AUVSI 2010 Student UAS Competition

Team VAMUdeS: Journal Paper

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1 Introduction

Unmanned aircraft vehicles (UAV), since their first appearance in 1916, have evolved considerably. Their roles are getting more and more important: from the training missions they were first built for, they are now able to undertake search and rescue, attack and reconnaissance missions. Evolution in miniaturization technologies in the 1980s greatly helped the UAV industry. No longer exclusively controlled by humans, the UAVs were able to perform autonomous part of their task such as take-off, landing, target recognition, etc. Ideal for missions that are deemed too dangerous or too long for a manned aircraft, UAVs roles are bound to become more important and more diverse.

This year, team VAMUdeS (which stands for Micro Aerial Vehicle from the University of Sherbrooke) is attending the AUVSI 2010 Student UAS Competition. This extra-curricular project is completely managed by undergraduate students. From the four students the team was first composed when it started back in 2004, the team now counts a 15 students workforce. The group thrives on new challenges and is looking forward to perform at their best capacities next June.

2 Requirements

This year, the Unmanned Aerial Vehicles proposed by the team must support a company of US Marines on a patrol with intelligence, surveillance and reconnaissance. Prior to takeoff, the teams will be briefed with special instructions allowing them to develop a specific flight plan.

While supporting the patrol, the aircraft must be able to retrieve targets that are placed in the vicinity of the airspace and identify their five typical characteristics: shape, background color, orientation, alphanumeric and alphanumeric color. The location of the targets within 50 feet must also be provided. May the need arise; the original flight plan could be halted so that the UAV may assume an immediate reconnaissance mission. If the UAS operator is ordered to do so, he must be able to order the UAV to work outside the airspace and request a deviation. VAMUdeS's Mentor® will provide a live video feed during the course of the mission. The UAV must perform an autonomous flight from takeoff to landing and complete the mission within 20 minutes. At all time, the UAS needs to abide by the rules of the missions.

3 Aircraft Characteristics

AUVSI Student UAS Competition requires an aircraft with certain abilities that are critical for detection of ground targets. Indeed, the aircraft must have a low cruising speed, be easily transportable, easy to repair in a short period of time and able to lift a great payload so the autopilot and camera system can be included.

3.1 Airframe

The *VAMUdeS* team decided to adapt an off-the-shelf airframe for the 2010 AUVSI Student UAS Competition. Our final choice ended up being the Multiplex Mentor® (Figure 1). Many reasons leaded us to choose a ready to fly model. An evaluation of concepts has been made and allowed us to rate different types of airframes. The Mentor® has proven to be the best solution with its very low stall speed (around 25 km/h) and its great stability in high winds. Moreover the Mentor® has a strong motor mount, a big storage space inside the fuselage and landing gears. The landing gears protect the airplane and give the possibility to install extra payload under the fuselage. The Mentor® is also built in order to allow a single motor in the nose of the airplane. This will lower the motor cost and weight and unlike a dual motor airplane, there is no risk of imbalances of thrust resulting in a moment around the vertical axis (yaw). Moreover, when a battery is weak, one motor is usually stopped before another by the electronic speed controller (ESC) on a dual motor airplane. This problematic has been experienced by the team in the previous years and has been a major concern in the choice of this airframe.

Figure 2 : Multiplex Mentor

Physical Specifications

The Mentor® is a trainer class model aircraft built with resistive patented foam called Elapor®. This kind of foam is rigid, lightweight and rapidly fixed with foam friendly Cyanoacrylate glue. The wing span is 1.63 m and it has a lift area of 45 dm². The root chord is 25 cm and the tip chord, 16.5 cm. Table 1 provides general specifications about the system components. This list of components weights provides a total weight assumption of the UAV.

Table 1 - Payload components for the total weight assumption.

Component	Weight (g)
Foam airframe	1988
4 cells Li-Po 8000mAh	633
Video system	200
2X hs-322 (servos)	86
2X Hs-85mg (servos)	44
Video roll and tilt system	250
Autopilot system	100
Axi 4120/14 Brushless Motor	320
Overall aircraft weight	3751

3.2 Motor Selection and Specifications

With a primary weight approximation, the team has been able to focus on the selection of a propulsion system. The choice between gas and electric motors had to be made. Even if the gas powered engines are more powerful, they are more complex to operate and to maintain in good working conditions than an electric motor. Also, a battery does not move the Center of Gravity (CG) during flight unlike a gas engine's fuel tank.

The Axi 4120/14 electric brushless outrunner (Figure 3 : Axi 4120/14 electric brushless motor) was chosen for its high efficiency and for the reliability of Axi motors. This motor works with a 4 cells 8000mAh lithium-polymer battery and has a nominal 660 RPM/volt. In other words, we have a very efficient and low RPM motor capable of spinning a 13"X7" propeller. This motor also has the advantage of being able to provide a great amount of power if the flight conditions require it, which is necessary for our application since missions often have to be performed when flight conditions are far from being ideal.

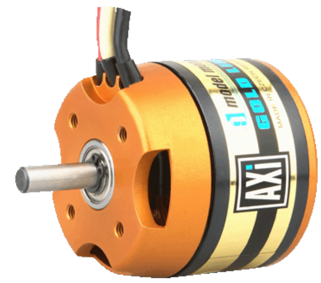

Figure 3 : Axi 4120/14 electric brushless motor

Flight Performance

With this motor and propeller combination, the Mentor® has a flight autonomy of approximately 1 hour in normal conditions. With a takeoff weight of 3.6 Kg, the approximate cruise speed is evaluated at 12m/s and the stall speed is 7 m/s. The maximum level speed provided by the powerful motor has proven to be about 28m/s. The Mentor® has a glide ratio of approximately 12. Finally, the Mentor® is very stable, easy to manoeuvre and to repair: the team is very pleased with the choice of this airframe as a UAV platform.

