VAMUdeS

Autonomous Aerial Vehicle

AUVSI Student Competition 2014

Journal Paper

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Abstract

This paper describes the approach taken by VAMUdeS to design an Unmanned Aerial Vehicle (UAV) that fulfills the requirements for the 2014 AUVSI student competition and other UAV competitions. The Artemis system is a fixed wing aircraft with a wingspan of 8.8 ft, a length of 5 ft and height of 2 ft. It has a gross weight of 25 pounds and is powered by two 6 cells 8000 mAh lithium-polymer battery.

The system is controlled by the White Rabbit autopilot, a custom version of Lisa M 2 by paparazzi and the system can execute autonomous takeoff, flight and landing. The telemetry link is established via an Xtend modem on 900 Mhz using Zigbee protocol. A manual override is possible via the RC controller using spektrum DSMX 2.4 Ghz communication.

The payload is a Nikon D3200 camera controlled by a custom linux payload controller, MapUS Air, which sends images almost realtime to the ground where they are analysed with the manual and automatic software MapUS Ground, images are sent to the ground via Ubiquiti 2.4 Ghz module and tracking antenna. An IR camera, FLIR A65, sends pictures to the ground in real time via a 5 Ghz Ubiquiti device. A side camera, Gopro Hero 3, is installed sideways to capture the Off-Axis target and analog imagery is sent to the ground via 1.2 Ghz video transmitter.

An Air-drop device is installed to autonomously drop safely and precisely an egg on the target. A SRIC communication device, an Ubiquiti 2.4 Ghz is installed on the UAV. Finally, these systems have been tested mainly at the Unmanned System Canada competition, in South Port, Manitoba, Canada.

Contents

1 Mission Context and team

According to the U.S. Forest Service, a huge fire is raging in the forest of south central Idaho. 100,000 acres are lost and more will come. The Forest Service has requested intelligence, surveillance and recognition support, through the use of Unmanned Aerial Vehicles (UAV). These UAV will be used to identify and survey the progression of fire activity and report its position to improve firefighting operations. At the same time, the UAV is called to bring retardant to assist firefighters. The UAV will be used to receive additional information via a Simulated Remote Information Center (SRIC).

VAMUdeS team, from Université de Sherbrooke has a solution for this mission. This group, including engineering students in the computer, mechanical and electrical specializations, is specialized in the development of fixed plane UAV since 2007. The team's UAV is able to accomplish this mission efficiently and safely.

This year, the VAMUdeS team is executing 4 missions : the Unmanned System Canada UAV competition, the AUVSI Seafarer Chapter competition, the Outback Challenge and the Wildlife Conservation UAV Challenge. Each mission has different requirements and limitations and the team conceived a universal UAV, which can execute them all.

This report explains the VAMUdeS system and its conception, the engineering approach, the test results and the safety considerations.

2 Systems engineering approach

The development of a UAV is a difficult integration task. Most of the system's parts are vital and if one of them fails, the whole system could fail. At the same time, the system is very complex and a lot of problems can appear during the integration process. This is why the group uses an iterative method to develop the UAV. All subsystems are designed to be interfaced with older versions. Therefore, even if a new subsystem is developed, it's always possible to revert to a previous version to always have a fully functional system.

Also, due to the nature of the UAV, a flying machine, tests can be difficult to execute and the results of a failure in these tests can be dramatic for the team. As it is a complex machine, multiple in-flight tests must be executed and special attention must be put in the execution of extensive and complete tests.

2.1 Requirement Analysis

VAMUdeS team is in a unique situation : it is on his way to accomplish 4 different missions. Each of them has different requirements. It's very difficult to satisfy every requirements for every mission, especially for the Seafarer Mission, which is very demanding this year. Choices must be made.

As this is not a requirement report, only the most important task requirements are displayed. To do so, the AUVSI Seafarer task requirements were separated in 5 different sections:

Table 2.1 Functional requirement	
Requirement already meet by 2013 systems	**Rules section**
Autonomous takeoff and landing	*7.1*
Autonomous flight	*7.1*
High resolution imagery	*7.2*
Real Time imagery transfer	*7.2*
Failsafe systems	*6.3*
Requirement sine qua none	
Team coordination for new task	
Requirement needed for other missions	
Air-Drop	*7.10*
IR Imagery	*7.9*
Requirement partially developed or easy to develop	
Automatic image analysis	*7.3*
Interoperability	*7.8*
Requirement heavy to develop	
Off-Axis target	*7.5*

Also, there are additional requirements that the team must respect :

Table 2.2 Requirement from other missions	
Functionnal requirement	**Mission**
1h flight endurance	*Outback Challenge*
Hardware watchdog	*Outback Challenge*
< 22 lbs gross weight	*USC competition*
Image mosaicking	*USC competition*

2.2 Design Rationale

The challenge is to develop a multi-mission airframe,. As the 2013's UAV is functional, the design is based on the new requirements in the 4 competitions in which VAMUdeS participates.

2.2.1 Airframe design rationale

Some requirements must be met to participate to different missions and these must be taken into account while developing the airframe:

Table 2.3 Airframe requirement
Technical requirement
< 22 lbs
7.5 lbs payload
1h flight time
Easy Access to electronic components
Easy and fast fabrication

The last airframe of the team, the Aigle Noir series, met the weight, payload and endurance requirements, but it was difficult to build and had poor accessibility to electronic components. A new body was designed, similar in weight and size, but with a large openable cover which gives great access to each component. Also, to ease and speed up the production of new planes, a mold was built and was used to create new airframe with composite materials. Additionally, landing gear configuration has been changed from being a tail dragger to a tricycle to have a better direction during takeoff and landing.

