourthly, the system had to be reliable, as an electrical failure would result in mission failure and possible aircraft loss. Fifthly, the system had to have a relatively light weight.

The first three requirements for the power system effectively ruled out a completely battery setup through the fifth requirement. Batteries of the right voltages and capacities to power the electronics would have pushed us far beyond the acceptable weight range, outweighing the inherent reliability of batteries.

The solution that was found was the design and construction of a generator based power system with battery backups. This system is comprised of a brushless DC motor acting as a three phase AC generator along with a custom power supply which converts the AC current to twelve, nine, six, five and three volts DC. A schematic of the power system is shown in Figure 3.5.

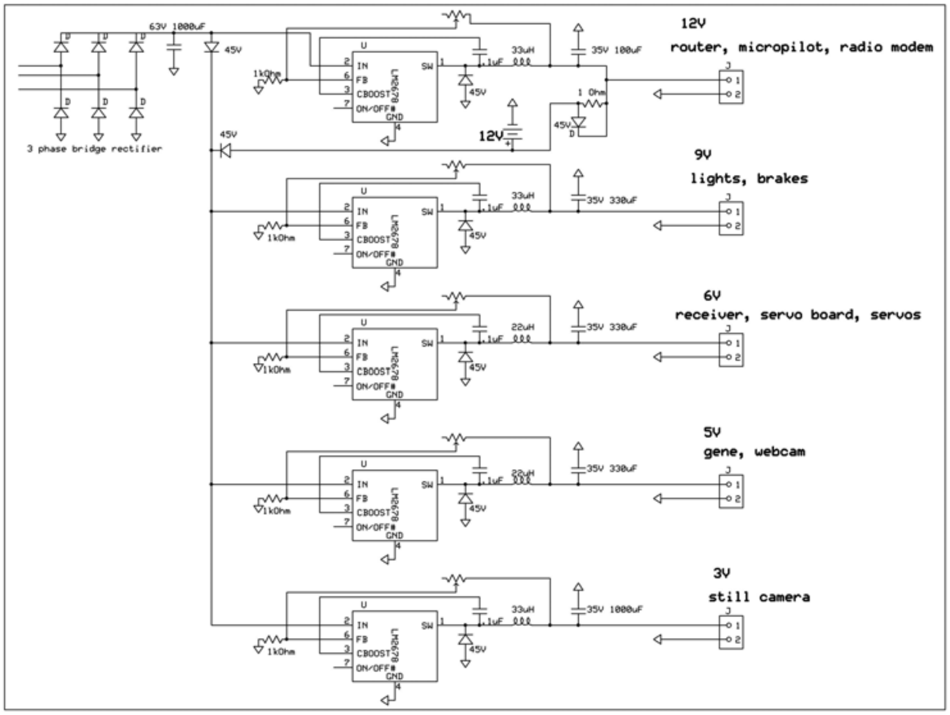


Figure 3.5: Power System Schematic

The brushless DC motor is an Aveox 27/26/4 capable of seventeen amps of continuous current output and twenty-three amps of surge current. The high current capability allows for the motor to operate at a high efficiency, with little cooling needed. It also provides for later expansion of the electronic systems. The motor is driven by a 2-stroke RC engine by way of a belt and timing belt/pulling setup for a 7 to 1 gear ratio.

The generator output is a three-phase AC that is linearly variable from 0 to 38 volts. This is converted to DC using a 3 phase bridge rectifier but still presents a problem in the design of the power system since most DC-DC converters do not have such a wide voltage range and those that do generally don't have a high enough current capability. This was overcome by designing custom power conversion circuitry. National Semiconductor LM2678 adjustable switching voltage regulators were used to convert the variable DC voltage to the 5 voltages required for the electronic systems. All circuits are fully adjustable from 2-13 volts by way of a potentiometer. The circuits were placed on a custom 4 layer PCB that is 4in X 4.5 in. The board is contained in a modified PC power supply casing and connects to the rest of the electrical system by way of standard Molex connectors.

The electrical system also consists of a battery backup. Two 12V nickel-metal hydride batteries of 2100 and 3700 mAh capacity are utilized for backup and startup purposes. The high current draw of the on board computer mandated the use of high capacity batteries in order to start the system without engine running and still have sufficient capacity to function as a backup. Both batteries are trickle charged by the on board generator and power conversion circuitry to maintain capacity in the event of failure.