3.3 The Autopilot

Paparazzi

Over the last years, *VAMUdeS* had to choose which autopilot was going to be used by the team. The question was characterized by a lot of unknown and heavy consequences. The team evaluated two different autopilots often used for this type of UAVs, Micropilot and Paparazzi. Paparazzi was chosen for its versatility, low cost and because it is an open source and open hardware project. Since then, the team has successfully autonomously flown various types of UAVs, with wingspans from 50 cm to 1.6m, in various international competitions and is persuaded to have made the right decision.

The paparazzi open source autopilot project first started in 2003 at the ENAC University in Toulouse, France. Paparazzi system has been specially designed with safety in mind. Over the years the project has significantly grown due to the input of developers all around the world.

Attitude Determination System

Most of the paparazzi equipped UAVs use infra-red thermopile sensors to determine the attitude of the aircraft. This technique is based on the fact that the earth is usually warmer than the sky. The horizontal IR sensor uses a pair of thermopiles to measure temperature differences on each longitudinal and lateral axis. For example, if the lateral axis is aligned with the IR horizon, both sensors will receive equal amounts of energy and the differential output will be at its neutral value. Otherwise, if the airplane is banked, a temperature difference will be measured. This difference is then compared with earth to sky reference contrast, measured by a pair of thermopiles installed in the vertical axis, in order to determine the bank angle. Figure 4 to Figure 6 illustrate this principle.

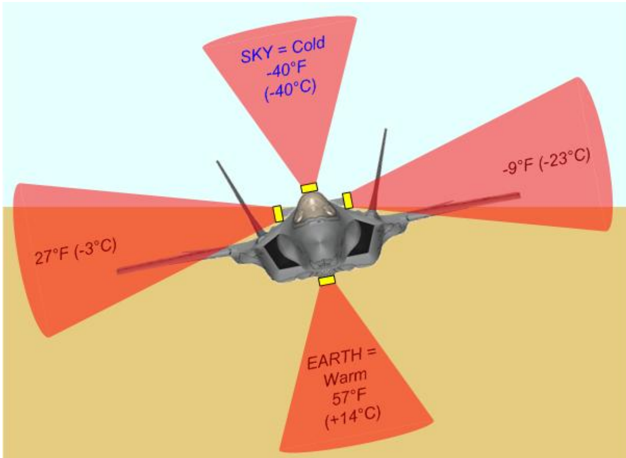

Figure 4 : IR attitude determination principle

(paparazzi.enac.fr)

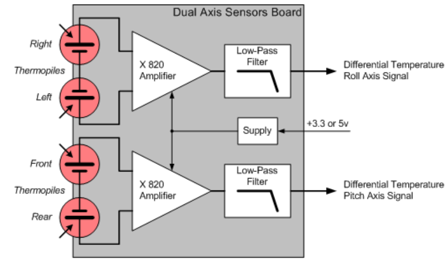

Figure 5 : Horizontal IR Sensor Blocs Diagram

(paparazzi.enac.fr)

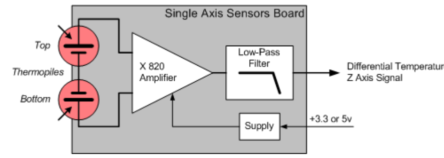

Figure 6 : Vertical IR Sensor Blocs Diagram

(paparazzi.enac.fr)

The TWOG

Hardware is one of the aspects of the project that has evolved the most since *VAMUdeS* started using paparazzi. In fact, most of the paparazzi softwares are platform independent so a variety of hardware solutions have been developed and are available to the community. The TWOG (Figure 7), a version of the popular Tiny 2.0 with GPS apart is particularly interesting because the GPS receiver can be installed far from all EMI emitting sources to ease satellites reception. This hardware version can be bought fully assembled at a low price thanks to production quantity.

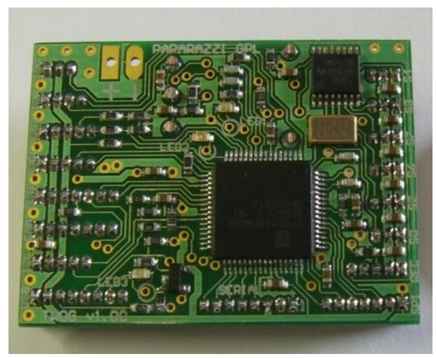

Figure 7 : TWOG

(paparazzi.enac.fr)

However, the TWOG like all the current paparazzi hardware solutions was designed to be flown in small MAVs around 50 cm wingspan and less than 500 g. Size and weight has been reduced at the expense of other functionalities. In fact, its integrated power supply is barely enough to supply two big servos, which is by far not enough for our application. When supplying more than two servos, the 5 VDC can drop, causing the autopilot to reboot in flight. An external power supply had to be use. Moreover, the small connectors used don't really provide a secure connection since they are not equipped with a proper lock mechanism.

The SHERBY

Considering these drawbacks and the fact that a few extra grams aren't really an issue in larger aircrafts like the Mentor®, the team started designing a new homebrew hardware version called the SHERBY. The SHERBY is based on the TWOG schematics, but has many new features making it the best solution for larger UAV.

The power supply has been completely redesigned in order to be able to provide 30 Watts to the servos, while avoiding unwanted in-flight reboot of the autopilot. The power supply also provides a completely electrically isolated 12 Watts to the payload. This isolation will improve the video signal quality by eliminating noise created by inductive loads such as motors and servos without using a separate battery for the video system. Power to the camera and video transmitter can be removed manually or remotely, for battery economy and better GPS reception. A current probe has been integrated to the design. This addition will help the team to select the best propeller for highest efficiency and give more accurate flight time estimation. The layout of the prototype built to validate the SHERBY power supply design is shown in Figure 8.

