Design paper 2016 AUVSI Student competition
Dronolab – École de technologie supérieur

Abstract

Dronolab is an expanding student club from École de Technologie Supérieure (ETS) located in downtown Montreal, Quebec. Our mission is to operate a fully autonomous multirotor to perform aerial surveys for various civil applications. The design is about constant improvement, such a UAS involvement, the collaboration of several engineering fields including software, electronics and mechanics. The ingenuity, creativity and contribution of each faculty help the team achieve safe and professional flight operations

In order to have a fully autonomous platform, we choose to use a 3DR Pixhawk autopilot along with a reliable data link on the 900 MHz band. Collect and transfer data during the flight are handling by a ARM dual-core based system with QX30 camera to take pictures on which we add GPS location information. The data is then sent using a high-speed 5.8 Ghz modem (Ubiquiti Bullet M5). The whole system is included in a local network to allow efficient data processing.

Throughout this year, we have tested our platform for countless hours in multiple weather conditions to achieve reliable operations.

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Introduction

1. System Approach

1.1. Mission requirement analysis and expected task performance

Will accomplish:

- Full autonomous flight with autonomous take-off and landing.
- Ability to hold a current position in order to achieve various tasks.
- Live picture transfer during flight, ability to drop probes.

Will attempt:

- IR target detection, being as focused as possible on precise task to be able to achieve maximum success.

Will not attempt:

- Map the all-terrain due too tight time frame.

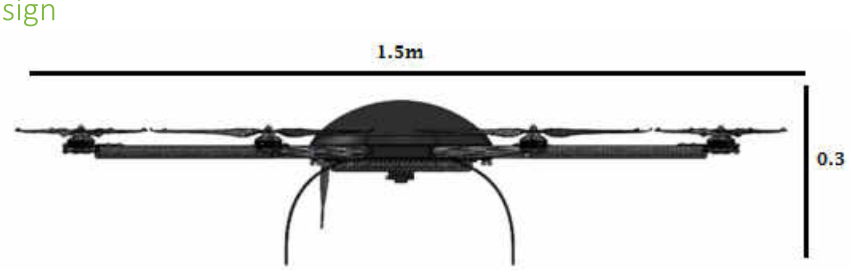
1.2. Design rationale and evolutions from 2015

Due to our last year's problems, we optimized this year concept to not only correct them, but to vastly surpass the capabilities of its predecessors. Our latest design was thought around redundancy. The optocopter give us the ability to have multiple motors failing and still be able to fly. Our autopilot provides us a lot more feedback on the UAV behavior and it allows us to have a lot more control over itself. We also changed the remote controller frequency to 433 MHz to obtain a better communication link at a greater distance. The telemetry link is using the Xbee protocol which is renowned to be a very stable radio link. We also implemented a second data link with our ubiquity. Said Wi-Fi modules are used to transmit live pictures taken by our high precision camera to our ground station. We not only changed our autopilots and platforms, but we also redesigned our payload in order to obtain a higher image resolution. Our camera, the QX30 from Sony, has a 20.2 MP and it provides us with a large enough resolution to detect any target during the competition.

1.3. Programmatic risks and mitigation methods

In order to minimize bug or strange behavior from the software, we decided to put in place multiples solutions: first, we use as much as possible open source and already tested codes (from our previous development or from public project). We also try to test as much as possible our software and our hardware, first during the development time (unit test and system test) and by running our software and flying our platform in a lot of flight test session.

2. UAS Design



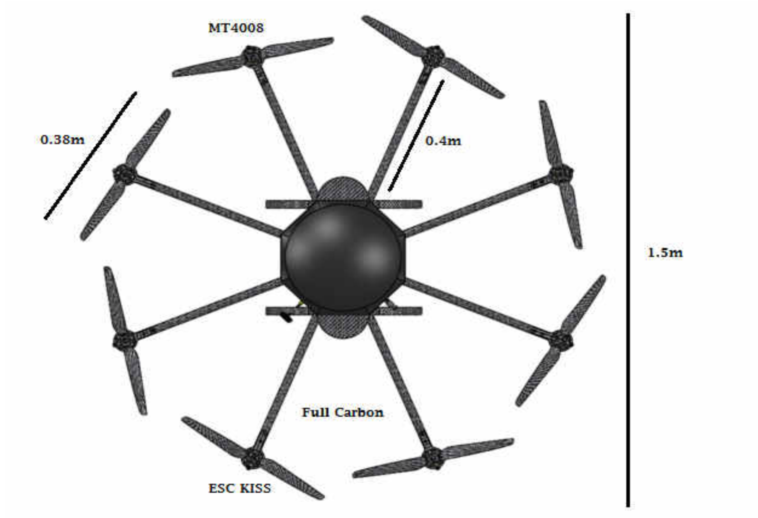


Figure 1. UAV physical model (from CAD plan)