The servos also have their own independent battery backup. This battery is connected by way of a 6V relay such that it is only powering the system in the event the 6 V conversion circuit fails. This setup means the power supply to the flight control system, including autopilot, receiver and servos is doubly redundant. The system can suffer a generator failure along with a 12V and 6V circuit failure and safely return to the landing site. All batteries are sized to allow at least 20 minutes of full electronic system operation in the event of generator failure.

Interference

In order for each system to perform properly, shielding is applied to all EMI components and all ground loops were removed. The MP2028g, AGL sensor, Radio Modem, and Router are encased in custom-built aluminum boxes. Servo wires and power supply cables are wrapped in aluminum and a common ground for EMI dissipation is added. The cameras remain in their factory casing.

Ground Control

The ground control station comprise of two computers. One computer, whose sole function is to monitor the ground track and performance and control the Xipiter, is attached to the 900 MHz radio modem. The other computer has the camera control software and the Lab-view software for data processing. The ground video antenna is attached to it.

Software

An attractive quality of the Linksys routers is their use of open source software to operate. This means that vendors are able to create a secondary market for router firmware. Sveasoft has done just that, and the result is a better feature set and more configuration options on top of Linksys's already-proven hardware.

The Alchemy series of Sveasoft's firmware is currently installed on the routers. Minor tweaks are made, but the significant change is the boost to wireless transmission power. According to various forums, one is able to change the transmit power field from the default of 28 to a value in the 60's without harming the router. Higher values are available but will potentially destroy the hardware over time.

In designing the communication patterns, it was decided to use two routers and to bridge them. However, the Linksys routers do not have that option available at the moment, so router-to-router communication is only possible with one router acting as a wireless client. While this configuration works, it only allows for one Ethernet port on the client router to be active at a time.

Although it would be a cleaner solution to use an Ethernet bridge for use in the airframe, a simple fix is to use a switch to provide the extra Ethernet ports. As one was on hand, we used the switch instead of buying new hardware. In this configuration, the network is setup as follows:

- To keep extra hardware out of the airplane, the airplane router is the access point. It manages the 192.168.1.* network.
- The ground station router accesses the airplane as though it was a wireless card and uses the static address 192.168.1.50 as its external IP address. Internally, it manages the 192.168.2.* network
- The TrendNet webcam connects to the airplane router via Ethernet and uses a static address of 192.168.1.51.
- The Gene 6350 also connects to the airplane router via Ethernet and uses a static address of 192.168.1.52.
- The switch connects to the ground station router via Ethernet and provides multiple Ethernet ports for the laptops on the ground.
- Ground station laptops acquire an address from the ground station router via DHCP. Requests for machines on the 192.168.1.* network are forwarded through the routers to the appropriate place.

A network layout for the Xipiter UAV System is in Figure 3.6.

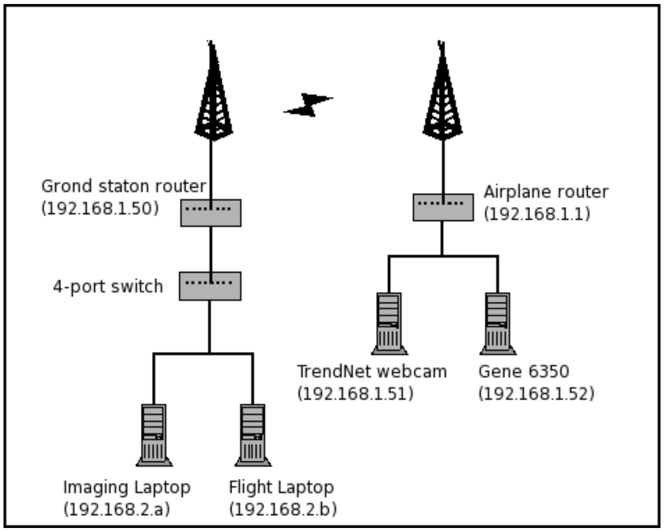


Figure 3.6: Network Layout

3.1.1 Camera Software

Camera control is achieved through the use of several software packages. Since the ground station laptops run Windows, a DLL was created that contains functions to connect to a specified server, request a picture, and receive a picture. Communication occurs over TCP/IP using the Winsock library. The ground station acts as a client for purposes of requesting a picture but runs a server on port 7001 through which it receives pictures.