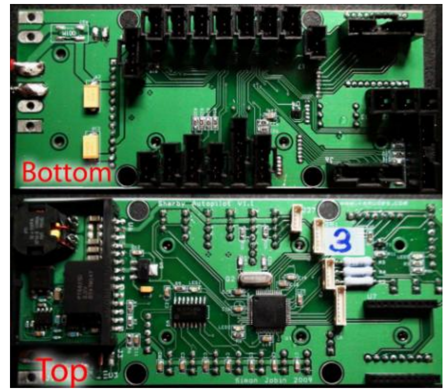

Figure 8 : Sherby Autopilot

The SHERBY avionic system will be installed in rugged plastic cases to protect the electronics. Having multiple modules integrated in the same system will reduce the number of hookup wires connections. In addition, only connectors with a proper lock mechanism will be used. All these restrictions will significantly increase the reliability of our UAS. Figure 8 shows an overview of the autopilot.

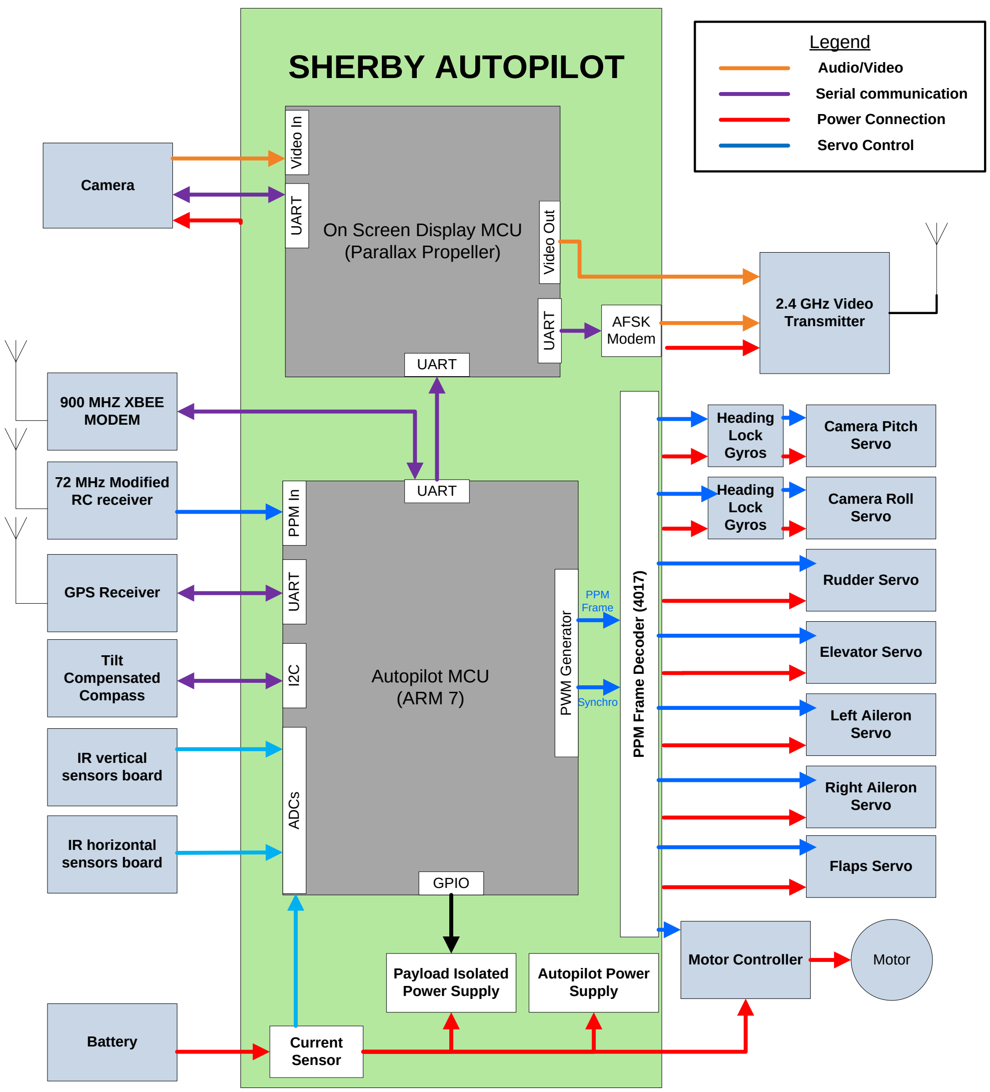

Figure 9 : Mentor® Avionic

The team hopes schematics and layout of the design will be available to the paparazzi community after this year's competitions if no problem is found during the year. VAMUdeS is looking forward to see the SHERBY becoming the new preferred paparazzi hardware solution for larger aircrafts.

3.4 Imagery System

In order to maximize the chances of success with the Mentor® our imagery system must meet many requirements. First, the imagery sensor should be stabilized in order to ease identification and localization of the targets by the team. The sensor should have a high resolution capacity and be equipped with a zoom in order to provide high quality images to the team. The camera system specifications are summarized in the Table 2 - Camera system specification.

The Sony FCB IX11A Block Camera

The Sony FCB IX11A (Figure 10) has been considered as a solution. The integrated DSP provides high-quality while remaining small and lightweight. The zoom focus (40X) and other functionalities can be controlled via a high speed serial communication using VISCA® protocol (Property of Sony). This would be handled by the payload dedicated processor of the company Parallax® integrated on the SHERBY avionics board. However, it has been impossible to install this camera on a pan&tilt system on board the Multiplex Mentor®. The necessary structure required to support and move efficiently the camera required additional space and resulted in a lot of extra weight within the system. The only way this camera could be used was by inserting it in the frame of the plane itself. This solution resulted in a non-stabilized, uncontrolled and inconvenient system.

