IMAV2016-16
http://www.imavs.org/pdf/imav.2016.16

Development of a Quadrotor with an original shape in order to do rescue applications

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Abstract

This project is included in Mechatronics engineering education at the National Institute of Applied Sciences (INSA) of Strasbourg. It consists in designing, building and controlling a Micro Aerial Vehicle with quadrotor structure in composite materials. In this article, the design, manufacturing and control approach is detailed.

The drone is completely homemade. The choice of an innovative shape and the research of a reliable material will be developed. The MAV is able to drop a parcel or carrying and fulfilling a water container and contains image sensors for precision landing and cartography applications.

This article will also talk about embedded electronics and control, control done with a LabVIEW interface we designed.

The link between the work of the team and the competition is also made. Indeed, the specification of the Quadcopter project at school coincides with the one of the outside competition. A closer look will be taken at the Bambi-Bucket, a system imagined by the team to collect water for the “Sample water around the oil rig and then release the water into a specified water container” mission.

1 Introduction

This project have been developed in the INSA Strasbourg's school, a French engineering school based in Strasbourg. It began five years ago with the aim of designing and creating an innovative quadrotor. The first team was composed by ten members who worked on this project as a part of the mechatronic cursus (four hours per week). A new team of six members will take over the project as an internship this summer in order to attend the IMAV competition. The following pages will present the work done the first team and the former ones.

First the innovative and optimized body will be presented. Then will come the electronical and programming part to describe how the MAV is from a far fully controlled. Finally, according to the competition specifications, the Quadrotor adapted for rescue missions part will be developed.

2 An innovative and optimized body

The entire structure of the MAV has been thought out to be as light as possible to carry the maximum amount of rescue objects. It is well known that MAV structures should be as light as possible to be able to add lots of sensors, cameras, different kind of payloads and high capacity batteries [1]. Our quadcopter has a specific design and is completely manufactured in composite structures which provide excellent mechanical properties for such application.

1) Global design of the Quadcopter

The plates have been designed in a drop form. Indeed, they are not circled to be less fragile to eventual impacts. They have been thought out to be the more ergonomic as possible.

The layout of the plates is noteworthy compared to drones made with carbon tubes. Indeed, the electrical parts are protected between these plates [2].
Vibrations are also better absorbed with this structure.

Below is a screenshot of the latest quadcopter CAD version:

Figure 1: CAD of the Drone

2) Arms design and manufacturing

The structure of the arms is composed of two rotational symmetric elements, made of a three-layer sandwich composite material, based on carbon-kevlar tissue and airex, in an epoxy matrix [4]. This composite provides excellent mechanical properties for such applications. Its special shape allows arms work in traction and compression, in conjunction with traditional bending, and demonstrated great strength, a very good vibration absorption and a very weak distortion at the end of the arms. Moreover, the structure embraces and protects the embedded electronics while allowing free access to components and a modularity of the elements that provides easy and fast intervention. The minimalist and uncluttered characteristic of the structure gives us a very good compromise between protection and weight. The two main parts of the structure, strictly identical, were produced by vacuum lamination with a mold realized on a Computer Numerical Control machine. The two elements of the structure are ready for use and provide an easy assembly thanks to the direct integration of fastening systems

Below is a CAD view of an arm assembly:

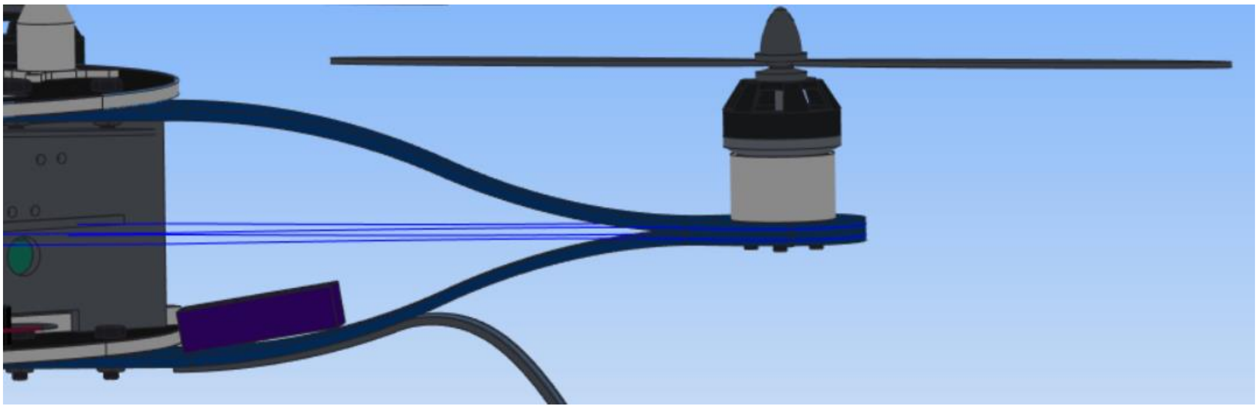

Figure 2: CAD of one arm assembly fixed to the MAV

The arms have been designed to be screwed on the shell made by the plates described above.

The machining and fabrication of the MAV's own arms shape is done at the INSA. It is designed with composite materials such as Kevlar, carbon and fiberglass. All molds are self-made, designed and tooled in the school.