The tail of the Aigle Noir, the wings and the motor are reused with this new airframe.

2.2.2 Autopilot design rationale

Additional requirements for the autopilot are mainly given for the Outback Challenge mission.

Table 2.4 Autopilot requirement
Technical requirement
Hardware watchdog
Additionnal sensors
- Barometric altimeter
- Pitot tube
- RPM sensor
- Gyroscope
Low complexity

Since the Johnny Autopilot, developed by VAMUdeS, cannot meet these requirements, a new autopilot had to be developed. Building an autopilot is a large amount of work and time is limited, so VAMUdeS chose to use an existing autopilot (Paparazzi Lisa/M v2.0) and adapted it to some specific needs mentioned above.

The advantages of Paparazzi Lisa/M v2.0 over the Johnny Autopilot are the use of Paparazzi 5.0 software, the integration of a functional IMU system (Aspirin 2.2 IMU) with a barometer and to have redundant RC receivers. Also, to reduce the number of pieces and the complexity, IR sensors are removed and XTend modems are incorporated within the autopilot.

2.2.3 Payload design rationale

Nearly all requirements for payload are already met by 2013's system, except for those :

Table 2.5 Payload requirement
Technical requirement
IR Imagery
Off-axis imagery
Automatic identification
Automatic classification

An IR camera was acquired from FLIR systems to provide aerial photography. As the minimum frame rate is 9hz and the minimum picture size at full resolution is 550 KB, a total of 5 MB/s is needed to transfer these images. It is possible to use the payload controller to grab one frame every two seconds, but the current payload camera, the Nikon D3200, already uses its full capacity. Also, the network bridge cannot give an additional 5 MB/s. Therefore, an additional 5 GHz Ubiquiti antenna system will be used to transfer the IR imagery.

The off-axis target would require a pan system on the camera. There is not enough resources for the team to develop a functional pan system, so an additional camera, a Gopro Hero 3, is deployed on the side of the airframe to provide additional imagery. The image transfer is supported by analog video transmitter on 1.2 GHz.

2.3 Risk management

In UAV development there are 3 major risks : schedule delay, lack of test and crash. These three risks can be fatal for the project's development and each of them can impact the others.

2.3.1 Schedule Delay risk

If every project has this risk, it's especially true when you have a specific date and time for a mission. This is the case for this mission: it's impossible to extend the project final deadline. A good way to reduce the delay risk is the use an iterative engineering approach. That way, if a subsystem's development failed to meet the deadline, it's possible to revert to a previous version of subsystem to have a usable product in time.

Another way to preserve the project timeline is to have a good planification of resources needed. Lots of delay can come from material in transit between stores and the workshop.

Also, it's very important to keep a clear overview of subproject priority and critical path. If there is a delay in the critical path, it is necessary to sacrifice low priority aspect of the project to preserve the critical path. Finally, to reduce schedule delay risk, it is important to reduce lack of test risk and crash risk. Each of them will dramatically increase your schedule delay.

2.3.2 Lack of test risk

Tests are the most important thing in a complex integration project like unmanned system. Furthermore, tests are very difficult to execute in aerial development. In a student environment, it is difficult to have safety pilot, ground control operator, ground video operator and weather all sync together in same times.

First of all, it's important to prepare more time than you expected to time purpose, the team consider 50% of the test planned won't happen. Sometimes, it's impossible to fly multiple days. A good habit of the team is to plan tests very early in the morning (5h-6h AM) : winds are usually lower and most team members are available.

Second, the team prepares each test : complete system test in the development area before bringing it to test area. Also, goals and objectives are clearly established. Finally, the team has multiple check-lists for the equipment to bring to the test area; tests can be canceled because battery or propeller is missing.

2.3.3 Crash risk

It's almost impossible to eliminate the risk of crashing, but it's possible to reduce this risk.

Having a good pilot is the most important thing. The team makes multiples training RC plane and a RC simulator available for its members. Special efforts have been made to train 2 pilots and external pilots are sometimes invited to execute tests with the team.

Weather surveillance is a first priority for the team, specific weather limits are respected. Usually, the tests are planned very early in the morning, between 5 am and 7 am ; winds are usually low.

Even with good risk reduction, crashes can occur. In this case another system is needed, which is why the team always keeps 3 backup of every of UAV systems. This prevents delay after a crash.

2.4 Expected Performance and Mission task attempted

The airframe's expected performances for this mission are presented in this table :

Table 2.6 Airframe expected performance	
Parameter	**Value**
Weight	*25 lbs*
Endurance	*60 minutes*
Maximum range	*5 NM*
Payload max weight	*7.5 lbs*
Cruise speed	*40 knots*
Stall speed	*24 knots*

The payload expected performance are :

Table 2.7 Payload expected performance	
Parameter	**Value**
Visible picture resolution	*24 Mpixel*
Visible picture frame per second	*0.3 pictures/s*
IR picture resolution	*0.5 Mpixel*
IR picture frame persecond	*9 pictures/s*
Geolocalisation precision	*< 100 ft*
Real time visible transmission	*Yes*
Real time IR transmission	*Yes*
Off-Axis target imagery	*Yes*
Autonomous Air-Drop	*Yes*
Air-Drop precision	*< 100 ft*
SRIC communication	*Yes*
Automatic visible image analysis	*Identification*

The autopilot expected performance are :

Table 2.8 Autopilot expected performance	
Parameter	**Value**
Autonomous takeoff	*Yes*
Autonomous landing	*Yes*
Autonomous waypoint	*Yes*
Autonomous search area	*Yes*
In-Flight retasking	*Yes*
Interoperability via RS-232	*Yes*
Failsafe	*Yes*