Figure 10 : FCB-IX11A (*sonybiz.net*)

The KPC-S226C Color CCD Camera

The second considered solution is the KPC-S226C camera (Figure 11). Because of its light weight and its small size this camera certainly fits in the Mentor® airframe. It can also be combined with Pandora Pan&Tilt system in order to stabilize the video camera and ensure appropriate view angle. However, this camera has no active zoom capability other than by changing the lens.

Figure 11 : KPC-S226C Camera (*ktncamerica.com*)

The Pandora Pan&Tilt system

Even though the Sony FCB camera seemed a good solution to our needs, this system was still too big to fit in the Mentor®. The team then decided to choose the KPC-S226C camera, which is lightweight and small enough to use with the Pandora Pan&Tilt system (Figure 12). VAMUdeS decided to orientate this camera support according to the pitch and roll axis of the aircraft. The advantage of this configuration is that it allows the team to perform adequate observation of a specific area as well as offering the possibility to cancel the perturbation coming from wind gusts or from quick roll/pitch manoeuvres of the UAV.

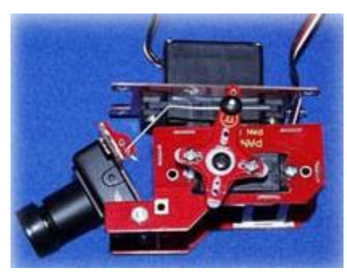

Figure 12 : Pandora Pan&Tilt www.dpcav.com

Table 2 - Camera system specification

Characteristics	Value
Image device	1/4 Sony HAD CCD
S/N Ratio (dB)	48
Resolution (TVL)	380
Min. Illumination (lux)	0.5
Operation temperature (°F)	14 to 122
Mass (grams)	250
Travel speed (s/60°)	0.12
Travel Amplitude	170° (both axis)

On Screen Display Module

An On Screen Display (OSD) module (Figure 13) has been added to our imagery system in order to increase the situation awareness and to help localize targets. Many off the shelf OSDs were considered. Mainly two different types were available; some are designed to be used in RC aircrafts, others in more generic design to be controlled by external devices. We narrowed our selection to the generic type because they procure more flexibility. The HC-OSD from Hitt Consulting was particularly interesting because the project is open source and open hardware. Team VAMUdeS chose this solution and has been able to design its own version of the OSD based on the original schematics. It is now in a more compact form and integrated to the SHERBY avionics. From that point, we only had to reprogram the Propeller chip from Parallax® to have different display modes. We are planning to show data feed by the Paparazzi autopilot such as the compass, GPS coordinates with a grid, battery status, distance from the ground station, roll status and the speed of the plane; as shown on Figure 14.

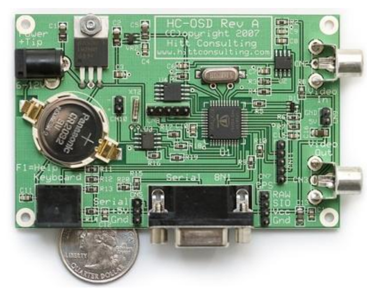

Figure 13 : HC-OSD (*hittconsulting.com*)

Figure 14 : On Screen Display overview

4 Ground Station

4.1 Overview

At first, it should be known that the term Ground Station defines all the systems required to operate the UAS from a ground based unit (RC remote control, communication system such as modems and antennas, video receivers and computers, etc.). The *VAMUdeS* team experienced many problems with the previous ground station such as portability, autonomy and efficiency. The system has been improved in order to correspond to the team's needs. It is now divided into two major distinct profiles: the Ground Control Station (GCS) and the Ground Video Station (GVS). The GCS contains all the systems needed to control the UAS through the paparazzi autopilot while the GVS acts in parallel with the previous station. Its role is to control the camera and offer an efficient video interface that allows the user to perform a high quality video observation. Figure 15 gives a quick overview of the Ground Station design and interconnection. The subsystems are described in the section below.

