The Anatomy of Athena: The Engineering Behind Polytechnic University's UAV

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Abstract
The Association for Unmanned Vehicles Systems International (AUVSI) issues an annual challenge to undergraduates to architect, develop, and present an unmanned reconnaissance aircraft capable of completing an assigned mission. The main goal of the mission is for our plane to fly autonomously to specified GPS coordinates, find a set of targets, and take high quality images of the target. Our UAV design is comprised of five major components: 1) the Aerial Vehicle 2) the Autopilot System 3) the Ground Communication Link System 4) the Surveillance and Target Acquisition System and 5) the Safety System. The aircraft is an off the shelf Piper Cub that can safely carry 9 lbf of payload. We are using a state of the art autopilot, namely Piccolo Plus from Cloud Cap Technologies. To further increase capabilities, customized Ground Station software is created. A navigation bullet size camera is used to provide live feed images to ground station for target identification. A high resolution camera, Sony 7.2 MegaPixel, was used to take high quality pictures. And lastly, to ensure the safety of the people involved in the competition, a four level Safety System is created. With all the described features, we have created a robust and safe UAV to complete the mission.

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1 INTRODUCTION

Unmanned Aerial Vehicles have increasingly been utilized for various civilian and military applications such as weather monitoring, fire fighting, reconnaissance mission, communication relay mission, target strike mission, or even agricultural applications (e.g., crop dusting, soil monitoring, etc.)[4, 5, 6, 7]. With advances in electronics, miniaturization of sensors, and fast microprocessors in the past two decades, feasibility of small UAVs performing complex missions have improved. There are various competitions promoting design and utility of UAVs. The AUVSI started an annual UAV competition in 2002. The basic rules of this competition are given in the next subsection. To respond to this competition, Polytechnic University's UAV Club has integrated a UAV, namely Athena.

Athena is based on a commercial off-the-shelf (COTS) RC fixed wing aircraft, namely a J-3 Piper Cup plane. We have integrated various subsystems to develop a UAV from this RC plane. These subsystems are:

- Auto-Pilot
- Ground Station and Communications
- Surveillance & Target Acquisition System
- Safety Subsystem

The aforementioned subsystems will be described in detail in the sequel. The auto-pilot is the Piccolo Plus from Cloud Cap Technology. Although the auto-pilot includes a feature to allow switching between the RC transmitter (pilot in command – PIC) and the auto-pilot (computer in command – CIC), we have also added further safety features through a second set of RC receiver and transmitter. The payload for our UAV, named Athena, is the Surveillance & Target Acquisition System required for meeting the objectives of the competition. To this end,we are utilizing a bullet video camera in conjunction with a high resolution digital camera mounted on a gimbal. The high resolution camera is commanded from the ground station, when the operator recognizes a target in the live video feed from the video camera. We have also developed required software to overlay GPS data on the live video feed and the still high resolution pictures as well as computing the coordinates of the target based on aircraft altitude, position, and the gimbal orientation. The detailed descriptions of the above subsystems and our effort in their proper integration are given in the upcoming sections.

1.1 2006 AUVSI Competition Rules

The aircraft's weight cannot exceed 50 lbf. The aircraft must fly within the altitude restriction of 50 ft to 500 ft above ground level during its mission. The total mission time from preflight checks to data processing is limited to 40 minutes. The main mission is to fly to a set of given GPS waypoints autonomously, and along the way spot and photograph targets on the ground. New GPS waypoints will be given during mission to assess dynamics control of the UAV. Once the mission is completed, the aircraft must be landed in the designated landing area. Autonomous landing and takeoff is considered extra credit.

2 System Overview

The Athena (Figure 1) is comprised of five components: the Aerial Vehicle, the Autopilot System, the Ground Station, the Surveillance & Target Acquisition System, and the Safety System . The Autopilot System is what makes autonomous operation possible. Our Autopilot System consists of Cloud Cap's Piccolo Plus avionics and Piccolo Ground Station. The Ground Communication Link System is the operator's link to the UAV. The operator can input new flight plans or GPS coordinates during flight through the Ground Communication Link System. The Ground Communication Link System is a 900Mhz radio modem from Microhard Systems which is integrated into Piccolo Plus avionics and integrated into Piccolo Ground Station. The Surveillance & Target Acquisition System consists of a Navigation camera and a high resolution camera, both of which are mounted on a pan & tilt gimbal. The gimbal is controlled by the operator on ground via Piccolo Plus's I/O port. The overall components onboard Athena are given in Figure 2 The navigation video camera feeds back to ground station live via a video transmitter. When the operator spots a target through the live feed video, the operator can take a picture of the target with the high resolution camera commanded through the ground station. The Safety System is a 4-layer fail-safe system. In the first layer, safety is addressed by the pilot. The pilot has access to PIC/CIC switch that enables the pilot to have full control of the aircraft. The second layer is Autopilot's own fail-safe which commands the UAV to orbit a preset GPS coordinate when ground communication is lost. The third layer is addressed by the relay switch, that switches from Autopilot control to human control via an auxiliary RC receiver onboard. The fourth layer is the RC fail-safe which sets the UAV for a nose dive in case the worst should happen. The final component of our design is the Aerial Vehicle that can support our payloads and still be able to meet our performance requirements.