Uav Dimension		Propulsion system		Operation performances			
Uav Diam.	1.5m	Motor Power	109W	Speed Metrix		Operation	
Height	0.30m	Prop. Size	15x5	Ascending speed	2 m/s	Endurance	1 h
Weight	7kg	Barreries	22.2 V	Maximal Ascending speed	4 m/s	Minimal crew	2
Core Diam.	0.3 m		30 Ah	Descending speed	1.5m/s	Maximal range	1.5 km
Arm lenght	0.4 m	Motor count	8	Max horizontal speed	15 m/s	Min. Operational Temp.	(-30 °C)
core Height	0.10 m	Esc	Kiss	Cruise speed	8 m/s	Max. Operational Temp.	40 °C

Table 1. Mechanical and flight characteristics

Figure 2. Photo of our two identical UAVs

2.1. General specification

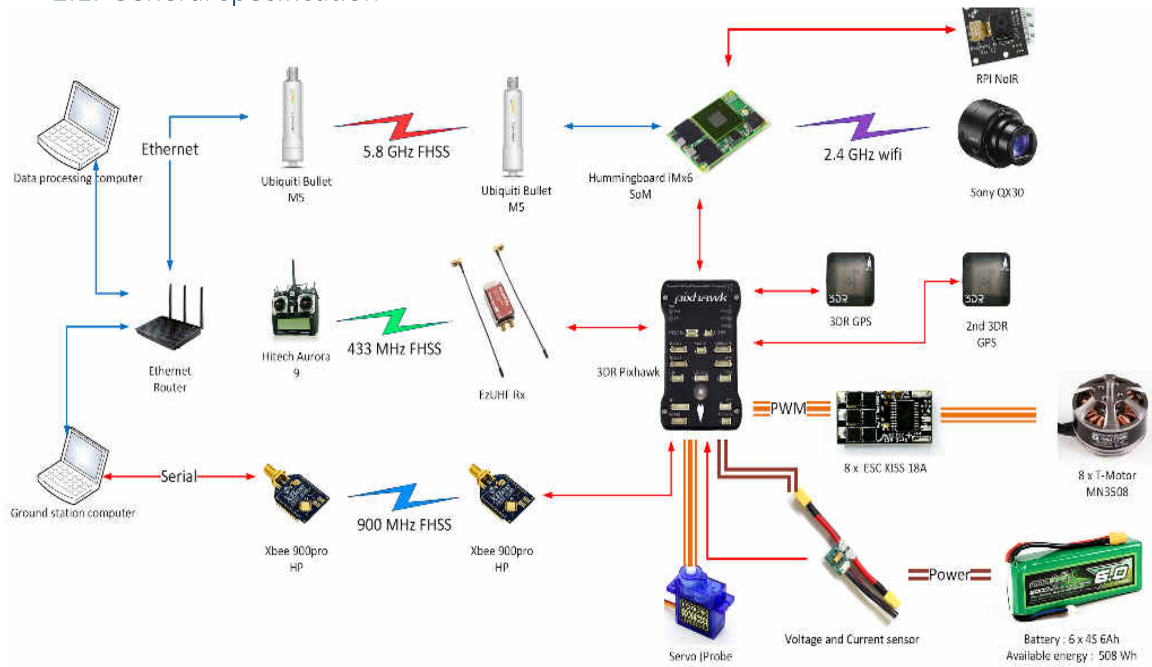


Figure 3. Complete system wiring schematic

2.2. Airframe

2.2.1. Composite Airframe

This year, we have designed an octocopter mainly in order to have a motor redundancy, and by doing so increase its safety and reliability. We decided to place the batteries inside the drone's core to allow a better protection against various weather conditions and shock. Moreover, we've added on the platform all of photogrammetry systems to reduce the number of payloads and setting time. We've created a universal payload plug to allow of a quicker payload change. As for its size, the airframe measures 46 inch from the center of one propeller to the opposite one.

2.2.2. Propeller & propulsion system

The propulsion system is composed of eight motors MT4008 with 15x5.5 inch propellers and 30A ESC. Overall we use the same propulsion system than last year, but we double it (eight arms instead of four). The drone weight 7Kg and the motors can lift a maximum of 16Kg.