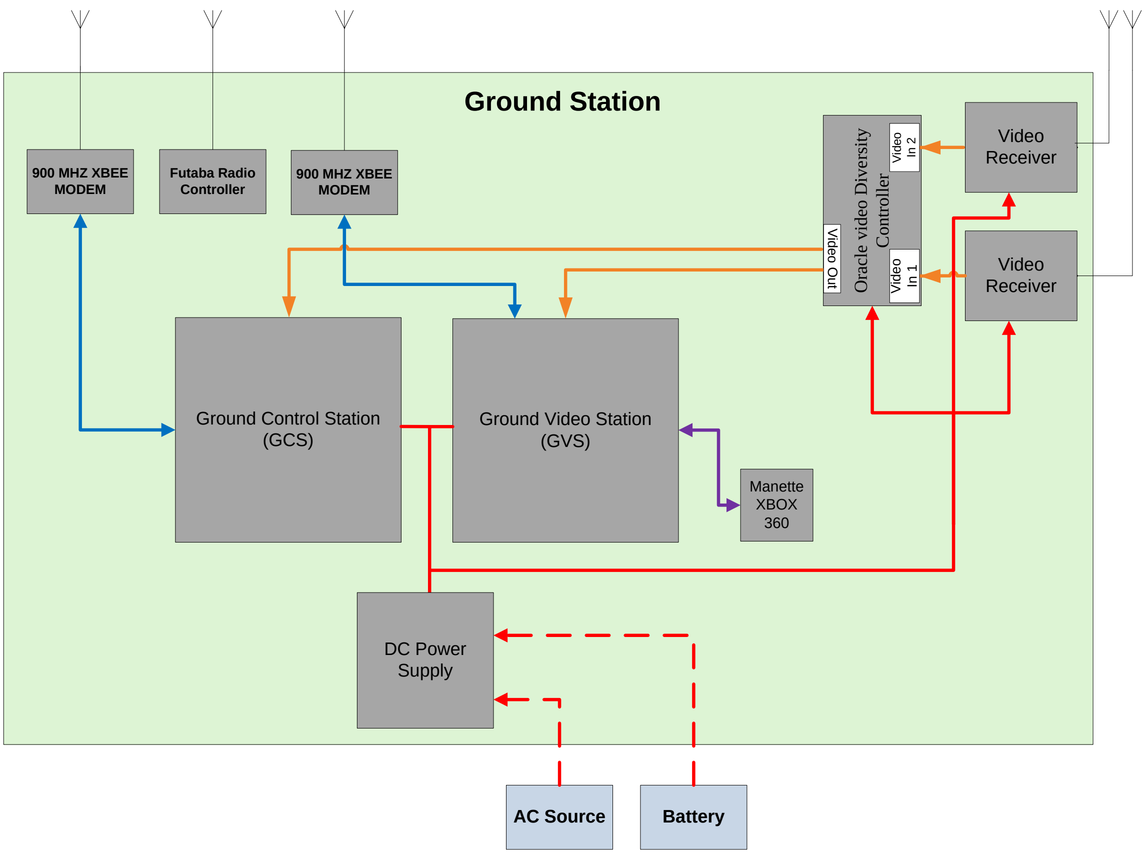

Figure 15 : Ground Station

4.2 Transportation Case

First of all, two laptops are required during flight: one for the Ground Control Station (GCS) and the other for the Ground Video Station (GVS). The solution chosen by the team was to buy simple netbooks which offer sufficient performance for the team's needs. The team purchased two *Dell Inspiron Mini 9* laptops which are relatively small (9'' screen), yet performing. With this compact and lightweight solution, the team members can carry the laptops on the field during the flights without any problems. The visibility under the sun still remained problematic. In order to obtain an adequate video interpretation, *VAMUdeS* decided to acquire two 20'' LCD flat screens that will be paired to the laptops. These screens have been tested under sunlight and still demonstrated a clear and bright image with almost no glowing effect.

Another problem that the team had to deal with was the transportability. As a solution, *VAMUdeS* decided to create independent cases for the Ground Control Station (GCS) (Figure 16) and the Ground Video Station (GVS). The required components, one laptop, external keyboard, mouse and a 20'' flat LCD screen for each station, have been fitted into a solid plastic transportation case. This solution facilitates the team's transportation and improved the efficiency of the team during the competitions and flight tests.

Figure 16 : GCS

With these tools at hand, *VAMUdeS* is confident that it will be able to provide high quality video interpretation.

4.3 Oracle Video Diversity Controller

In order to always get the best video signal available for both ground stations, *VAMUdeS* needed a piece of equipment that would be able to choose the best video signal quality from different sources and bridge them into one single signal. The system also needed to offer the possibility of splitting that video signal into two identical outputs, one for the GCS and the other for the GVS. The Oracle Video Diversity Controller (OVDC) made by Dpcav was the solution found by the team. The team can now enjoy the best video quality from one of two receivers. Here is how the system works: whenever the OVDC determines that the currently chosen audio/video source is corrupted, it automatically switches to the other audio/video source. By doing this, the video quality is no longer altered by ghost interferences as it used to be when only one receiver was used. Specifications of the Oracle video diversity controller are shown in the Table 3 - Oracle video diversity controller specifications.

Table 3 - Oracle video diversity controller specifications

Characteristics	Value
Video receiver compatibility	Universal wireless (NTSC or PAL)
Audio channel support	2 channels (stereo audio or voice/data)
Video	RCA-Input and Output
DC Power	6VDC to 14VDC
Small size	6.0 inch x 4.5 inch x 2.3 inch
Other characteristics	Very high bandwidth. No A/V signal degradation

4.4 Paparazzi Ground Control Software

The Paparazzi ground control station (GCS) runs under a Linux based operating system called Ubuntu. As showed in Figure 17 the ground control station displays a variety of crucial information in regards to the mission status.