Matching the client on the ground is a server on the Gene. Upon initialization, it binds to port 7000 and awaits a connection. It also initializes the camera by erasing the current contents of the camera's flash disk. When connected, any data sent through the socket is interpreted as a request for a picture. A picture is then taken, downloaded to the Gene's disk, and then an attempt is made to send the picture to a machine at a hard coded address. What this means is that several clients may connect and request pictures, but any pictures taken are sent to a central repository on the ground.

Communication between the Gene and the Coolpix camera is handled by the Gphoto2 library. It is an open source library for remote control of digital cameras via a serial or USB connection. Though it contains support for many vendor-specific protocols, the simplest way to talk to the Coolpix is via the PTP (Picture Transfer Protocol.) However, slight modifications were needed to enable the library to talk to our particular model. The way Gphoto knows how to communicate is to match the USB id's to a specific protocol. Since the Coolpix 4100 was unknown to the library, we added the relevant IDs, taken from the camera itself, to the PTP list. Once this was done, we were able to control the camera

3.1.2 Video Camera Package

The TrendNet webcam ships with an on-board HTTP for configuration purposes. Since the webcam is not the primary source of visual data, it is configured to provide high frame rates at a loss of image quality. The resolution is set to 320x240 with medium compression. The framerate was left at the automatic setting which defaults to 20 fps whenever possible.

The video stream can be accessed through the same HTTP server by accessing either an Active-X object or a Java applet. Both options provide the video stream as a rapid succession of JPEG images. An advantage of having a standard web interface to the camera is that any browser that can handle Java applets will be able to display the video feed. This fact was exploited when creating the imaging GUI for the ground station.

3.1.3 Custom Ground Control Image Package

The custom-built base station control center software enables all of the targeting, photography, and image processing for the mission. An event-driven Labview-based architecture was chosen due to its availability, its ease of use, and the skill set of the project team members. It was anticipated that a complex graphical application was needed to communicate with the various instruments and provide a simple user interface, so Labview seemed a natural choice. The software used was Labview 7.1.1 with the NI Vision add-on, running on Windows XP.

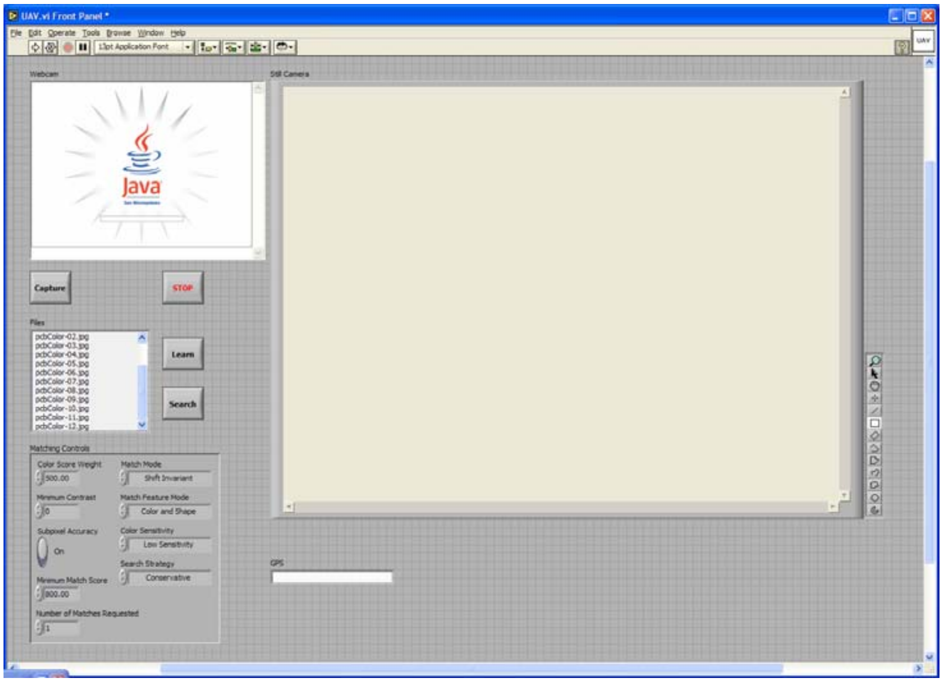
The Labview control center serves three major functions. First, it provides constant monitoring of the video camera mounted on the aircraft. The camera is a webcam, viewed by accessing a Java applet at an IP address on a local network. In the control center, this is accomplished through the use of an embedded Internet Explorer ActiveX control. When activated, the control loads a simple web page on the local system that embeds the camera’s Java applet. The effect is a video display on the control center’s front panel.