3 AUTOPILOT SYSTEM

The requirements for the autopilot are the following:

- It should have a user friendly and tunable control systems so that it can be tuned for a variety of aircrafts.
- It should have G.P.S. navigation system
- It should be able to handle dynamic flight plan changes
- It should have at least 5 servo outputs (Throttle, Rudder, Elevator, R&L Ailerons)
- It should have I/O ports for gimbal and video controls

Cloud Cap's Piccolo Plus meets all the above requirements.

3.1 Piccolo Stability & Control & Tuning

The avionics and auto-pilots for UAVs are comprised of navigation sensors and control systems to achieve autonomous flights. The navigation sensors on board the Piccolo Plus are equivalent

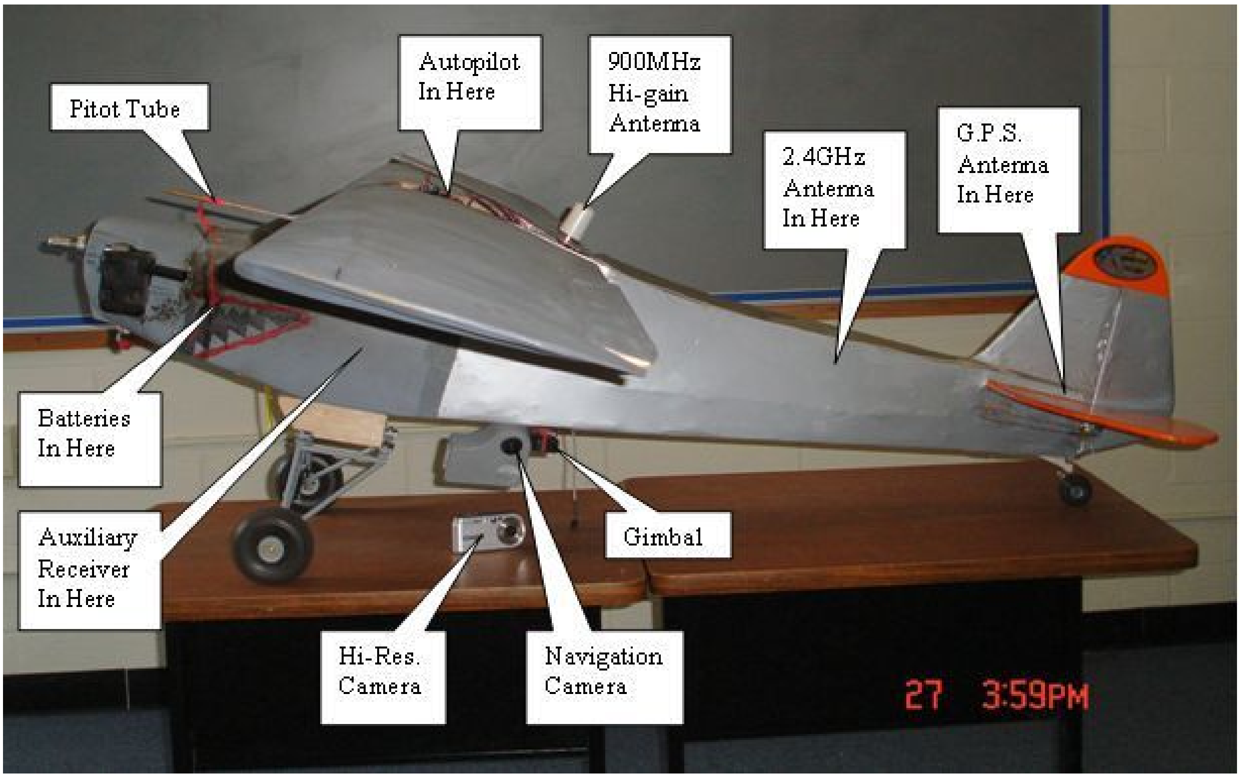

Figure 1: UAV

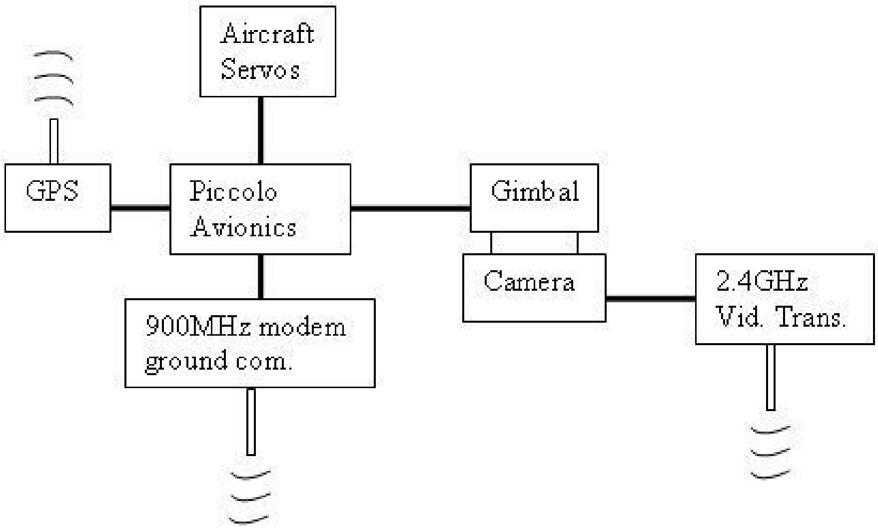

Figure 2: Block Diagram of Subsystems Onboard Athena

to a six degree-of-freedom inertial navigation unit (i.e., three gyros and four accelerometers), an absolute pressure sensor (for altitude measurement), a relative pressue sensor (for air velocity measurement) and a GPS unit. The reference commands to the control system are provided through the ground station software via waypoints inputed by the user, and the control system develops the required servo outputs to drive the plane's control surfaces as well as the throttle. The control system in the auto-pilot is comprised of PID feedback loops for different control surfaces as well as a number of feedforward signals to account for cross coupling in dynamics due to various degrees-of-freedom.