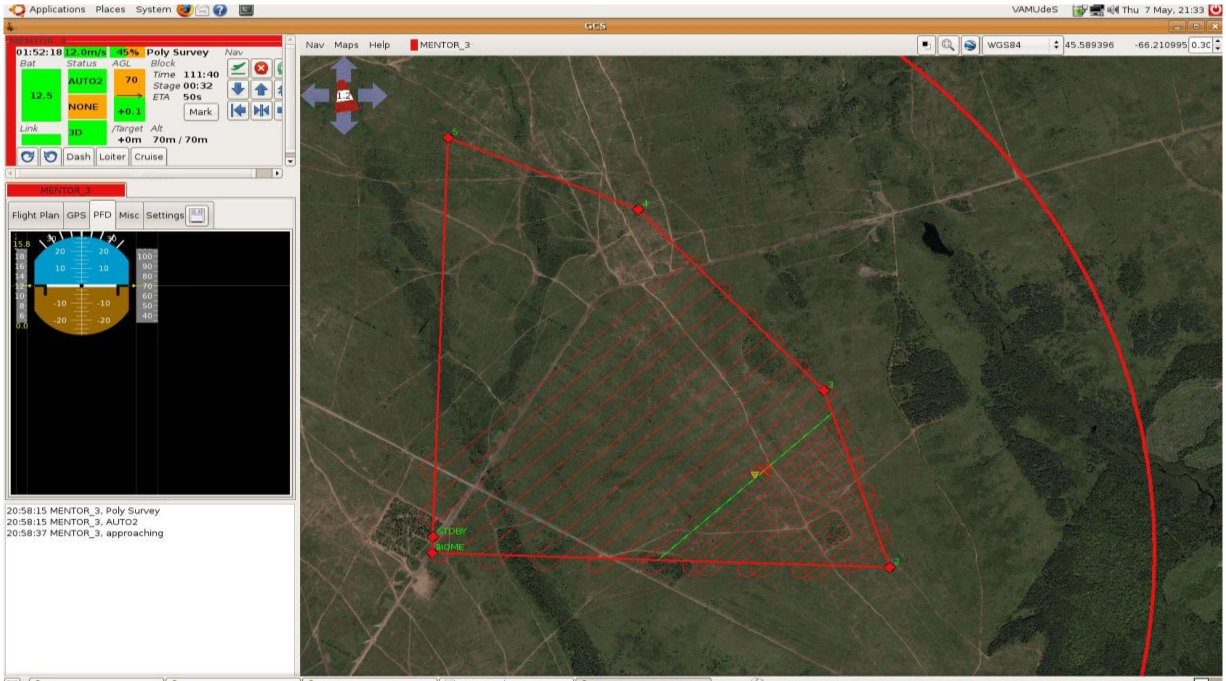

Figure 17: Paparazzi Ground Control

First, on the right side of the window is a 2D map on which important navigation information are displayed. The background can either be loaded directly from Google Earth or from any other prior scaled picture. The current position of the aircraft is displayed and combined with a track of previous positions. Waypoints may be moved as desired on the map in order to provide new instructions to the UAV. On the lower left of the window is the console, which is used to display notices of critical events like warnings, changes in flight plan and switches to safety pilot mode. Right above this console is the notebook which contains a lot of information sorted by tabs. These tabs lead to an interface where the user can access information or modify the major settings of the Unmanned Aerial System such as the PID gains, navigation gains, failsafe activation/deactivation, etc. The GPS tab displays the signal strength of each satellites captured and the position accuracy. In the misc tab, the wind speed estimation can be found.

Finally, on the upper left, there is a set of shortcut buttons and quick displays (battery level, speed, altitude, climb rate, etc.) to facilitate the work of the ground control station operator.

The paparazzi ground control software offers a lot of authority on the control of the aircraft and allows dynamic adjustment of the flight plan as well. This open source software has proven to be a powerful tool and seems to be ideal to suit the requirements of the AUVSI Student UAS competition.

4.5 Camera Control

When performing video surveillance, it is essential to be able to manually manipulate the camera in order to obtain good results. The system proposed by *VAMUdeS* allows the camera to pivot following two different axis and can be remote controlled from the ground station if needed. A difficulty encountered was about controlling the camera: the team needed an efficient and precise way to manually orient the camera in order to perform the best video surveillance possible. The solution found by team VAMUdeS is to operate the camera system using an X-Box 360 USB wired controller. Using joysticks, the user can modify the angle of observation in one of the easiest ways.

5 Wireless Communication

There are three different wireless links between the ground and the plane during the flight. Each of those types of link are described in the following sections. The Table 4 - Table of frequency summarized the frequency used.

5.1 Data Link

The data link is defined as being the link between the ground station running paparazzi and the on-board autopilot. This radio link is used to relay all the data gathered by the autopilot to the paparazzi operator and the command given to the plane during the flight. In the case that this link is broken during operation, the plane will continue to follow the programmed course but it will not be possible to send commands to the aircraft except manually by the safety link.

5.2 Wireless Video transmission

The video link is used to send the video signal to the Ground Video Station. With the onboard OSD, this link can also provide vital information in case of a data link failure. It uses a VHF video transmitter to send the data and the ground station uses a dual antenna with an OVDC to ensure the best video reception at all times.

5.3 Safety Link

The last link is the safety link and is used to take control over the autopilot. It is provided by a T7CAP Futaba remote controller and operated by the Safety Pilot whom tasks is to observe the UAV at all times and never lose sight of it. In case of emergency, when there is a complete loss of the data link or a major problem within the autopilot operation, the pilot must regain control of the aircraft using this safety link.

Table 4 - Table of frequency

Wireless signal	Frequency	Power
Data link (XBee-PRO XSC)	900 Mhz	100 mW
Video link	2.4 Ghz	1000 mW
Safety link (Futaba T7CAP)	72 Mhz	800 mW

6 Mission Design

For this mission, the team will follow a series of steps starting from the installation until the manoeuvring of the UAV. These sections will present every step followed by the team throughout the course of this mission.

6.1 Arrival and Installation

Before the trip to the airfield, all the necessary components are placed in separated ‘’ready-to-use’’ boxes. As the team arrives on the field, each system will have a person in charge of the set-up and operation. The systems are separated into: GCS, GVS, aircraft and support hardware. The aircraft will be powered on and we will then proceed to a verification of the communication link range, the attitude determination system and the GPS signal.

6.2 Target Detection and Flight Plan

When all systems are ready and we have the authorisation to takeoff, the team will handlaunch the aircraft into its autonomous mode. The mission will then begin with the chosen search pattern. As soon as a target has been identified, the video operator will tell the GSC operator to mark the current position with a “circle here” marker. The video identification will be made by a team member watching the displayed video. The GCS operator will wait until complete identification and localisation of the target by the GVS operator before sending the aircraft back on its research pattern. Furthermore, we will use an on-screen display grid to precisely identify the target GPS coordinate. The grid is automatically generated by the Parallax Propeller which reads the data provided by the autopilot in order to rotate and have a constant latitude and longitude display.

6.3 Landing

Once all targets are identified, a fully autonomous landing will be performed. This maneuver is divided in two phases which are: compass lock and approach. The compass lock phase is used to orient the airplane in the wanted position and altitude. Similar to a circle, this phase will bring the airplane to the right altitude and orientation for the final approach. The orientation is chosen by the direction of the wind. The approach is governed by a fixed gliding rate until touchdown and will be a belly landing. Mission objectives are summarized in Table 5.