2.2.3. Power

The drone is powered by three 6S batteries; each has a capacity of 10000mAh. Not all the components have the same power requirement. Indeed, we use 5V for the on board computer, 24V for the Ubiquiti and 12 V for the payload system. We use KISS ESCs because we've found that they're the more efficient and have the best quality to weight ratio. Moreover, they fit perfectly in the drone's arm

2.3. Flight control system and autopilot

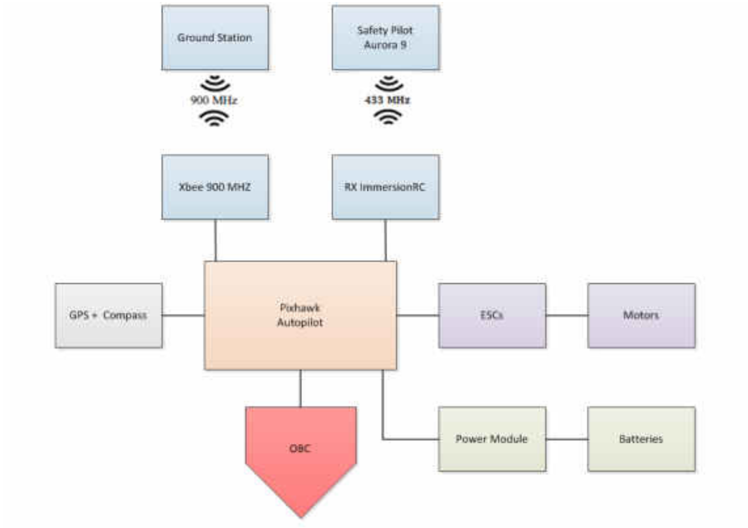


Figure 4. Block diagram

2.3.1. General guidance and navigation

Pixhawk is an open source autopilot, which allows our team to develop new functions and tasks with great ease. We consider open source to be great since it allows us to implement new software tasks and it allows us to share our findings with others. The navigation architecture is designed for multi-rotor drones. This architecture allows our team to edit the motor's layout through the signal mixer. The autopilot allows us to place a location point list. The device will treat information at the beginning of the mission.

2.3.2. 3DR Pixhawk

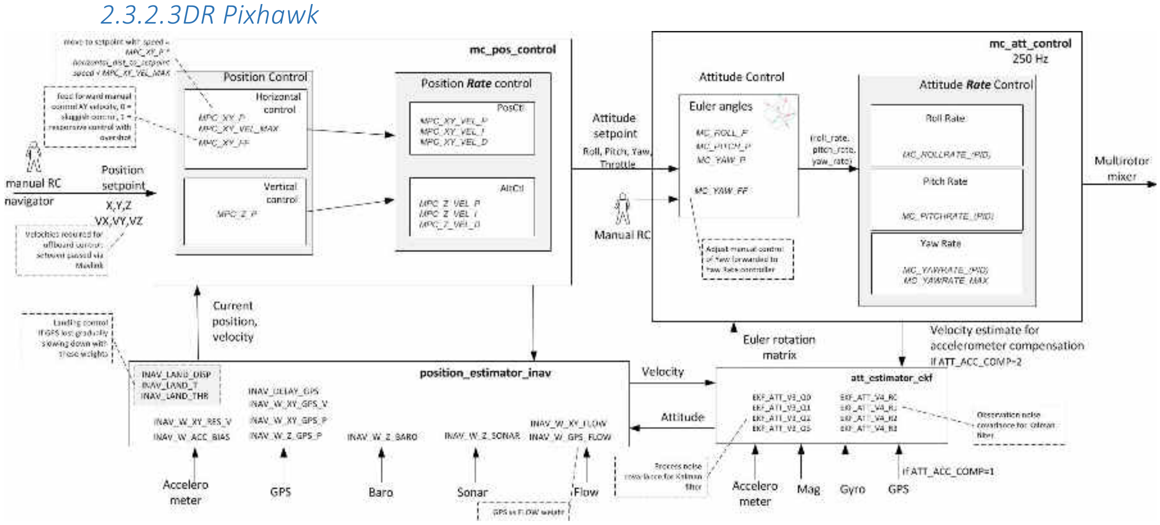


Figure 5. The Pixhawk hardware architecture

2.3.3. Software overview

The following schematic indicate the Pixhawk integration into the whole system architecture.