The second major function is to identify targets. For this, the control center must interact with the digital camera on the aircraft. This is done through a custom-built dynamic link library (DLL) on the local system that interacts with a miniature PC on the aircraft. When the control station detects that the user has pressed the “Capture” button, it runs a timing function, then calls the required function in the DLL, which in turn causes the camera to take a photograph. The PC on the aircraft then returns the image to the base station. When the control center detects that an image has arrived, it automatically loads it into a large image display window on the front panel. Once loaded, the user can easily identify and indicate various targets by simply clicking on them with the mouse.

The last major function of the base station control center is to record the exact GPS coordinates of the targets the user has identified. This is accomplished through an interface with the Micropilot autopilot system on the aircraft. When running, the control center constantly monitors a data stream from the Micropilot and extracts relevant data, such as GPS coordinate, airspeed, bank angle, and heading. These properties are combined in a series of mathematical functions to result in a grid of coordinates that corresponds to the still image being displayed on the screen. When the user clicks a target, its coordinates on the grid are recorded.

In the event that such manual clicking does not identify all of the targets in the images, an automatic pattern recognition system is also implemented, using the built-in recognition functions included in the National Instruments Vision add-on. With a still image displayed on-screen, the user draws a box around a sample target. He or she then pressed the “Learn” button, which causes the control center to capture the coordinates of the box and the image enclosed and send it to Labview’s learning function. The user then clicks the “Search” button, which causes the control center to iteratively call the pattern matching function for each captured image. The GPS coordinates corresponding to the centers of these matched patterns are recorded and optionally compared to those recorded during the manual selection. A simple matching control panel is also provided, allowing the user to tweak parameters to fit the situation at hand.

Screen shots from the Labview code is presented in Figures 3.6, 3.7, and 3.8.



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Minimum Contrast: 0
Subpixel Accuracy: On
Minimum Match Score: 800.00
Number of Matches Requested: 1
Match Mode: Shift Invariant
Match Feature Mode: Color and Shape
Color Sensitivity: Low Sensitivity
Search Strategy: Conservative