The main effort in achieving autonomous flight is the integration of the auto-pilot in the RC plane, and tuning of the various control loops that drives the servos on board the vehicle. The tuning to be performed is mainly to ascertain the gains in the several PID controllers utilized in the auto-pilot. It turned out that the initial gains loaded in the auto-pilot were reasonable in achieving stability; nevertheless, a reasonable amount of flight and tuning needed to be performed to tune the gain in the various axes (refer to Piccolo manual for tuning procedures). The basic PID Controller is described in the next subsection.

3.2 PID Controller

Piccolo utilizes a standard Proportional-Integral-Derivative (PID) controller. The transfer function for a PID is given by

$$G_s(s) = K_P + \frac{K_I}{s} + K_D s \tag{1}$$

- K_P is the proportional coefficient and affects stability and speed of response.
- K_I is the integral coefficient and affects the steady-state tracking error of the closed-loop system by increase the type of the system.
- K_D is the error-rate coefficient and affects the stability of the system by providing damping.

The controllers output in time domain is,

$$u(t) = K_P e(t) + K_I \int_a^b e(t)dt + K_D \frac{de(t)}{dt} \tag{2}$$

To achieve the desired response of the PID controller, the parameters K_P, K_I, K_D, and have to be changed. This is called "tuning" the controller's gains. This is a major effort to achieve proper performance of the system. Several flights were performed and data was collected from the auto-pilot system in order to further fine-tune the gains.

4 Ground Station

The ground station is comprised of a laptop computer running the operator interface for the Piccolo Plus auto-pilot, ground communication link system, video monitor and video receiver and antenna, and gimbal controls. The overall components are given in 3. The ground communication system maintains constant communication with the UAV. The video system provides live feed and controls the gimbal through the in-house developed software.