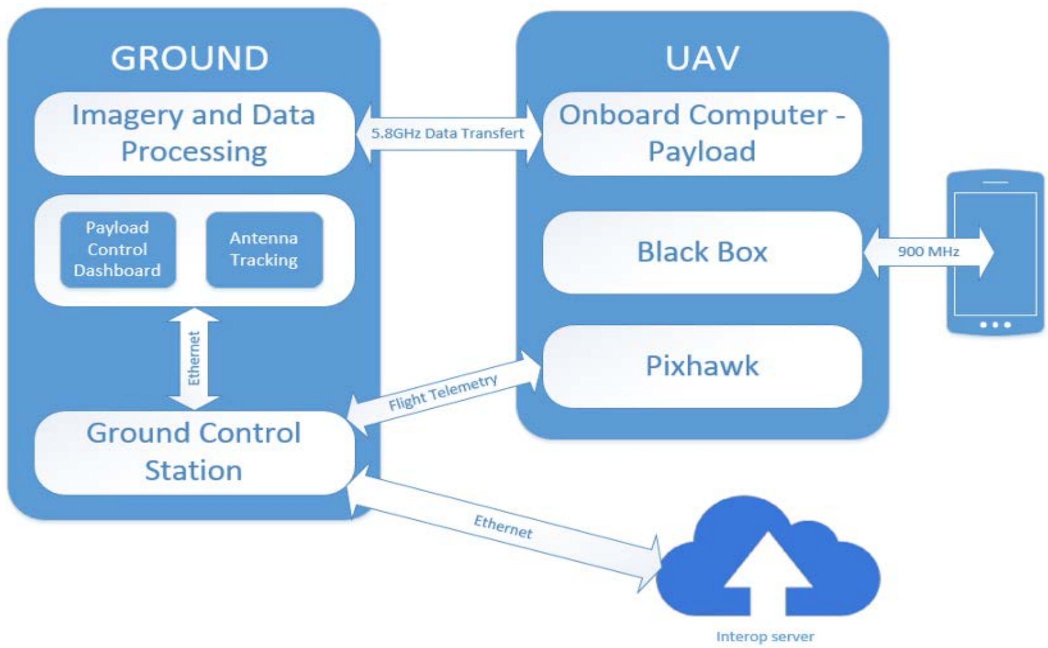


Figure 6. Software overview diagram

2.4. Communication and data links

2.4.1. Data links

The data link telemetry will use the Mavlink protocol and Xbee 900 Pro HP modem. This modem allows high speed (200 kbps) and long range (5km) on the 900 MHz band transmission, with security features (AES crypto) and mesh capability. The Mavlink protocol is an open source data link protocol used by various UAV controllers that allows fast and reliable link. Since Xbee uses Frequency Hopping Spread Spectrum (FHSS), it is very resilient to jamming and interference.

2.4.2. Communication sum-up list

Use of the link	RC controller	Flight Telemetry	High speed data transfer	Wifi connectivity
Model	ImmersionRC EzUHF	Xbee 900 proHP	Ubiquiti bullet M5	Integrated wifi modem
Frequency	433 MHz	900 MHz	5.8 GHz	2.4 GHz
Tx Power	600 mW	250 mW	600 mW	100 mW
Tested range	4 km	4 km	3.5 km	100 m
Data speed	N/A	200 kbps	50 Mbits	30 Mbits
Security feature	FHSS	FHSS + AES	FHSS + WPA2	FHSS + WPA

Table 2. Telecom system list and details

2.5. Payloads system

The payload system schematic is available in the general specification.

2.5.1.Stabilization gimbal

We choose the Sony QX 30 mostly because weight is very important factor especially when deciding on a camera that you want to be carry in flight. This camera is significantly light and has 20-megapixel resolution sensor. So, it makes it one of the most affordable and still with a good quality/weight ratio. This camera communicates by Wi-Fi with the on board computer. Sony's API allowed us to develop an embedded script, which takes 20 megapixels every 5 to 6 seconds and send those through Wi-Fi to the onboard computer and afterward to the ground. Shutter time, ISO and other photographic parameters will be adjusting regarding post-flight weather conditions.

2.5.2.Air drop system

The camera previously describe is used for photogrammetry and in order to have the best picture quality at possible it needs to be stabilized. We are able to do so with an originally designed two axes gimbal system: multi-rotor UAV can bank in multiple directions by more than 20° and still ensure camera stability. Our gimbal is also controlled by our onboard computer.