And the task the team will attempt are

Table 2.9 Attempted task		
Task	**Rules**	**Condition**
Autonomous take off	*7.1*	*If weather permit it*
Autonomous landing	*7.1*	*If weather permit it*
Autonomous waypoint	*7.1*	*Yes*
Autonomous search area	*7.2*	*Yes*
Autonomous target identification	*7.3*	*Yes*
Autonomous target classification	*7.3*	*Will be attempt*
Actionable intelligence	*7.4*	*Yes*
Emergent target	*7.6*	*After search area*
SRIC	*7.7*	*After search area*
SRIC mission	*7.7*	*If time permit it*
Air-drop	*7.10*	*If time permit it*

3 Description of UAS design

3.1 Airframe design

VAMUdeS new airframe is named Artemis. It is a 3 m wingspan standard fixed wing aircraft with a takeoff weight of approximately 25 lbs. The aircraft is tracked by a single electric motor 1.6 KW E-flite 80 motor. Energy comes from 2 lithium polymer 8000 mAh batteries connected in parallel.

Illustration 1: The new airframe : Artemis

The wings and tail are the same as the 2013 VAMUdeS airframe "Aigle Noir", designed for a stable and efficient level flight. They are made of foam and covered with fiberglass layer. The landing gear is designed in tricycle with a controlled front wheel for a better control of yaw during takeoff and landing.

The fuselage is molded from custom fiberglass design. It is separated in two pieces : bottom and top. The bottom contains all the heavier parts of the aircraft including motor, wings, tail fixation and most electronic devices. It has a double deck to have more space. The top is a simple, non structural cover with antennas and other communication devices.This airframe is ergonomic, efficient, reliable and easy to reproduce.

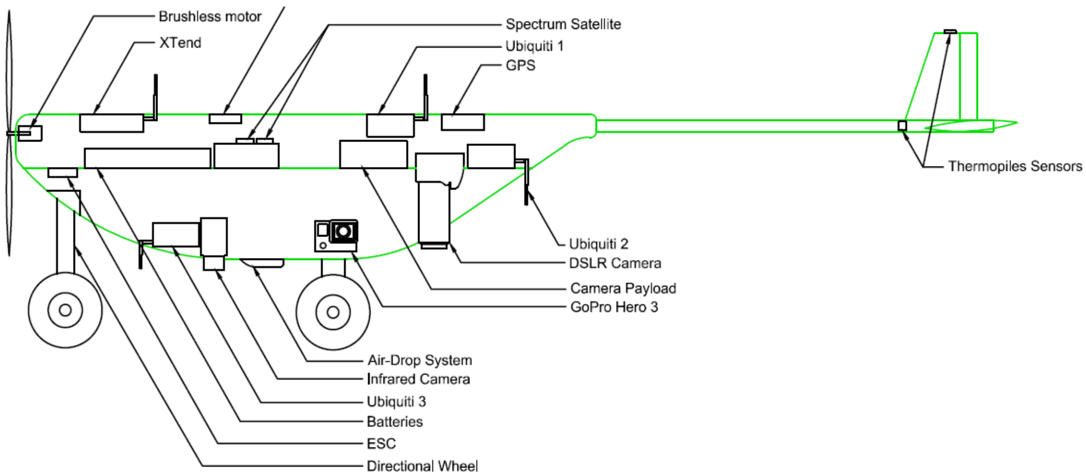

Illustration 2: Airframe schematic

3.2 Autopilot and Ground Control Station design

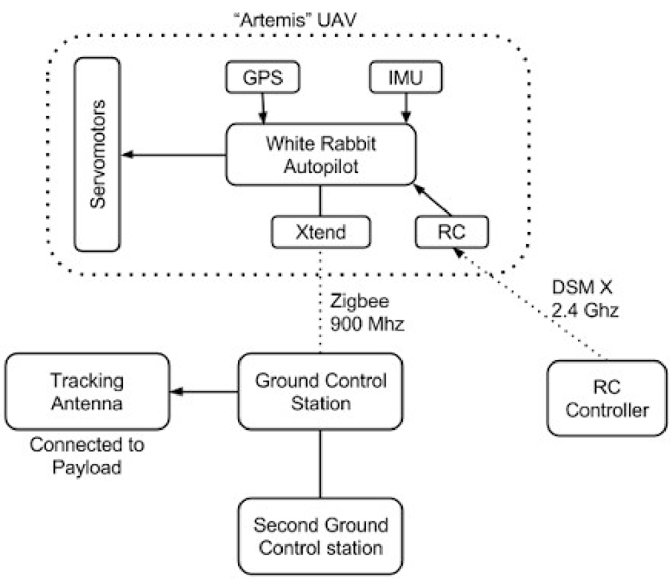

Illustration 3: Autopilot schematic

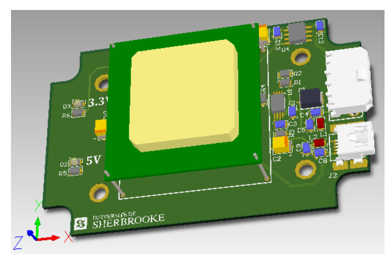

Illustration 4: The GPS

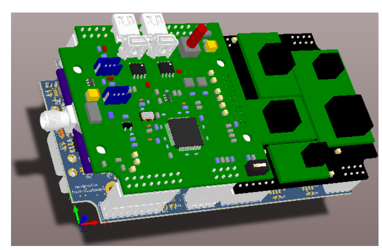

Illustration 5: The autopilot : White Rabbit

The control system is achieved with the new VAMUdeS autopilot: White rabbit. This autopilot is developed from the Lisa/M v2.0 Paparazzi autopilot and runs Paparazzi 5.0 software. The team's design has additional input protection, better power supply, an additional FTDI board, an XTend on board and can be connected with an hardware watchdog.