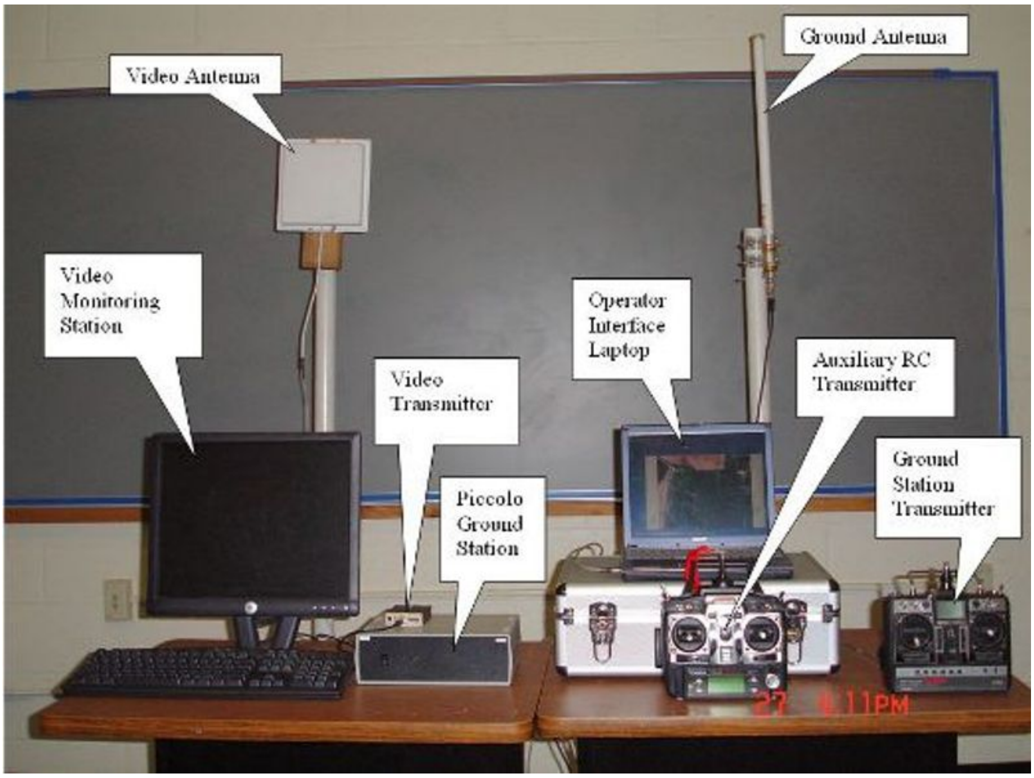

Figure 3: Ground station

4.1 Ground Communication System

The Ground Communication System consists of Microhard Systems' 900MHz 1 Watt radio modems which is integrated into Piccolo avionic and Piccolo ground station. The sensitivity of a receiver is a measure of the threshold signal strength needed for the receiver to accurately decode the signal. The signal strength from a transmitter is given by

$$W_{radiation\_density} = \frac{Power_{radiation\_power}}{4\pi d^2} \tag{3}$$

Since the signal strength at distance d is inversely proportional to d^2, the communication ranges d_1 and d_2 corresponding to gains G_1 and G_2, respectively, of the receiver are related as

$$\frac{d_1}{d_2} = \sqrt{\frac{G_1}{G_2}}. \tag{4}$$

The gain of antenna is given by $gain = 10^{\left(\frac{Power(dB)}{10}\right)}$. A transmitter with an antenna gain of 2 can radiate twice the power in decibels. Piccolo Plus has an integrated 1 Watt radio modem.

According to waypoints given at last year's competition and the size of the field, the maximum range was 0.75 miles. To be confident that our UAV will maintain communication link with the ground station, a desired minimum range of 1 mile is chosen.

To test the sensitivity of Piccolo's radio modem which is a 900MHz modem, a ground range test was conducted. Piccolo's operator interface indicates signal strength. A signal strength of

-71dBm is optimum, whereas a signal strength of -115dBm is minimum. For our ground range test setup, the 0dB antennas were mounted both onboard and on the ground station. All other onboard systems and the engine were off to prevent range loss by interference. A member stood by the ground station to monitor signal strength, meanwhile another member taxied the UAV away maintaining clear line of sight. The ground station operator recorded the distance where the signal strength fell below -71dBm. The ground range with 0dB or 2.1dBi antennas both onboard and at the ground station is 0.6 miles. The radiation density at 0.6 miles is given by:

$$W_{rad.} = \frac{Power_{rad.}}{4\pi d^2} = \frac{1Watt}{4\pi(0.6mile \cdot 1609\frac{m}{mile})} = 8.53 \times 10^{-8}\frac{Watt}{m^2} \quad (5)$$

This means that the radio transceiver can decode properly any signal with a power of $8.53 \times 10^{-8}\frac{Watt}{m^2}$ or greater. Using (4), if an antenna with a gain of 3dB is used instead of a 0dB gain antenna, the range would be increased by a factor of $\sqrt{10^{\frac{3dB}{10}}} = 1.412$ yielding $d_{new} = 0.6mile * 1.412 = 0.848mile$. If a 3dB gain antenna is used at the other end also, the range is increased by a further factor of 1.995 yielding a range of $d = 1925m = 1.19mile$. The use of omni-directional 3dB antennas at both the ground station and the UAV prevents loss of communication when the UAV makes sharp turns or banks at a particular angle where a dipole antenna emission spectrum can not cover the ground station.

5 Surveillance and Target Acquisition

The Surveillance and Target Acquisition system consists of a video transmitter, a navigation camera, a high resolution camera, and a gimbal. A 2.4Ghz video transmitter is chosen to prevent radio interference with the 900MHz radio modem. The Navigation camera has a resolution of 768x494 pixels. This resolution is low enough to be transmitted through our video transmitter, and at the same time good enough for the operator to spot possible targets. Once the operator spots the target, the operator can chose to take a snap shot of that target with our high resolution camera. Our high resolution camera has a resolution of 7.2 Megapixel. The two cameras are mounted on a two-axis gimbal.

5.1 2.4GHz 1 Watt Video Transmitter

The goal here is again to achieve a minimum range of 1 mile. The ground range test setup for video transmitter is similar to the one used to test the 900 MHz radio modem. The engine and all other systems were off to prevent interference. A member stood by ground station monitoring live feed quality, meanwhile another member taxied the UAV away maintaining clear line of sight. Since we don't have instrument to tell us signal quality, we took the maximum range to be the distance where snow appeared on the live feed video. The ground range test with 0dB or 2.1dBi antennas is 0.25 miles. Using (4), the use of a 14dB antenna at the video receiver gives an increased range of $0.25 * \sqrt{10^{\frac{14dB}{10}}} = 1.25$ miles.