2.6. Ground control station

2.6.1.Flight management console

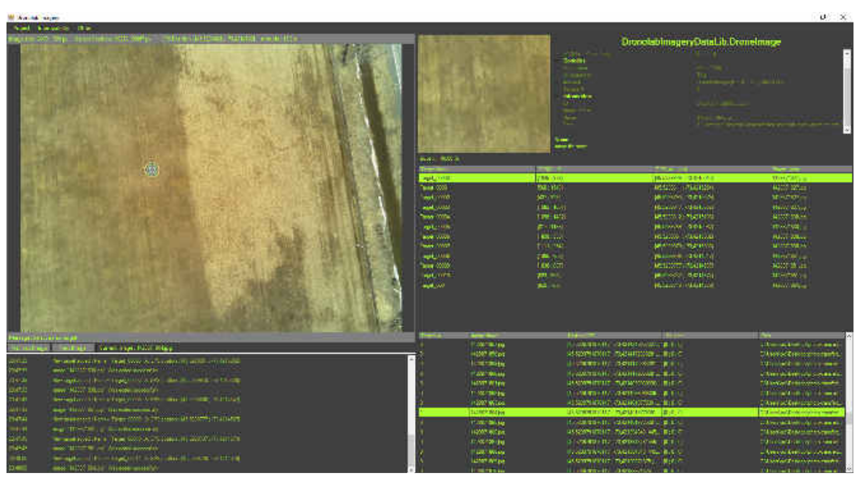
With the desire of pushing the drone limits to an other level, we choose what we consider being the greatest open source autopilot: the Pixhawk. Pixhawk's community is composed by amateur and professional UAV enthusiasts. Moreover, researchers use said platform because of its multitask architecture. The flight management console that we chose is QGroundcontrol GCS. Our reasoning is the following: the software supports both Pixhawk and APM flight stack. It's also open source as is Pixhawk. If we need custom widget for specific mission, we can simply design them. The code is made in C++ language and using Qt as our framework for the graphical user interface. The application contains a multitude of feature such as mission logging and playback, open source code, plotting sensor data and more.

Figure 7. Mission example on QgroundControl

2.6.2.Status console

Last year, the only way to keep track of the entire drone's data was to read all the log files dumps. It was messy and unclear. We decided to improve our data analysis by designing an entire program that displays all the necessary information formatted with clear and concise graphics. This dashboard will also allow the possibility to execute commands like toggling the photo capture system. The software will acquire our drone data by querying the current MavLink packets using QGroundControl program. The interface has been developed using web technologies (HTML5, CSS3, Javascript). Its stack is perfect to rapidly create beautiful interfaces. The backend part of the program is done with the Python programming language, which is great to do network tasks like request handling. The status console is definitely an innovation considering what we had last year.

2.6.3.Imagery console



Pictures taken by the UAV are automatically shared through our network by P2P allowing multiple team members to process the data. The target selection operations are human-made and assisted with our own imagery software. The software is capable of retrieving all the pictures and meta-data send by the UAV in real time. The software operators can quickly go through all the pictures and select the area of interest of which the GPS position is calculated immediately. Multiples ways to save the generated data allow the operator to quickly input the targets in a report. The software is also capable of communicating targets data with an interoperability server.

2.6.4.Safety pilot

Before each flight, the team and the safety pilot has to go through a precise and detailed check list. The pilot has to check if the terrain is compatible with safe flight operation (buildings, trees, etc.) and choose the altitude of each navigation points accordingly within a flight zone bound by ground observers. During the flight, the whole team monitors the air and ground traffic for any potential problems. If any hazardous situation appears, the safety pilot can override the autopilot and manually take full control of the UAV. This operation can be done at any moment, and it permits a quick landing if needed. For each flight the pilot has to log in the flight time as well as any noteworthy events that occurred during the test. For the V9, UAV we have for this moment has a total of six hours of flight.

2.7. Development process of specific mission

Due to extensive tests and practice flights, the skills of our ground station operator are being constantly sharpened. Before every flight, our team creates a flight scenario and the ground station operator exacts said flight plan at the same time according to the competition's scenario. In conjunction to these operations, the interoperability responsible is also double-checking the waypoints of the flight plan before doing the mission.

2.7.1.Autonomous waypoint navigation

The interoperability supervisor and the ground station operation will be in communication at all times. In order to avoid obstacles, the interoperability supervisor will communicate the position of the obstacle and the operator will manually correct the flight path.

2.7.2.Search area and imagery processing

Helped by our QX30 camera and our imagery software (described previously) we will be able to determine target location, provide maximum target characteristics electronically and decode the message on QRC targets. Every search task will be done autonomously and supervise trough our ground station. Imagery processing can be done in real time or afterwards with our software.

2.7.3.Interoperability

In creating and testing process of the interoperability client, we installed a server on our domain. Said server is always up to date. The client was created in C#. This client receives the drone telemetry from custom Json packets send from MAVProxy software. The client is using free of charge map stock in the cash, witch mean they can be accessed without an Ethernet connection. The interrupt client is the access point of our Imagery software. It will receive the images and sends the discovered target to the competition server. The client is composed of modules which are asynchronous to optimize the bidirectional data transfer. The main function of the client is to show the drone position and the position of any potential obstacles to better avoid them.