Additionally, the attitude is not given by IR sensors anymore, IMU Aspirin 2.2 are used instead, with barometer sensor embedded. This autopilot can be programmed with multiple failsafes and can modify its flight plan in real time.

The autopilot uses XTend 900 MHz Modem to transfer telemetry to the ground. The modem can satisfy the channel package specification for the competition. The autopilot also uses a U-Blox 6 GPS with WAAS which can give precision up to 3 ft. The U-blox signal is sent to the payload controller computer.

The telemetry is sent in real time to the Paparazzi Ground Control Station. This system allows the user to display critical informations : battery level, speed, altitude, status, telemetry link etc. The software allows the user to monitor the position of the system and modify his behavior. Another computer is connected to the principal ground control station. This second station act as a redundant system and allows a second user to modify the flight plan without interfering with the first user.

UAV position is sent to another computer which controls the tracking antenna and sends NMEA message via an RS232 port.

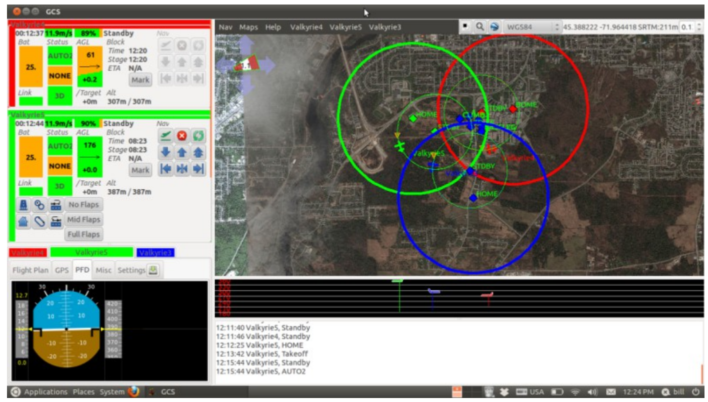

Illustration 6: The GCS : Paparazzi

3.3 Payload design

The payload consists of 5 different parts : visible payload, IR payload, off-axis target payload, air-drop payload and SRIC payload.

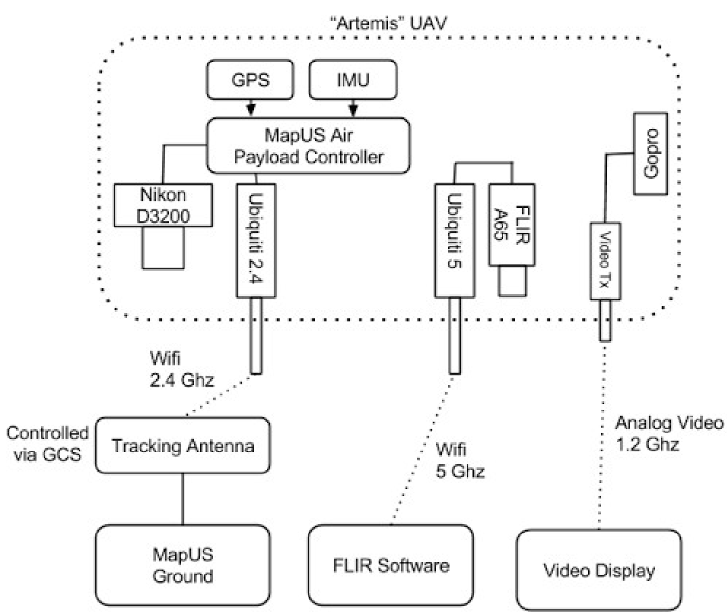

Illustration 7: Payload schematic

3.3.1 Visible Payload

A Nikon D3200 high resolution DSLR camera is used to take 24 MPixel pictures. The camera is controlled by the payload controller : MapUS Air. This controller is a linux embedded controller Gumstix Overo (Cortex A8) mounted on a custom board.

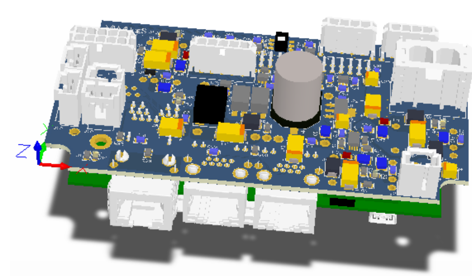

Illustration 8: The payload controler

The payload controller triggers the Nikon camera at 0.33 hz and receives the aerial pictures. MapUS Air incorporate ,in exif metadata, the position and attitude of the UAV when the picture was taken. The image is sent to the ground via a Ubiquiti network bridge on 2.4 GHz.

3.3.2 IR Payload

IR imagery is accomplished by a FLIR A65 camera at 9 Hz. The resolution is 640 x 480 pixel. These pictures are directly sent to the ground via an additional network bridge on 5 GHz. As the camera interface is gigabit ethernet, a special network adapter is needed with Power Over Ethernet (POE) of 56 V. On the ground, the image is received by a computer using the FLIR display software.

3.3.3 Off-Axis target Payload

The best solution for the Off-Axis target would be a pan on the Nikon D3200. Unfortunately, this solution is not implemented due to the lack of resources. To have images of this target, an additional camera, a Gopro Hero 3, is installed on the side of the fuselage with a fisheye lens. The signal is transmitted in real time to the ground via an analog video transmitter 1.2 GHz where it is received by an patch antenna, and displayed on a computer.