Table 5 - Mission objectives

Objectives	Criteria
Mission Completion	-It is intended to successfully complete the mission in the required timescale.
Degree of Autonomy	-Achieve fully autonomous flight. -Capability to transit to manual control in flight in case of emergency at any time.
Aerial Surveillance	-Have real time aerial high resolution video and real time global positioning of targets. -Have a range of at least 4km.
Safety	- Avoid crash and potential injuries. - Have different safe termination features.
Innovation	-Create an innovative autonomous imagery platform. -Develop the Paparazzi autopilot.
General	-Respect the time scale

7 Test and Experimentation

In order to operate its Unmanned Aerial Vehicle with confidence, team VAMUdeS dedicated important amounts of time testing every subsystems developed by its members over the last months. Every system has passed through *Paparazzi* simulation and ground testing before obtaining air-worthiness approbation by the team. The in-flight experimentations were performed on a dedicated Multiplex Mentor® airframe especially built for this purpose. In-flight test time was dedicated to multiple projects, but only a few are described in the following section.

7.1 Safety Link Interference

Over the last years, the team kept experiencing interference within the radio control wireless link between the RC Safety Pilot and the UAV. Having major safety concerns, this problem has been a priority to the team members during the last months. As a solution, the team decided to implement in the system a piece of hardware provided by the *Paparazzi UAV* online store: the PPM encoder. This equipment allowed the team to modify the type of receiver in the aircraft and switch to a more sophisticated one such as a PCM receiver. Testing has first been made with a regular radio controlled aircraft built for crash tests, and then adapted to the simulation tool provided with the *Paparazzi Ground Control Software*. When the team gained confidence in this type of equipment, the integration to the autopilot have been completed.

7.2 The Sherby Autopilot

The design of a completely new hardware for the Paparazzi Autopilot established a fundamental need for intensive field testing. Once again, the equipment has first been carefully analysed under simulation in order to verify the integrity of the system's behaviour. A lot of time has then been accorded to on-the-field testing of this brand new solution which now counts over 200 hours of flight over the last year.

7.3 Imagery Systems

In order to control the camera system with an Xbox controller via the *Paparazzi Ground Control Software*, the autopilot's settings had to be considerably modified. This necessitated a great knowledge of the system's most detailed structure. The control software has been developed on-parallel to the UAV platform and underwent simulation and ground testing in order to confirm the autopilot behaved normally at all times when moving the camera. Then, the integration of the *On-Screen-Display's* new hardware and software had to be paired to this innovation. At this point, a detailed test procedure had to be developed in order to efficiently validate payload integration:

1. Perform ground tests with all subsystems and validate integrity of the autopilot's behaviour.
2. Launch the aircraft in the non-autonomous mode (manual) in order to ensure aerial vehicle responds normally.
3. Transfer to the assisted (Auto-1) mode. Validate if the UAV still responds as expected.
4. Finally transfer to fully autonomous (Auto-2) mode and validate normal behaviour of the UAV.

7.4 Results

Over the last months, VAMUdeS developed many subsystems that have been incorporated into their Unmanned Aerial Vehicle. On-the-field testing gave the opportunity to the team members to validate the stability, reliability and safety of every component of the system under various conditions. Moreover, the team members now have acquired a high level of confidence into their solution and are convinced it will complete and surpass the AUVSI 2010 Student UAS Competition mission's requirements.

8 Safety

Safety is an important concern of the *VAMUdeS* team. Not paying attention to technical details, as insignificant as they seem, may result in undesired consequences and major losses for the team. This is why safety is part of the building process: from the first drafts, through fabrication and to the final flight tests.

8.1 Pre-flight Precautions

In all of the flight tests, safety of the operators and observers on site had to be ensured. To prevent crashes, tests were made before takeoff following a checklist to make sure that every system works properly and that vital maneuvers could be assumed by the plane. Also, to ensure safety of physical connection, snap-in connectors were used. This prevents disconnection caused by vibration which would most probably lead to a crash. Finally, considering that these flights were made in the vicinity of the *Université de Sherbrooke* campus, security officers employed by the university were always informed of the undergoing tests.

8.2 Safety Features

Experienced Flight Crew

Some of the *VAMUdeS*'s team members have a strong background of 4 years of experience in the world of UAVs. Throughout time, a flight crew has been developed in order to ensure the efficiency as well as the safe execution of the flight tests. The flight crew consists of 5 members all linked to different functions and responsibilities:

1. **GCS Operator**: Operates the ground control station.
2. **Safety Pilot**: Pilots the plane in manual mode and auto 1, engages auto 2 mode with the agreement of the GCS Operator. In case of a problem, the pilot recovers control of the plane; he must never lose sight of it.
3. **Video Operator**: Controls the camera in order to perform an efficient video surveillance.
4. **Scribe**: Identifies the targets on the video and takes notes about the flight conditions.
5. **Cameraman & helper**: Films and helps the other members of the flight crew.

On-Screen Display

VAMUdeS implemented an on-screen display system that allows the user to have multiple details about the plane directly on the video interface. Even in a loss of telemetry, crucial information such as GPS coordinates, altitude, battery level and speed will still be displayed on the GVS.

Visibility

The UAV has been coloured with safety orange day glow paint so that the pilot doesn't lose sight of the UAV at any time. LEDs have also been added to the plane so that the team can perform flights at dusk and at night securely. Also, in case of a crash, it is sometimes difficult to retrieve the plane in a remote area. This is why the team has implemented into the plane a system which emits a pulsing sound. This *buzzer* allows the team members to perform a quick recovery of the UAV when needed. Batteries can also be expulsed from the plane during a crash and lost in the environment. In order to avoid this possibility, batteries are wrapped in an orange day glow tape to ensure their maximum visibility.