Figure 3.6

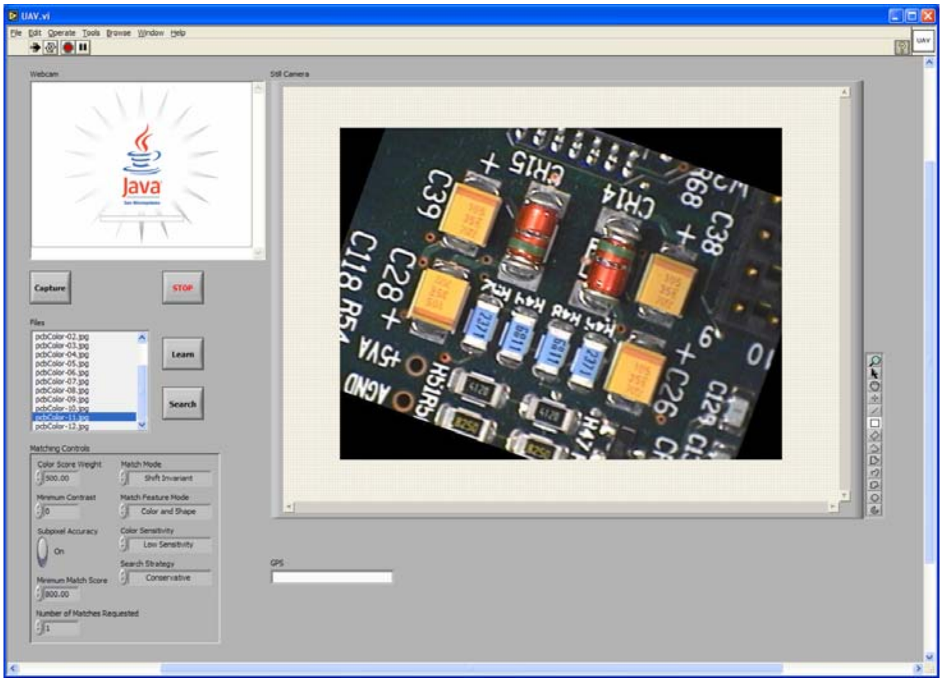

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Figure 3.7

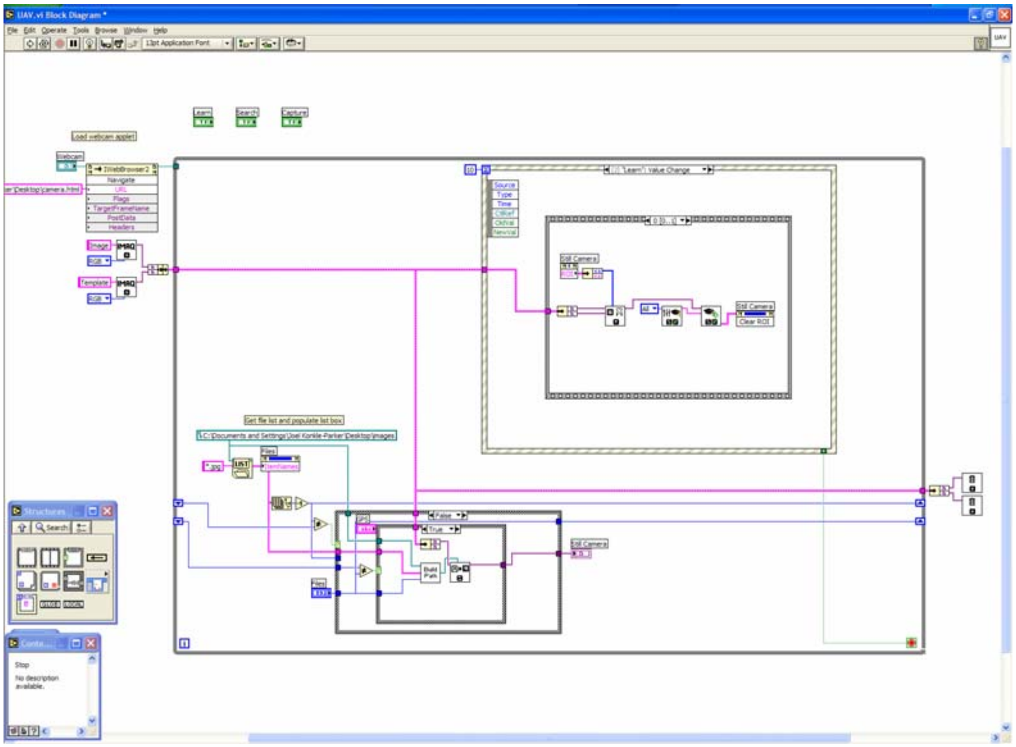

Figure 3.8

4.0 Airframe Overview

4.1 Justification behind building opposed to buying

In the initial design meetings, it was determined that the airframe team had to decide between buying an off-the-shelf RC aircraft kit or designing and building a completely new aircraft. The team decided to go with designing and building a new aircraft for two reasons. The first reason is that due to previous experience of trying to fit systems into a RC aircraft, it is considered easier to build around the systems than to modify an existing fuselage layout to carry them. The second reason is that it was decided that designing the airframe would expose the students to the world of aircraft design and flight testing. Xipiter is an airframe that accomplishes both of these goals.

4.2 Airframe

In designing the aircraft, the team determined the following features as the main design criteria:

- High wing aircraft for stability
- Maximum empty weight of 45 lbs
- Lift-Drag ratio
- Useful volume
- Manufacturability
- Strength
- Fuel consumption

After reviewing several possible concepts, the team decided that Xipiter should be a high wing conventional tractor aircraft with tricycle landing gear. When considering what materials to fabricate the aircraft from, there were two options: a built up balsa structure or a composite structure with bulkheads. The team needed to maximize the internal payload volume of the fuselage, so a composite shell structure with bulkheads was chosen as the best possible solution. Fabricating the airframe from composites allows the team to get the needed strength and structural integrity, while maximizing internal volume for the payloads. Xipiter is designed to perform the mission, but also has expandability built into the airframe. It has enough useable volume and is strong enough to hold future, and maybe even heavier, payloads. The team chose fiberglass as the composite material because of low initial cost versus carbon and familiarity with fiberglass. The airframe is built utilizing a "mold less" wet lay up process, pioneered by Burt Rutan. The entire airframe is built of composites with the exception of the empennage. The empennage utilizes a built-up balsa frame for the stabilizers and control surfaces. This technique is used to save weight in the tail. The wings are of a solid-core composite construction. High density insulation foam is used as the core material in the wings.