3.3.4 Air-drop payload

The drop mechanism is pretty simple. The relief canister is attached to the mechanism by two small hooks at each end of the egg. A small pin makes sure the egg can't move when the hooks do. Whenever the drop is required, the ground control operator sends the signal to the autopilot, which initiates the dropping sequence (rule 7.10.9.1). When drop is imminent, the servomotor drags the hooks upfront, releasing the package. The payload is designed in respect of AUVSI seafarer restrictions section 7.10.

Illustration 9: The drop mechanism

3.4 SRIC payload

To connect the UAV to SRIC, two network bridges Ubiquiti are deployed : one is used by the payload controller to send pictures and the other creates a network bridge between the UAV and the SRIC. At the moment of connection, the payload controller will stop the camera and execute a special script to recuperate files in the computer. After a successful connection and file recovery, the files are sent to the ground via the first network bridge.

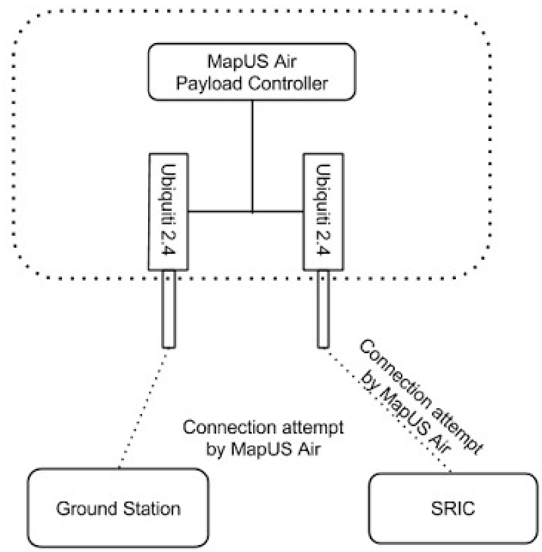

Illustration 10: SRIC schematic

3.5 Data transmission

There are multiple communication devices in the UAV.

3.5.1 RC communication

The RC communication is established between a 2.4 GHz DX8 spektrum 600 mW transmitter and 2 redundant DSM X satellite receivers which use frequency hopping technique.

3.5.2 Telemetry

Telemetry is transmitted with Xtend modems using the Zigbee protocol at 900 MHz. These 1 watt emitter/transmitter can be configured to execute frequency hopping to conform to rules section 5.3. Omnidirectional antennas are used.

3.5.3 Payload controller Network Bridge

The payload controller is connected to the ground via a Network Bridge established by two 2.4 GHz Ubiquiti devices: 1W pico station onboard with omnidirectional antenna and a 1W bullet device with 24 db directional antenna mounted on tracking device. It's possible to restrain the channel used to respect rules section 5.3.

3.5.4 IR camera network bridge

The IR camera is connected to the ground via two 5 GHz Ubiquiti 1W device with omnidirectional antenna. These systems can comply with AUVSI restrictions section 5.3.

3.5.5 SRIC network bridge

To connect to the SRIC, a Ubiquiti PicoStation device is used at 2.4 GHz using the channel 1. The power of this device is 1 W and it will connect automatically to the SRIC.

3.5.6 Analog video transmitter

GoPro Hero 3 for Off-Axis target uses a 1.2 GHz transmitter 500 mW. On the ground, the signal is received with an patch antenna. Channel can be set to comply with AUVSI restriction.

3.5.7 Ground video station

There are multiple computers on the ground to receive different informations.

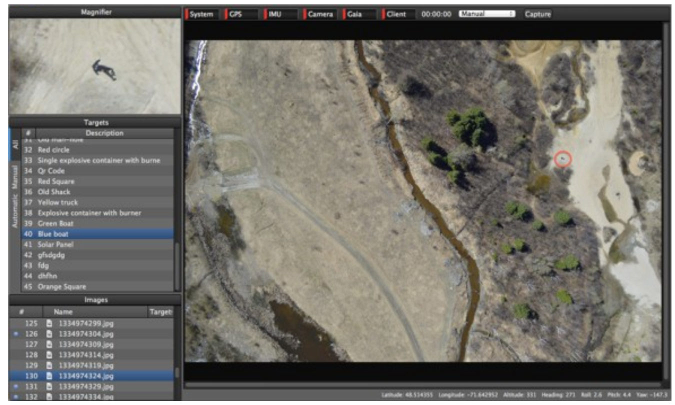

Illustration 11: MapUS ground user interface

The main tool to use the high resolution camera is MapUS Ground. This software is a Graphic User Interface (GUI) developed by Team VAMUdeS to display, geolocalize and identify manually targets or point of interest. It is possible to use the software in network with other MapUS ground software; in this case, one is the server and the other are the client. Each time the server receive a picture from the UAV, it transfers it to the client via TCP/IP. The targets and point of interests are sent back to the server to generate a report. MapUS ground can also execute automatic target detection and classification with its subsoftware MapUS Gaia. The automatic analysis is explained in the homonym section. Finally, MapUS Ground can generate an automatic report and a KML file for display on Google Earth.