Paparazzi Autopilot's Failsafes

The Paparazzi System, initiated in 2003, was developed with goals of safety and reliability. In addition to undergoing thousands of hours of testing, all of the autopilot's critical airborne code has been formally proven. In the event of an emergency situation, the user can define what the UAV should do. For example, in the event of loss of the data link, the UAV can be set to continue on its mission or to return home, according to the mission's requirements.

Also, at anytime, if a problem is encountered, a function called kill switch can be activated by whether the GCS operator or the Safety Pilot. This procedure results in flight termination: throttle closed, full up elevator, full right rudder and ailerons causing the plane to enter a spiral and crash. The UAV is pre-programmed to return home after a loss of signal of 30 seconds while the kill switch is executed after a loss of signal of 3 minutes. A brief summary could be found in the Table 6 - Safety procedure.

Table 6 - Safety procedure

Safety features	
Situation	**Result**
Too far	Return home
Telemetry link lost (30 sec)	Autonomous return home
Telemetry link lost (3 minutes)	Stop, spiral descent
RC link lost	Return home

9 Project Management

In order to keep track of the multiple projects going on within the team, the members from VAMUdeS established an organisational structure where the team has been divided into small groups (see Figure 18). Those groups worked together at their convenience and held meetings once per week. However, general meetings requiring the presence of all team members were planned every two weeks. During these occasions, objectives, progress, results and concerns were addressed. Communication among the members during weekdays was assured by a mailing list.

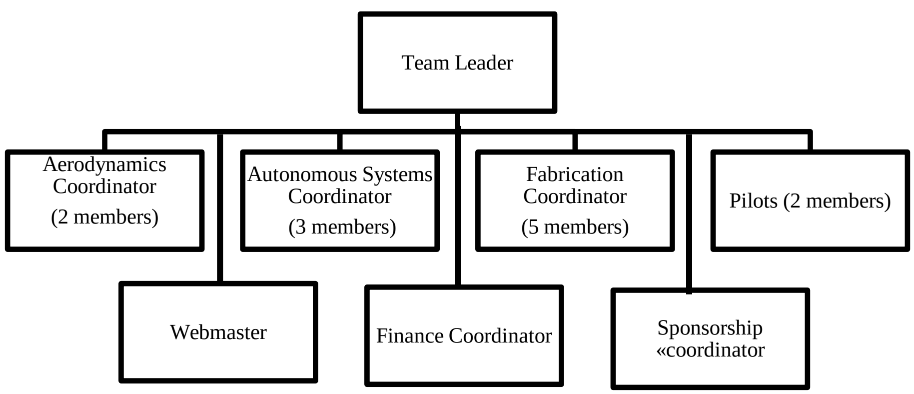

Figure 18: Structure of VAMUdeS team

9.1 List of Milestones

The management of the project is a key activity since several people are involved, a new designed autonomous onboard system and brand new payload systems are developed. The team sets itself six (6) major milestones. They are defined as:

1. Successful autonomous flight test without payload;
2. Successfully complete the development of the payload including the camera-mount and the video control system;
3. Having reliability and stable flight with the vehicle platform and the payload;
4. Successfully complete the ground station system / communication system on the ground;
5. Successfully achieve autonomous flight with payload;
6. Successfully complete the mission simulations at home.

These milestones are the most important things that must be achieved in time. The focus of the group had to be kept because the deadlines may not be postponed.

9.2 Risk Management

In order to have a successful project, it is essential to manage risks that can occur during competition preparation. To do so, there are three important phases, which are risk identification, evaluation and mitigation. Therefore, a list of all potential risks to the project has been created. Afterwards, it is possible to evaluate each risk by determining their respective probability of occurrence and their impact on the success of the project.

After evaluating those risks, it is then possible to identify the five most critical events that represent a threat to the good completion of the objectives. For each of these risks, it is essential to plan a response and fully understand the impact of that response. The five major risks identified by the team and each of their mitigation measures are fully explained below:

1. Limited flight test time due to bad weather;
   a) Winter weather in Quebec represents a major inconvenient for flight tests. It is critical to establish a planning that allows a long period for testing and troubleshooting in spring, before the competition.
   b) Training the pilot to fly at dusk and at night would have the advantage of significantly increasing the possible testing time available to complete flight tests.
2. Shortage of human resources;
   a) Even if the team presently has 13 members, the amount of work is important. The addition of new members is a good way to reduce the workload for everyone.
   b) To attain these objectives, even with new members, it might be necessary to increase work hours for every team member. Meetings and working sessions might be held week nights more often than planned, so the schedule is respected.
3. Equipment failures or breakage;
   a) From past experiences, it has been established that equipment failures and breakage are unavoidable. Therefore, it is necessary to have spare parts of every onboard and ground component, so that the progress of the project will not be interrupted.

4. OSD development delays;
    a) The OSD provides good precision in ground target location. However, it is possible to have a functional system without this component. So, in case of severe development delays, only the plane's GPS coordinates could be used to estimate the location of ground targets.
5. Camera control system development delays;
    a) A mobile camera system that can be controlled manually significantly increases the ability of the UAV to locate targets quickly and precisely. However, a fixed camera system would also be functional.

10 Conclusion

While operating in remote areas or while watching out for forest fires, characteristics like versatility, portability, reliability, low cost and safety are of major importance. Consequently, there is a need to develop a UAV satisfying all of these criteria. In order to achieve their goals, VAMUdeS team works day after day to improve the quality of their prototypes and to bring unmanned vehicles safer and easier to use.

An important quantity of work has been required by the whole team in order to be ready for this competition. However, the team is highly motivated and constantly works hard in order to improve their system. During summer or the hard winters of Quebec (Canada), team VAMUdeS can't wait to get outdoors for flight testing.