2.7.4. Simulated remote information center connection
After the antenna location and the wireless network name will be provided we will adjust our flight plan in order to execute a stationary flight over the router. We will also set all parameters require for the task (network passphrase, folder path…). In flight, the drone is going to automatically connect and stay within the SRIC beam width enough to log into the network, receive the secret word, and upload secret text file to the same folder.

2.7.5. Air drop system
The bottle of water is dropped one at a time with a release system controlled by servo motors. It is to note that the whole system only weights less than 300g without the bottle of water. Moreover, to offer more precision, the drop will be controlled by the autopilot distribution or balance of power.

2.8. Mission planning overview
For this year, our mission planning will start off with an autonomous take-off. Following said take-off; we will follow the flight path until we hit the search area. We will probe the area and find the required targets. When the area probing and the targets will be accomplished, the team will complete the server task. After establishing a connection with the server and completing this task, the water bottles will be dropped. After the drops, the emergency target will be detected. Throughout the mission, the team will be modifying the mission consequently to the obstacles faced during the drone's flight. The autonomous flight will be ended with an autonomous landing.

3. Tests and evaluations results
After flying our first prototype, the design had undergone extensive iterative testing to ensure that it meets all requirements for the competition. Those include structural tests which are currently being done and complete electrical simulations which have already been validated.

3.1. Overall aircraft performances
3.1.1. Aircraft structural tests
Computer simulations have been made for all the structural parts. Then, throughout winter, we will perform tests to confirm the structural reliability of our platform in sub-zero temperature (around – 30 Celsius). These tests consist of emergency landings, high velocity passes and rapid loss of altitude (motors off). Furthermore, the redundancy of our drone will be evaluated by shutting down one or two consecutive motors. The autonomy of our new platform, in outdoor conditions, has not yet been tested considering it is still being assembled but based on data from previous missions and our extensive testing; we can now safely assume that out drone will be able to complete this year's missions.

3.1.2. Static thrust tests
In order to choose the optimal propulsion configuration, static thrust experiments were conducted in combination with several propulsion parts (propellers, motors and batteries). We

then compared them based on thrust, weight, reliability, cost, performance and heat to best fit the needs of this year's mission requirement.

3.1.3. Weather resistance

Due to our closed and well integrated design, our drone is able to fly in a lot of harsh weather. Low rain condition, windy conditions and practically any winter condition. Our drone can also sustain hot weather. Our platform has been tested in practically any weather throughout the year.

3.1.4. Payload performances

The payload was first tested separately, then to acquire inflight data while staying on schedule, it was tested on last year's platforms. These tests allowed us to solve a couple of issues we had and provided satisfying results with both the camera and the stabilization system. Since the camera sensor is stabilized by a gimbal, the drone can be operating in harsh weather conditions without altering the quality of image. While testing the payload, we confirmed the chosen transmission system was able to send the payload dataset without any delay even when the drone is 1.5 kilometers away.

3.1.5. Autopilot and mission tasks performances

We will do multiple mission tests on open field (with authorization coming from competent authority) in multiple weather condition (wind, light snow, etc.) to verify the performance of our autopilot. Using the results of those tests, we will establish a clear table of conditions in which the UAV can flight. Our multi-rotor should be able to flight in rough condition (up to 30 km/h of wind speed for example) and still be able to follow its designated path. In addition, after correcting calibration, our autopilot will be able to manage to fly even with an uneven mass distribution or balance of power.

4. Safety considerations

4.1. Design safety

The main control loop that is able to emit its GPS position. The black box is equipped with its own battery in case of a failsafe occurrence, thus cutting the power flow. The black box starts emitting in case one of the following event occurs:

- Abnormal UAV attitude during prolonged time
- UAV enters a free fall during prolonged time
- Power flow through the UAV lost (the black box will switch to internal battery in this case). A smartphone, with an application we made ourselves and a USB Receiver, can retrieve the black box signal and guide it to the black box's location.

4.1.1. Innovation of the airframe

Each year, we innovate on our platform by making it more modular, more reliable and with longer flight time. Indeed, this year we've designed a universal plug for our payload that allow us to quickly inter-change them. The reliability of the platform is increased by using eight motors instead of six, rethinking the way we build our arm connectors and using 433 MHz for RC safety pilot that offer us more range. Finally, our flight time of one hour is much longer than the mission time to ensure that we can finish our path even in windy and cold conditions.

4.2. Operation safety

4.2.1. Pre-flight checklist

Before take-off, the safety pilot should make sure that all of our fail safes and security systems are operational. A full hardware checklist will be done in order to check battery's power for damages and to insure correct linkage, transmission, motor reliability and connection, payload components and propellers. As always, we will take in account of the current weather condition, especially wind intensity. This will allow us to adapt, if necessary, our flight plan (adjust speed or altitude for example). Thanks to this checklist, the team can ensure that each flight is safe and goes according to the plan.