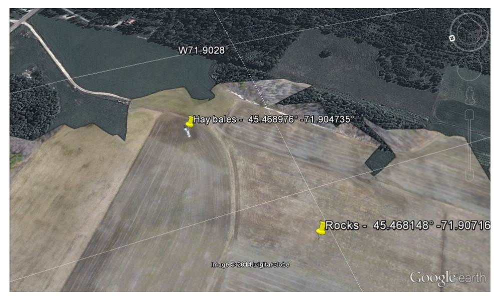

Illustration 12: GoogleEarth integration


Illustration 13: IR camera

To consult the IR camera, a computer connected to the 5 GHz displays the 9 hertz images on the FLIR program. Timestamp of the IR and visible camera are compared to get the position of the IR target. Finally, to get the Off-Axis target, the signal of the Gopro Hero 3 is received by a patch antenna and acquired by a computer via a Sensoray frame grabber.

3.6 Autonomous detection and classification

The detection is performed in four phases.


Illustration 14: MapUS Gaia

1. The first phase eliminates unsuitable pictures. A picture is deemed unsuitable when the altitude is too low or the pitch or the roll is too high.

2. The second phase proceeds to a blob detection based on the color.

3. The third phase geolocalizes the blob and compares its position to previously found targets. Duplicated or off-zone blobs are eliminated. Every blobs too small or too big are rejected. The remaining blobs, if any, are identified as potential targets.

4. The last phase tries to generate a mask for the remaining blobs. If a proper mask cannot be generated, the blobs are rejected. Otherwise, a new founded target is formed by the mask applied over the cropped original picture.

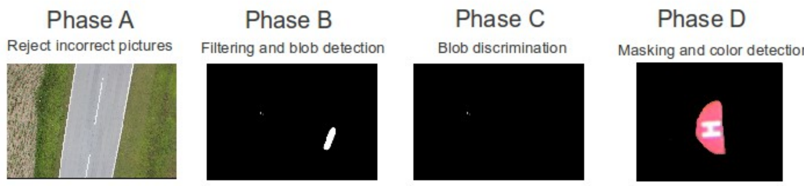

Illustration 15: Autonomous detection phases

There are currently two characteristics autonomously classified: the background color and the letter color. The color of each pixels contained in the target is estimated. Basically, the background color is set as the most common color and the letter color, as the second most common color.

Emergent target and IR target should not be detected. Otherwise, every other type of target must be autonomously detected, even if the accuracy may vary according to the colors of the targets.

3.7 Flight Plan

As the coordinates of the flight plan are not available, this is a prevision of the flight plan.

After weather check, checklist and team check, the UAV will attempt autonomous takeoff with the most favorable pathways.

Some verifications pattern will be executed to make sure the UAV control is fully functional and operational.

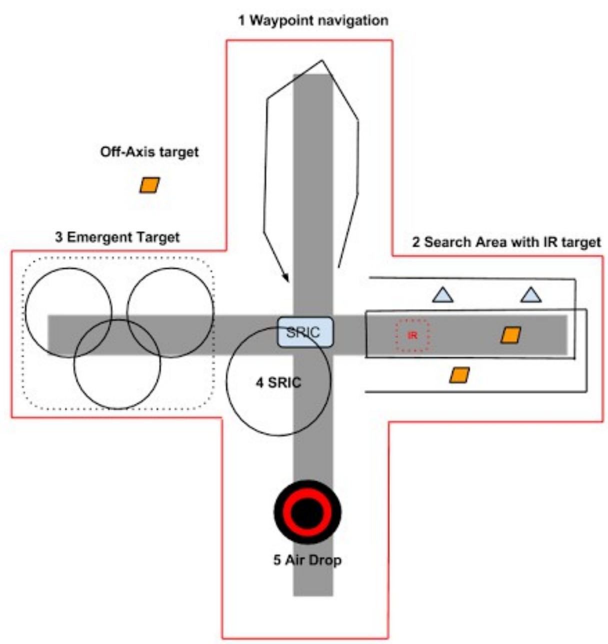

Illustration 16: Flight plan

1. The UAV will be send in the waypoint navigation section autonomously. During this task, the three payloads will take imagery and send it to the ground.

2. Afterwards, the UAV will begin the search pattern autonomously with automatic detection and classification with the Nikon D3200 camera. IR pictures will be sent to the ground to detect the two IR targets.

3. During the flight, the second ground control operator will enter the new position in the flight plan and the UAV will begin circle pattern in the emergent search zone to find the emergent target.

4. To connect to the SRIC, the UAV will execute circle over the SRIC. Afterwards, the message will be sent to the ground.

5. If the time allows it, the UAV will attempt an autonomous Air Drop.

If the time allows it, the UAV will execute the SRIC special mission

Autonomous landing will be attempted at the most favorable pathways.

4 Tests and evaluation results

4.1 Missions task performance

4.1.1 SRIC

Multiple tests have been made to find the best way to acquire the SRIC message. These tests revealed that two strategies had to be taken into account: “fly around” the SRIC or “fly over”. According to the results, with a circle of 300 ft of radius, the reception was way better with the “fly over” strategy. At these altitudes, the UAV was able to retrieve the files every time.