6 Onboard Power Consumption and Battery

Four batteries (Table 1)are used to power the onboard system instead of one to create redundancy. These batteries are two 11.1V Li-ion batteries, one 6V Ni-MH battery, and a 3.7V Li-ion battery. Piccolo, G.P.S. antenna, and the navigation camera would be powered by one of the 11.1V Li-ion battery because these components are essential for the aircraft to be autonomous. The reason for putting the navigation camera in with the essential components is to even out the load on the two batteries. The video transmitter and gimbal would be powered by the other 11.1V Li-ion battery. The high resolution camera is powered by the 3.7V Li-ion battery. The 6V Ni-MH battery powers the onboard servos which control the ailerons, elevator, rudder, and throttle. The onboard power requirement can found on Table 2. One important fact to consider is mission time which is 40 minutes. A safety factor of 2 is taken for battery operation time. The goal is to have the UAV run for at least 80 minutes between recharge.

System / Item	**Battery**	**Operating Time**
Piccolo + Navigation Camera	11.1 V, 2350 mAh Li-ion	6.01 hr
Gimbal + Video Transmitter	11.1 V, 2350 mAh Li-ion	1.62 hr
Hi-resolution Camera	3.6 V, 1222mAh Li-ion	3.70 hr
Aircraft Servos	6 V, 2300 mAh Ni-MH	1.5 hr

Table 1: Specifications for Required Batteries

Onboard Component	**Amp. (mAh)**	**Voltage**	**Tolerance**	**Wattage (Wh)**
Piccolo (AutoPilot)	300	12 V	8 V-20 V	3.6
Navigation Camera	80.0	12 V	N/A	0.96
Sony DSC-P200	330	3.6 V	N/A	1.2
Video Transmitter	450	12 V	8 V-13 V	5.4
G.P.S. Antenna	11.0	5 V	3 V-5 V	0.055
Gimbal	1000	12 V	9 V-12 V	12
Total	**2171 mAh**			**23.215 Wh**

Table 2: Power Requirement for Onboard Components

7 SAFETY

Safety is extremely important in the design and performance of UAVs, not only to protect the people on ground involved with the UAV, but also to guarantee the well being of the UAV's reconnaissance equipment and intelligence gathered. For our UAV, safety is addressed at four levels: level one and two which guarantee the safety of the aircraft and people on ground, and level three and four which only guarantee the safety of people on ground.

7.1 Level One Safety

At this level, safety is addressed by the pilot. By triggering the *Pilot In Command* switch on the ground station RC control or ground control workstation, the pilot can regain full control of the aircraft, maneuver the aircraft, and land if he/she considers it necessary. This way the well being of the aircraft and people on the ground is guaranteed.

7.2 Level Two Safety

At this level, safety is addressed by an auxiliary receiver on board. In case of Piccolo's total failure, the pilot will be able to regain full control of the aircraft by the use of an auxiliary receiver that is powered by the triggering of a relay. If Piccolo fails, a *Kill Engine* signal used to kill the engine will be issued by the autopilot. Instead of killing the engine, we are using Piccolo's signal to trigger a relay that will switch the power dedicated to servos from Piccolo to the auxiliary receiver. The relay is capable of handling up to 5A of current, featuring a nominal coil voltage of 5V. This way the pilot can regain control of the aircraft and land it safely without destroying it. This precaution is necessary because if Piccolo fails the pilot has no control over the aircraft at all, and the aircraft becomes a dangerous flying object for people on ground.

7.3 Level Three Safety

At this level, safety is addressed by Piccolo. In the event of the UAV losing communication with the ground station, Piccolo will follow a predetermined safety waypoint orbit specified by the ground control crew. This safety loop is programmed by the ground control crew before the UAV is airborne. Once communication is lost between the aircraft and the ground station, Piccolo will follow this loop keeping the aircraft flying at a safe altitude while burning fuel. In the event of not regaining communication with the ground station, Piccolo will keep orbiting until the fuel is totally consumed, in which case the altitude will start decreasing and the aircraft will spiral down to ground level. Because of this reason it is extremely important to determine the safety waypoint loop on an area that does not represent a threat for people on the ground.

7.4 Level Four Safety

At this level, safety is addressed by the auxiliary receiver on board. In case of total failure from Piccolo and losing total communication with the auxiliary receiver, the receiver will activate RC *RC Fail Safe Mode*, which will make the UAV go into a dive and destroy itself by crashing on the ground. Even though this does not guarantee the UAV protection, it prevents the UAV from becoming a dangerous flying object and a threat for people on the ground.