4.2.2. Inflight safety considerations and ground crew assignments

During each flight, every member of our crew is assigned a specific role according on everyone's competencies. To ensure the safety of every crew member, a minimal security distance from the drone is mandatory. The pre-flight checklist is essential to maximize inflight safety and prevent possible damages due to hardware failure.

4.3. Safety considerations matric sum-up

4.3.1. Safety criteria

This section covers all the possible issues while operating the platforms for this specific mission. Based on previous calculations, a maximum of X minutes of flight time must be respected to keep a safe voltage level during the overall mission to avoid battery damage. The UAS can only be operated in following flight conditions. This information corresponds to Dronolab's safety plan.

4.3.2. Safety risks and mitigation methods

Here is a presentation of the specific flight conditions needed to operate the UAS.

Conditions	Temperature	Wind Speed	Visibility	Rain
Values	40	up to 40 km/h	VLOS	Drizzle

Table 3. Maximum flight condition

4.3.3. Risk matrix

The risks engendered by the UAS's flights are numerous and must be assess by the team to assure safe flight operation. The following risk matrix can categorize the aforementioned risks. The next table presents the list of risks while operating the UASs based on the risk matrix.

Catastrophic	Moderate	High	High	Critical	Critical
Major	Moderate	Moderate	High	High	Critical
Moderate	Low	Moderate	High	High	Critical
Minor	Low	Moderate	Moderate	High	High
Insignificate	Low	Low	Moderate	Moderate	High
Severity / Probabilty	Rare	Unlikely	Possible	likely	Almost Certain

Table 4. Risk matrix

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Risk	Description	Probability	Severity
1. UAS loses communication with the RC	The UAS doesn't interact with the RC. Base cannot operate manual kill-switch. Base cannot take handover of the UAS.	**Rare** Using a commercial RC design to operate model aircraft.	**Moderate** The UAS will proceed with an autonomous landing starting from his current position.
2. UAS loses communication with base	The base doesn't receive the UAS's current status. The telemetry monitoring client becomes unusable. The base loses GPS position of the UAS. The UAS loses new command instructions from the base.	**Rare** Using a commercial data link system. The communication is on a reserved frequency. Using a commercial means of communication designed to cover the necessary distance.	**Moderate** Base cannot know the current status of the UAS. However, the pilot can take handover of the UAS and perform a landing. The UAS continue its mission regardless of the communication link for a period of 10 seconds and then will return to his home position.
3. UAS fly outside of mission boundary	The UAS flies outside of the GPS marked mission zone.	**Rare** The base uses mission manager and GPS tracking. Using commercial flight system.	**Moderate** The UAS continue to operate properly. Pilot can take handover of the UAS.
4. UAS loses GPS signal	The UAS doesn't receive its GPS position. The UAS cannot know its position. Base cannot know the UAS's position.	**Rare** Using a commercial GPS, outside, with no obstacle.	**Major** Navigation system loses precision exponentially. The UAS will at first hold his current position for 10 seconds and then will perform auto landing.
5. IMU malfunction	The UAS cannot measure it's orientation in 3D-space.	**Rare** Using a commercial IMU.	**Catastrophic** The UAS cannot operate without knowing its orientation. The UAS will deploy a parachute.
6. Motor/ESC malfunction	One or two motor stop functioning or do not operate at the correct speed.	**Rare** Using commercial motor. Using commercial motor controller.	**Moderate** The UAS can fly with more than 6 motors. The UAS will continue his mission.
	More then two motor stop functionning or do not operate at the correct speed.	**Rare** Using commercial motor. Using commercial motor controler.	**Catastrophic** The UAS cannot fly with less than 6 motors. The UAS will deploy a parachute.
7. UAS has unplanned behavior	The UAS doesn't behave according to the mission manager and commands.	**Unlikely** Exhaustive tests will be done on the prototype to prevent most if not all unplanned behaviors. Using commercial flight system.	**Moderate** Base cannot predict UAS behavior. Pilot can take handover.
8. Battery malfunction/explosion	Lipo battery can burn or explode if the casing of the battery is broken and/or that its cell is exposed to air. Lipo battery can also explode if not charged correctly.	**Rare** Using commercial Lipo Battery and charger. Battery is protected by the UAS's frame.	**Catastrophic** The battery explosion can burn people and material.
9. UASs trajectory interference (collision)	The UASs fly on a path that interferes with each other.	**Rare** The waypoint paths will be design considering the largest fly space possible between the two operating platforms and timings.	**Catastrophic** UAS's collision bring to a potential break of equipment which bring could bring platforms to crash. Exposed persons could suffer injuries.
10. Battery depletion	The battery cannot provide enough energy to the UAS.	**Possible** Battery's characteristics are known and can be monitored.	**Moderate** The UAS cannot fly without power. The flight system will detect the drop of voltage in advance and execute an auto landing.