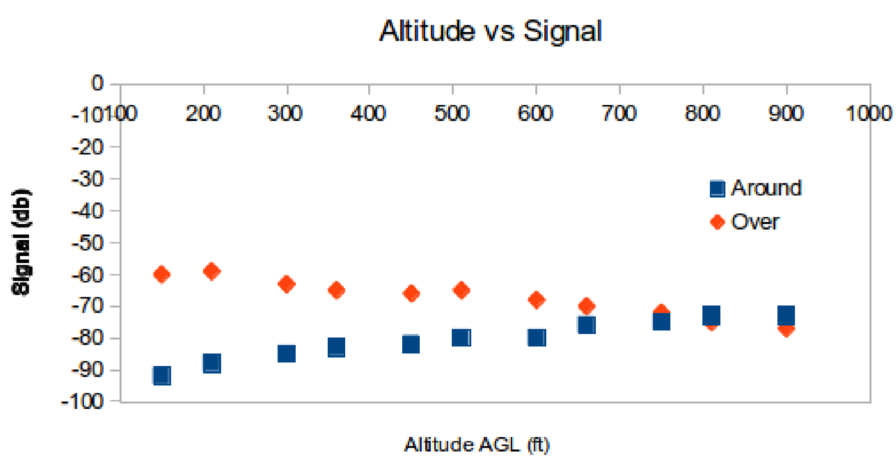

Illustration 17: Signal intensity according to altitude

4.1.2 Search Pattern

To make sure every square inch is covered and to have the possibility to use mosaicking algorithm, a good overlap on the pictures is required. With calculus and tests, it was determined that the good ratio is 50 % in front overlap and 30 % in side overlap. Also, it was determined by test that with a focal length of 18 mm, the maximum altitude to find and identify human shaped target is 500 ft.

4.1.3 Air-drop

The first concern to Air-Drop is the UAV’s stability after the drop. More than 6 drops have been executed to make sure the stability is assured after the drop. The drops of a 1-lbs bottle filled with water never affected the stability of the aircraft, which is largely heavier than the AUVSI drop package.

4.2 Payload system performance

4.2.1 Overall performance

The payload Nikon D3200 controlled by the embedded computer MapUS ground.

Table 4.1 Payload test result	
Parameter	**Value**
Visible picture resolution	
Visible picture frame per second	
Maximal range	
Geolocalisation average precision (600 ft)	*48 ft*
Near realtime transmission	*Yes*
Weight	*2.6 lb*

Precision tests have been made to evaluate the precision of geolocalization during the USC 2013 competition. At 600 ft of altitude, 31 targets have been analysed and the following results were extracted :

Table 4.2 Target precision test results				
Nb of targets analysed	**Average Precision**	**Standard deviation**	**Best precision Value**	**Worst precision Value**
31	*48 ft*	*30 ft*	*6 ft*	*120 ft*

4.3 Guidance system performance

4.3.1 Overall performance

Guidance system is probably the most tested system. The following table shows the overall performance :

Table 4.3 Guidance system performance	
Parameter	**Value**
Roll and pitch control for stabilized mode	*Yes*
Navigation and altitude control for autonomous mode	*Yes*
Failsafe programmable	*Yes*
Minimum turning radius	*210 ft*
Rate of defaillance	*0%*
Autonomous takeoff	*Yes*
Autonomous landing	*Yes*
Kill Switch	*Yes*

4.3.2 Position error in navigation

During the flight, especially in day of high winds, the position isn't exactly what is supposed to be, the next table shows the approximative average of theses imprecisions :

Table 4.4 Position error in navigation	
Manoeuvre	**Max error**
300 ft radius circle	*30 ft*
Search Pattern	*30 ft*
8 figure	*45 ft*
Time for an U-turn	*20s*
Error for a U-turn	*210ft*

4.4 Likely mission accomplishment

A full mission test has been completed by VAMUdeS at the Unmanned System Canada UAV competition at South Port, Manitoba, Canada. The mission consisted in covering an area of 0.3 NM² to evaluate the surface of different crop. Also, the team had to evaluate the volume of a rockslide and report any suspicious activities.

As the search area was 0.25 NM away from the takeoff zone, an autonomous flight was required and the UAV maximum range was around 1.2 NM. The allowed time for the mission was 45 minutes and past this time, no transmission was allowed.

4.4.1 Result

After 3 minutes of preparation, the UAV was up in the air and after few verifications, the system was sent to the research area. 12 minutes later, all pictures from the research area had been taken and sent to the ground for analysis. After the rockslide was found, the flight plan was modified to execute 8 patterns around the interested area.

All the affected crops and suspicious activities were found with a precision of 15 ft.

4.4.2 Evaluation

This mission proved that Artemis UAV is safe to fly autonomously, take pictures with a good precision and transfer them real time. The mission also proved that the team is ready to setup the system very quickly.

On the other hand, the mission did not perform any air-drop, SRIC or autonomous landing and takeoff. Therefore, further tests will have to be carried out regarding these mission criteria.

5 Safety considerations / approach

5.1 Li-Po batteries precaution

Li-Po batteries are used by the team to power the aircraft and the systems it contains. These batteries are inspected before each charge or use and they are always stored in explosion-proof bags. The battery charger recommended by the battery manufacturer, i.e. the TP820CD model from Thunder Power RC, is used by the team. This battery charger is equipped with built-in balancers to prevent over-charging that could potentially result in fire causing damage or personal injury. Moreover, a sealable sandbox which contains non-reactive sand is made available for battery disposal in case of malfunction or damage of Li-Po batteries. These latter are also wrapped in colored shrink in order to find them easily, even after a crash. Besides, the aircraft was built in such a way that the batteries would be expulsed from the plane after a crash. This would prevent the systems from suffering the damages caused by battery explosion for example.

5.2 Workspace precaution

Team members use security glasses and masks rated for organic particles while performing risky operations. A proper ventilation of the workspace is also provided whenever the team has to work with solvents or other volatile substances. Combustive and fuel chemical products are separated in fireproof lockers and tools are locked and can never be used without a convenient training.

5.3 Trainings

Within the team, safety roles are assigned to some of the flight crew members and each teammate gets involved in trainings to ensure the safe execution of all flight missions. Indeed, training is provided to members who play an important role during flight operations. For example, the safety pilot must undergo hours and hours of flight practice prior to any competitions. A flight simulator is made available to get these hours of practice. Moreover, the team takes advantage of a professional pilot to help them to tests their systems. This allows to mitigate the risk of crash due to the experience of the pilot.