8 Aircraft Performance Analysis

Knowing the performance limits of our aircraft is very important. For example, if one does not know the turning stall speed of the aircraft, one may input slower turning speed than stall speed. This can cause the aircraft to crash. The following analysis has been done to calculate our aircraft's performance limits.[2]

8.1 Aircraft Parameters

A conservative value of 0.6 had to be chosen for propeller efficienty m_p in the absence of a wind tunnel. Tables 3,4, and 5 lists the essential variables to calculate aircraft performance parameters [1].

$Vmax$	Maximum cruising speed
$Vstall$	Stall speed
CDo	Drag coefficient at zero angle of attack
$Emax$	Maximum lift over drag ratio.
W_{gross}	Gross weight
W_{fuel}	Fuel weight
HP	Horse power
S	Wing area
n_p	Propeller efficiency
f_d	Deceleration factor

Table 3: Aircraft Parameters

Vmax	Vstall	CDo	Emax	Wgross	Wfuel	HP	S	η_p	f_d
80ft/s	41ft/s	*0.0373	*9.6	24.7lbf	1.53lbf	2.2hp	8.958ft^2	**0.6	**0.3

Table 4: Aircraft Parameters

** Values are taken from actual Piper J-3 Cub
** Value is estimated

Item	**Weight**
Fuselage	6.59 kg
Wings	1.13 kg
Payload	3.52 kg
Total	**11.24 kg**

Table 5: Aircraft Component Weight

Maximum coefficient of lift (CL_{max}) is calculated using the following equation:

$$\Rightarrow CLmax = \frac{2\frac{W}{S}}{\rho {V_{stall}}^2} = \frac{2\frac{24.7lbf}{8.958ft}^2}{23.76\times10^{-4}\frac{lbf\cdot s^2}{ft^4}\cdot(41\frac{ft}{s})^2} = 1.38$$

$$K = \frac{(\frac{1}{2E_m})^2}{CDo} = \frac{(12\cdot 9.6)^2}{0.0373} = 0.0727$$

8.2 Take-Off Characteristics

The lift off speed is taken to be 1.2 times the stall speed. The lift distance can be calculated as follows:

$V_{L.O.} = 1.2V_{stall} = 1.2 \cdot 41\frac{ft}{s} = 49.2\frac{ft}{s}$

$\Rightarrow d_{L.O.} = \frac{{V_{L.O.}}^3}{1100\eta_p g\sigma \frac{HP}{W}|_{S.L}} = \frac{(49.2\frac{ft}{s})^2}{1100\frac{ft\cdot lbf}{s\cdot hp}\cdot 0.6\cdot 32.17\frac{ft}{s^2}\cdot 1\cdot \frac{2.2hp}{24.7lbf}} = 62.9ft$

8.3 Stall Characteristics

8.3.1 Level Flight

Level flight stall speed was measured during a flight test, V$_s tall$ = 41 ft/s

8.3.2 Turn

Turning stall speed can be calculated with the estimated propeller efficiency as follows:

$V_{stall,turn} = \left[\frac{1100\eta_p \frac{HP}{S}}{\rho_{S.L.}\sigma(CD_o+KCL_m^2)}\right]^{\frac{1}{3}} = \left[\frac{1100\frac{ft\cdot lbf}{s\cdot hp}\cdot 0.6\cdot \frac{2.2hp}{8.958ft^2}}{23.76\times 10^{-4}\frac{lbf\cdot s^2}{ft^4}\cdot 1\cdot (0.0373+0.0727\cdot 1.38^2)}\right]^{\frac{1}{3}} = 72.8\frac{ft}{s}$

$n_{stall,turn} = \frac{\rho_{S.L.}\sigma V_{stall,turn}^2 CL_{max}}{2\frac{W}{S}} = \frac{23.769\times 10^{-4}\frac{lbf\cdot s^2}{ft^4}\cdot (72.8)\frac{ft}{s}^2\cdot 1.38}{2\cdot \frac{24.7lbf}{8.958ft^2}} = 3.15$

The following calculations represents the maximum bank angle ($\Phi_{n_{stall}}$), maximum turn rate ($\dot{\chi}_{stall}$), and minimum radius (r_{stall}) possible for this aircraft:

$\Phi_{n_{stall}} = \arccos\frac{1}{n_{stall}} = \arccos\frac{1}{3.15} = 71.6^o$

$\Rightarrow \dot{\chi}_{stall} = \frac{g\cdot\tan(\Phi_{n_{stall}})}{V_{stall,turn}} = \frac{32.17\frac{ft}{s^2}\cdot\tan 71.4^o}{72.8\frac{ft}{s}} = 75.2\frac{deg.}{s}$

$\Rightarrow r_{stall} = \frac{V_{stall}}{\dot{\chi}} = \frac{72.8\frac{ft}{s}}{1.31\frac{rad}{s}} = 55.5ft$

8.4 Best Range

The maximum distance is calculated to be 51.3 miles. The corresponding engine power at this condition is 20% of maximum.