5. Project management

5.1.1. Overall budget

Departements	Descriptions	QTY	Unit price	Price
Management and competitions fees				
	Inscription fees	1	200 $	200 $
	Tests expenses	1	1 700 $	1 700 $
	Competition expenses	1	6 000 $	6 000 $
	Sub total			7 900 $
Mechanical				
	Competition frame parts	2	500 $	1 000 $
	Tools and components	1	500 $	500 $
	Sub total			1 500 $
Electrical				
	Camera QX30	1	400 $	400 $
	Gimbal	1	100 $	100 $
	Transmitter 433 MHz	2	250 $	500 $
	OBC	2	100 $	200 $
	Power distribution PCB	2	150 $	300 $
	Meteo station	1	40 $	40 $
	Antenna tracking	2	300 $	600 $
	Motors-ESC	20	100 $	2 000 $
	Batteries	16	30 $	480 $
	Xbee 900MHZ	3	50 $	150 $
	Sub total			4 770 $
Software				
	SD Card	5	20 $	100 $
	Router	1	80 $	80 $
	Simactive 1 year licence	1	3 000 $	3 000 $
	Sub total			3 180 $
Total				17 350,00 $

5.1.2. Gantt

	Nom	Durée	Début	Fin
1	Partnership research	273j?	09/03/2015	09/13/2016
2	USC inscription	42j?	09/03/2015	10/30/2015
3	Autonomous flight test	1j?	10/30/2015	10/30/2015
4	Conference call USC	1j?	11/27/2015	11/27/2015
5	Design papers	1j?	01/15/2016	01/15/2016
6	Winter condition flight test	3j?	02/25/2016	02/29/2016
7	Proof of flight Video USC	3j?	02/25/2016	02/29/2016
8	Attendance sheet	1j?	03/15/2016	03/15/2016
9	Media release	1j?	03/15/2016	03/15/2016
10	Second winter condition flight test	3j?	03/24/2016	03/28/2016
11	Description, logo and photo creation	1j?	04/01/2016	04/01/2016
12	Resumes	1j?	04/15/2016	04/15/2016
13	USC Competition	8j?	04/26/2016	05/04/2016
14	Old platforms autonomous flight test	85j?	09/03/2015	01/05/2016
15	Transmission systems test	65j?	10/05/2015	01/01/2016
16	Flight and image transmission test	30.5j?	01/04/2016	02/15/2016
17	New UAV design and conception	89j?	09/03/2015	01/05/2016
18	Assembling new UAV	19j?	01/12/2016	02/05/2016
19	New platforms test	108j?	02/08/2016	07/08/2016
20	Weather station design and conception	39j?	09/03/2015	10/27/2015
21	Autopilot tests	174j?	09/03/2015	05/03/2016
22	Ground & Station developpement	172j?	09/03/2015	04/29/2016
23	Tracking antenna design and conception	63j?	09/03/2015	11/30/2015
24	Pilot's training	272j?	09/03/2015	09/16/2016
25	Other flight test	172j	09/03/2015	04/29/2016

5.1.3. Important dateline

Task	Date
USC inscritpion	31-09-2015
Conference call USC	27-11-2015
New platforms test	31-01-2016
Proof of flight Video USC	01-03-2016
Attendance sheet	15-03-2016
Media release	15-03-2016
Description, logo and photo creation	01-04-2016
Resumes	15-04-2016
USC Competition	01-05-2016

6. Draft SFOC for flight test

Dronolab presents SFOC documents which combines all tests and competition flight periods. Entire documents are sent to Transport Canada.

Conclusion

This paper summarizes the work done by our team at our faculty in ETS in preparation for the 2016 AUVSI student competition. Using last year feedback, Dronolab team designed, developed and tested our new unique systems that aim to complete mission tasks using a high level of autonomy. Drawing upon extensive experience in designing multi-rotor drones, our team has designed a robust, modular airframe from composites. Ground control station, payload and flight controller were completely redesigned to maximize our score in core tasks. Redundant safety mechanisms were thought and incorporated in the system and procedures were developed to make sure the system is safe for audience in the competition audience and personnel here. We are currently and always will be trying to make our system better in every way shape or form and we are willing to see the result of our hard work during.

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