5.4 Preflight precaution

VAMUdeS must always go through some checklists prior to any flight. Regarding this, a physical inspection of the aircraft and a check of flight-termination procedures are initiated before allowing the plane to leave the ground. Moreover, the aircraft undergoes a communication status check performed by the GCS operator in order to know if the communication is properly established between the aircraft and the GCS. Furthermore, critical systems are minutely inspected in order to reveal any bad connection that could eventually result in control loss. Actually, each systems have been designed to make wires accessible from the top of the plane in order to facilitate the check-up.

5.5 In-flight precaution

While performing a flight mission, the team always chooses a site which is located far away from cities and villages. This practice helps to prevent any citizen to be injured because of a crash. The aircraft is always kept in the field of vision of the safety pilot and the GCS operator. In this case, maneuver such as manual override (if it is necessary) are made easier. A good communication between each flight crew member is of paramount importance in order to properly achieve the mission. Considerations about communication abilities between teammates are brought forward during each flight test session performed by VAMUdeS.

Table 5.1 UAS Failsafe Procedures legend	
Code green	Mission continues with autonomous flight
Code orange	Mission compromised or manual flight engaged
Code red	Mission aborted, spiral descent

Table 5.2 UAS Failsafe Procedure			
Failure Mode	Effect Analysis		
	Step 1	Step 2	Step 3
RC link failure	Autonomous return home, visual warning displayed on the ground control station	After 6 minutes : Mission abort, spiral drive	-
Outside mission boundary	Reach the nearest waypoint or return to the previous one	Near 30 seconds: autonomous return home	More than 30 seconds: mission stops, spiral drive
Telemetry link loss	Quickly try to troubleshoot communication system	After 30 seconds: autonomous return home	After 3 minutes: Mission stops, spiral drive
Autonomous return failure	Switch to manual flight if the pilot is able to take over the autopilot	If the pilot is unable to take over the autopilot, kill the aircraft	-
Unsafe battery level	Battery voltage low: try to finish the mission	5 minutes of flight left: manual overdrive, force return home	Very weak batteries : motor is turned off, emergency landing
Image acquisition system failure	Try to troubleshoot via computers in the ground control station	After 2 minutes : recycle the transmitter and receiver power	If unable to restore the image acquisition system, return home
Unstable Flight	In-flight PID tuning	If unable to hold altitude autonomously and behave properly, shift to manual overdrive	-

5.6 Safety risk mitigation

An evaluation of the main risks, their effects on the project and the mitigation method proposed to overcome the potential issues brought by these risks are provided in the following table.

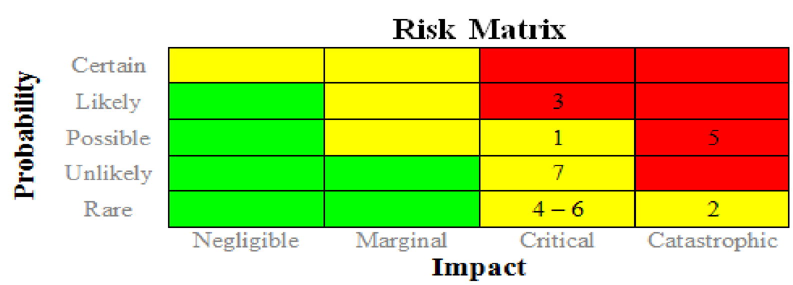

Illustration 18: Risk matrix

Table 5.3 Risk assessment						
ID	Risk	Cause	Result	Mitigation	Probability	Impact
1	Flight session	Weather conditions are not suitable for the flight	Flight sessions are delayed	Lots of tests are preformed throughout the year	Possible	Marginal
2	Mechanical concerns	Weakened parts are not seen during inspection.	The aircraft may suffer from in-flight damages or even break apart into the air	Prior to any flight, the aircraft is inspected by more than one person	Rare	Catastrophic
3	Payload	The launching device fails to operate	The air-drop target is not reached and this part of the mission is not achieved	Launcher will be inspected by the team and by competition safety inspectors	Likely	Critical
4	Power outage	Power regulation is not properly performed	On-board navigation systems will fail to operate which will result in a bad in-flight attitude or even a crash.	All printed circuit boards made by the team are tested	Rare	Catastrophic
5	Communicat ion	Communication between the aircraft and the GCS is lost	The GCS does not receive information from the plane and/or the autopilot detects wrong instructions.	Every transceiver are tested before operation, redundant RC link is provided and failsafe procedures are implemented	Possible	Catastrophic
6	Autopilot	An autopilot failure occurs during the mission	The aircraft reacts badly and may do wrong operation or leave the flight zone.	Back-up autopilots are provided and the autopilot has never failed so far	Rare	Catastrophic
7	Software	Mapus Ground and/or Mapus GAIA fail to operate	Imagery analysis cannot be performed and critical mission information are lost	The software can be quickly restarted	Unlikely	Critical

6 Conclusion

The VAMUdeS system is a UAV that can perform automatic takeoff and landing and is controllable via GCS. The payload can take high resolution pictures and transfer them in real time to the ground video station. Also a safe drop can be executed and SRIC can be reached with VAMUdeS' system. The team finished a year of hard work, but it already has in mind improvements for the next year.

For the next year, a new version of White Rabbit, the autopilot, is on the table and a completely new version of payload controller is desired. But at the moment, after AUVSI competition, the next challenge for the team is the Outback Challenge.