$\xi = \frac{m_{fuel}}{m_{gross}} = \frac{1.53lbf}{24.7lbf} = 0.0619$

$V_{BR} = V_{md} = \left(\frac{2\frac{W}{S}}{\rho_{S.L.}\sigma}\right)^{\frac{1}{2}}\cdot\left(\frac{K}{CD_o}\right)^{\frac{1}{4}} = \left(\frac{2\frac{24.2lbf}{8.958ft^2}}{23.769\times 10^{-4}\frac{lbf\cdot s^2}{ft^4}}\right)^{\frac{1}{2}}\cdot\left(\frac{0.0727}{0.0373}\right)^{\frac{1}{4}} = 56.9\frac{ft}{s}$

$\Rightarrow X_{BR} = \frac{375\eta_p E_{max}}{\hat{c}}\ln\frac{1}{1-\xi} = \frac{375\frac{mile\cdot lbf}{hr\cdot hp}\cdot 0.6\cdot 9.6}{2.7\frac{lbf}{hr\cdot hp}}\ln(11 - 0.0621) = 51.3 \text{ miles}$

$\Rightarrow \frac{P_{BR}}{W} = \frac{V_{BR}}{E_{max}} = \frac{56.9\frac{ft}{s}}{9.6} = 5.92\frac{ft}{s} = 20\%$

8.5 Endurance/Loiter Time

The maximum loiter time is calculated to be 1.25 hrs. This calculation is based on constant coefficient of lift and velocity, i.e., $t_{CL,V} = \frac{375\eta_p E}{\hat{c}V}\ln(\frac{1}{1-\xi}) = 1.252\text{hr}$

8.6 Landing Distance

The landing distance will vary depending on the runway terrain. To have an idea of required runway distance, a common deceleration factor (f_d) of 0.3 was chosen. The distance from the moment UAV touches the runway to a complete stop is given by

$d = \frac{1}{2} f_d V_{stall}^2 = \frac{1}{2} \cdot 0.3s \cdot (41\frac{ft}{s})^2 = 252ft$

The overall aircraft performance specifications are given in Table 6.

Take Off Dist.	62.9 ft
Take Off Speed	49.2 ft/s
Level Flight Stall Speed	41 ft/s
Turn Stall Speed	72.8 ft
Tightest Turn Radius	55.5 ft
Turn Stall Bank Angle	71.4^o
Best Range	51.3 miles
Max. Loiter Time	1.272 hr
Landing Dist.	252 ft

Table 6: Aircraft Performance

9 Developed Software for the Reconnaissance Subsystem

The ground station software provided by the autopilot was not sufficient to complete the assigned tasks required in the mission. Customized software was created to control other essentials components such as gimbal and high resolution camera. Above all, the customized software allows us to automate tasks such as refreshing the high resolution camera to prevent camera from going to sleep mode.

The software was geared towards three goals: 1) flexibility - the ability to add or modify applications without redesigning the current application, 2) ease of use, and 3) functionality - features that is crucial to complete the mission. Four applications were created to meet the three goals and the ultimate mission. These applications are the Thinker, Live Feed, Gimbal Control and Image Overlay.

9.1 Communication Among Applications

Each application either sends, retrieves, or calculates valuable information that is essential to the mission. That is why well coordinated communication among applications is crucial. To test out different data sharing techniques, simple programs were created to explore the full capabilities of each data sharing technique.

First technique was reading and writing data to files. The major drawback was if a small amount of data, such as 1 byte, was instructed to be written to file, it would be cached in memory instead. Small amount of data is cached because writing to hard disk is a costly operation (it

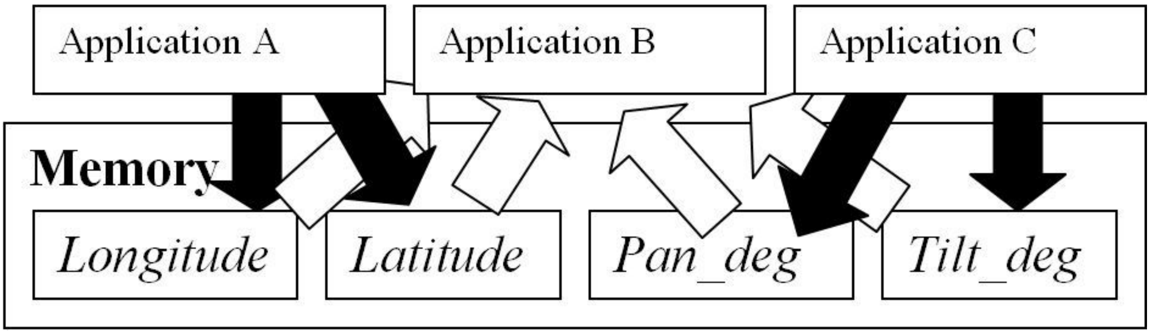

Figure 4: Demonstration of how DLLs were used in the current software. Black arrows point to memory box represents data being written. White arrows point to application represents data being read.

takes significant amount of time to perform an operation). The application would need to close the file in order to write the small amount of data to file. Opening and closing a file causes delays. Another drawback is that other procedures such as semaphores (classic method of restricting access to shared resources, in this case the file system, while it is in use) would be necessary to ensure that this technique works properly.