The wing uses a Selig-Donovan 7062 airfoil shape. This airfoil is a good low Reynolds number, high-lift airfoil. Other high lift airfoils were considered, but the SD7062 was chosen due to its thicker shape and thicker trailing edge. These two facts allowed for easier fabrication of the wings using a wet lay up process. Due to the size of the aircraft, the team decided to use symmetric airfoils for the tail surfaces. The airfoil chosen is the J5012.

Figure 4.1: Xipiter

Xipiter has the following specifications:

Wingspan	117.5 in
Wing Area	1886 sq in
Wing Loading	0.027 lb per sq in
Aspect Ratio	7.3
Wing Airfoil	SD7062
Empennage Airfoil	J5012
Weight – gross	53 lb
Weight – empty	51 lb
Weight – airframe	47 lb
Weight - systems	4 lb
Engine	Fuji BT-64A
Propeller	20 x 10
Length	77 in
Number of Servos	5
Radio	Futaba 9CA

Table 4.1: Aircraft Specifications

4.3 Performance and Stability

The team designed Xipiter to not just be able to structurally carry future loads, but to also be able to fly these payloads and perform future missions. The aircraft has enough power to fly the mission well above its stall speed of 32 mph and its cruise speed of 45 mph. Additionally, it has enough available power to fly heavier payloads at its cruise speed. Xipiter's power required curve is shown in Figure 4.2.

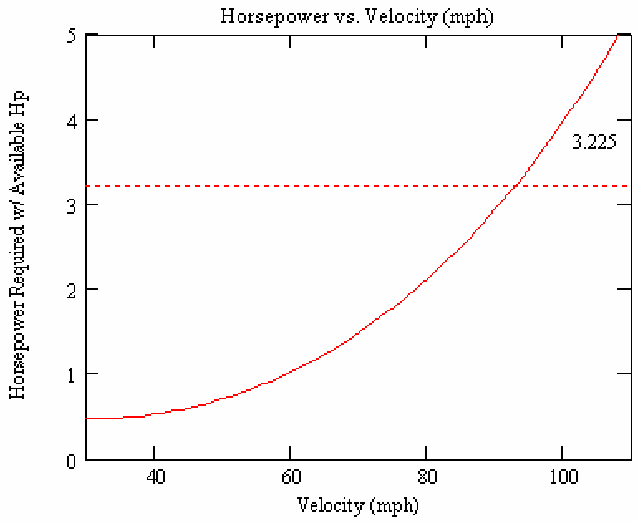

Figure 4.2: Power Polar of Xipiter

One major reason the team decided to use a high-wing tractor aircraft is that it provides a very stable aircraft to be used as a sensor and reconnaissance platform. According to Xipiter's longitudinal stability analysis, the team has succeeded in designing and building a very stable platform. The airplane's CG range is 2 inches.

4.4 Engine

An Fuji BT-64A gasoline engine as shown in Figure 4.3: Fuji BT-64A Engine powers the Xipiter UAV. This particular engine has the following specifications:

- 1200 – 9000 rpm
- Output of 5.7 hp @ 9,000 rpm
- Weight of 5.7 lb
- 3.85 cu in capacity

Figure 4.3: Fuji BT-645 Engine

4.5 Transmitter, Receiver, Servos

The transmitter is the Futaba 9CA transmitter. This is an 9-channel PCM transmitter that is fail-safe configurable. The receiver built into the Xipiter UAV is a Futaba R138DP with the following specifications:

- 8 channels
- 72Mhz band
- Operating voltage range of 3.5-6.0V
- 6000+ ft. range
- Weight of 1.75oz.

5.0 Testing

The aircraft demonstrated both static and dynamic stability both under manual and automatic control. The level of stability was sufficient for ISR.

At idle throttle, the generator provides the power supply with enough voltage to run the 3V, 5V, and 6V circuits. At cruise throttle, the generator RPM is well above the threshold to produce enough voltage to run the rest of the circuitry.

Electronic systems have been thoroughly bench tested, and all major goals have been met. Wireless ranges were initially found to be lacking, but further work has increased the range of both the 72 MHz and 2.4 GHz signals to acceptable levels.

In timing the cameras, it was found that a person watching the video feed would experience about 1-2 seconds of delay between witnessing an event and actually capturing a still image. Additional users viewing the video feed increases this delay further.

In testing autonomous flight, the Micropilot was found to achieve its waypoints with reasonable accuracy and respond well to in-flight retasking.

Acknowledgement

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Jersey Modeler
Miltech
FAB-Corp

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X-IPITER
MISSISSIPPI STATE UNIVERSITY

If it Kwax, then it must be a Xawk.