Second technique was socket (or network) communications. Immediate draw back was identifying the data that comes in. The data that is being exchange will need some type of identification. For example, if two applications need to exchange GPS coordinates and pan and tilt degrees from the gimbal, we would need to somehow identify if the data received is GPS coordinates or pan and tilt degrees. We could attach identification to the data, but managing the id will be a major hassle when the amount of data we need to exchange grows. Even worse case scenario is managing the id across many different applications.

The solution is to use Dynamic Link Library (DLL). Normally variables in applications have their own memory space. DLLs allow us to load variables in the same memory space into the applications. Therefore, it is a shared variable. Accessing the shared variables is no different from accessing a local variable in the application. With the shared variables, the applications can freely read and write from the variables. We are free to create more applications or modify functionalities in current applications to meet other needs and not worry about how the applications will communicate with each other. Figure 4 shows how share memory works.

9.2 The Thinker

The Thinker performs calculations of target GPS coordinates having aircraft altitude, position, and gimbal orientation and communications with autopilot. To calculate the GPS coordinates for the target, the tilt and pan angles of the gimbal, plane GPS, and altitude is required. This calculated GPS coordinate will be overlaid in the Live Feed application (refer to next section). Thinker also has user interface buttons that send signals to trigger high resolution camera to take pictures and to turn on/off the camera. At the same time, the shared variable "shoot" becomes true and the Live Feed stores current frame in file. Since the Sony camera has a 3 seconds delay after taking a picture, the Thinker has a button that allows us to take capture frames from the

Live Feed for the duration of the 3 seconds.

9.3 Live Feed

The Live Feed was created using Microsoft DirectX DirectShow, and interacts with the TV tuner card to retrieve live video. Live Feed not only shows live video, but also produces GPS overlay. The GPS coordinates are updated every 500ms. The Thinker writes the GPS coordinates to the shared variables "longitude" and "latitude" and the Live Feed reads from those variables.

The Live Feed has a timer that reads the "shoot" variable every 10ms to determine whether or not to place a frame in a file. Picture frames are converted into a bitmap (.bmp extension) format and GPS coordinates are overlayed onto the frame before storing. The ability to capture a frame is an important feature because if there are unexpected events that cause the loss of high resolution images on board, we still have the low resolution pictures.

9.4 Gimbal Control

The Gimbal Control controls the gimbal by sending a sequence of ASCII values to the gimbal. Gimbal Control has a grid to make it easier and friendlier to control. The user clicks on certain coordinates on the grid, the coordinates are translated into degrees of pan and tilt, and the information is transformed into a sequence of ASCII values sent to the Gimbal. The degrees of the pan and tilt are put into the shared variable for calculation of the GPS coordinates of the target.

9.5 Image Overlay

Image Overlay was created using ImageMagick [3] to overlay GPS coordinates on high resolution pictures. Unfortunately, Image Overlay was not integrated due to conflicts between Microsoft Visual Studio 6 and .NET platform. Although time was invested into trying to resolve the conflict, it is more sensible to find another solution. That solution is to use Cgywin, a Linux like environment for Windows. With ImageMagick successfully compiled and installed on Cgywin environment, the Image Overlay was created.

Since the Image Overlay and the aforementioned software modules are based on different software platforms, the easiest solution to provide the GPS coordinates to Image Overlay is for the Thinker to write the GPS coordinates to file when a snap shot command* is given. Image Overlay was designed to take three parameters: 1) filename 2) latitude 3) longitude. To ensure that the application was user friendly, a script was written in Perl to automate the overlay process in one command. Two directories were created by default. They are "original" and "overlay." The original images go to into "original" and the overlaid images goes to "overlay." The script reads the "original" directory to get the filenames of the pictures, reads the GPS coordinates from the file produced by the Thinker, and finally runs Image Overlay to overlay the coordinates.

*The snap shot command provides the command for the high resolution still camera to take a picture.

10 Conclusion

The PolyUAV Team has successfully integrated a robust reconnaissance UAV. Our design incorporates a proven autopilot system from Cloud Cap Technologies therefore resulting in a more reliable design. Our Surveillance and Target Acquisition System uses two cameras that give the operator the capability to scan the area and also take high resolution images using a 7.2 MegaPixels digital camera, as well as live feed video images of the area being scanned from a low resolution bullet camera. In terms of safety, our design introduces redundancy by having an auxiliary RC receiver as a standalone safety system.

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