Arms are made of a sandwich composite material composed of a symmetrical structure made of a layer of aramid fibers textile (trademark Kevlar) between two layers of cross linked polymer foam (Airex C71). This structure is placed between two layers of Carbon fibers textile, as described in the figure below.

Figure 3: Sandwich composite structure of the arms

This kind of composite structure is widely used in aerospace design [3]. This sandwich advantage is due to the strength and stiffness properties of Airex combined to the high rigidity of carbon fibers. The central layer of aramid limits the risk of shredding of arm in case of shocks. The other advantage of the Airex is its high vibration absorption possibilities. It also helps to limit the weight of the sandwich and absorbs low frequencies vibrations.

Sandwiches we use for our tests and for our quadrotors are composed of two layers of carbon fiber (65g/m² Torayca® T300J) and one layer of carbon aramid (210 g/m² twill wave) between two layer of 1.2mm of Airex C71 and an Epoxy matrix (Resin L from R&G composite)

Arms molds have been modeled using a CAD CAM 3D software (CREO). This 3D model has then been used with a CAM software in order to machine the mold on a CNC Milling Machine. The material of the mold is a high density tooling board (Figure 5).

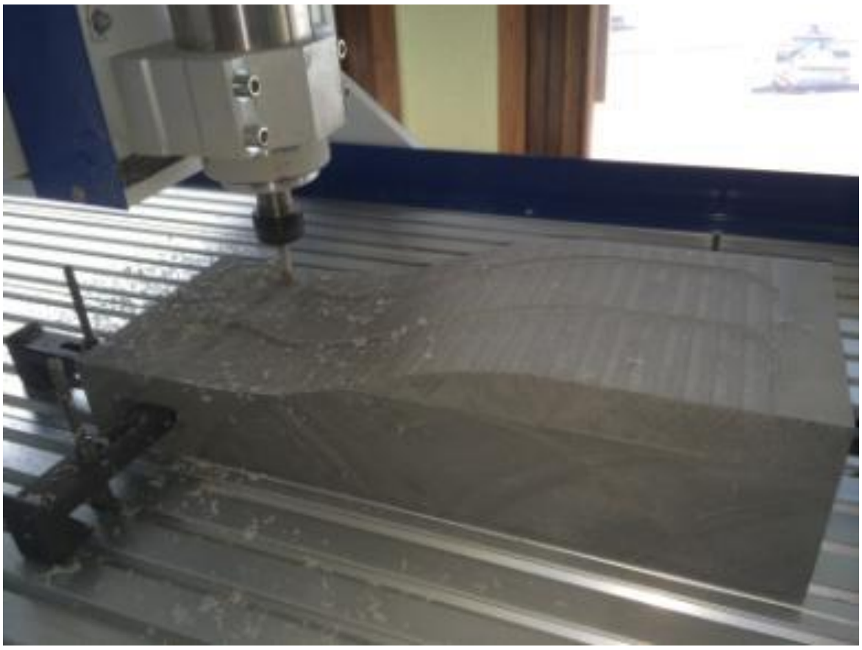

Figure 4: Arms molds are tooled in high density tooling board

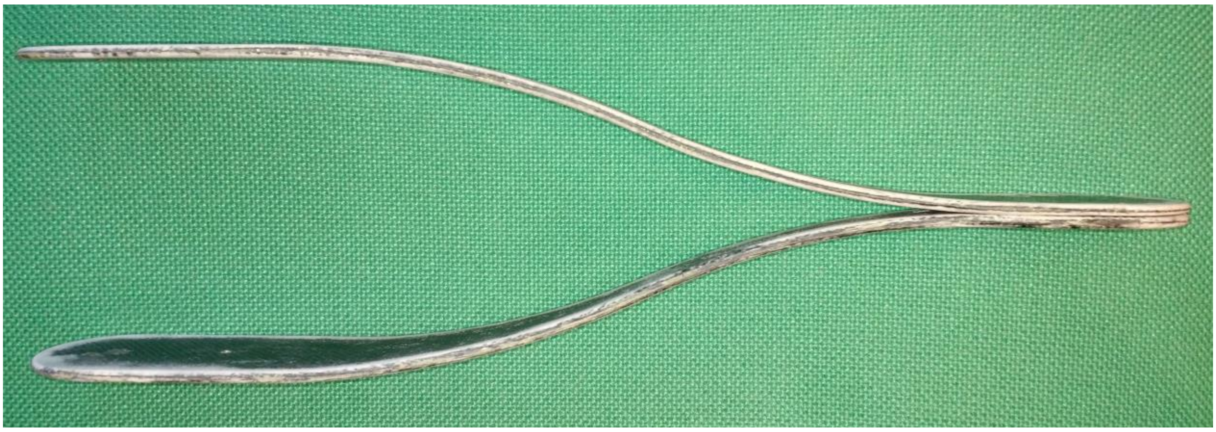

Figure 5: Asembly of one arm, each part molded at the INSA

Several vibration, resonance measurements and simulations have been made to determine the behavior of the arms through different conditions and to avoid any vibrations or resonances due to motors and propellers rotations.

Specimen have been manufactured and tested using a tensile test machine according to norm ASTM D 3039 (Tensile Properties of Polymer Matrix Composite Materials). Tensing tests have been done on (Zwick/Roell tensile machine) with two kind of test specimens with carbon fiber oriented at 90° and 45°.

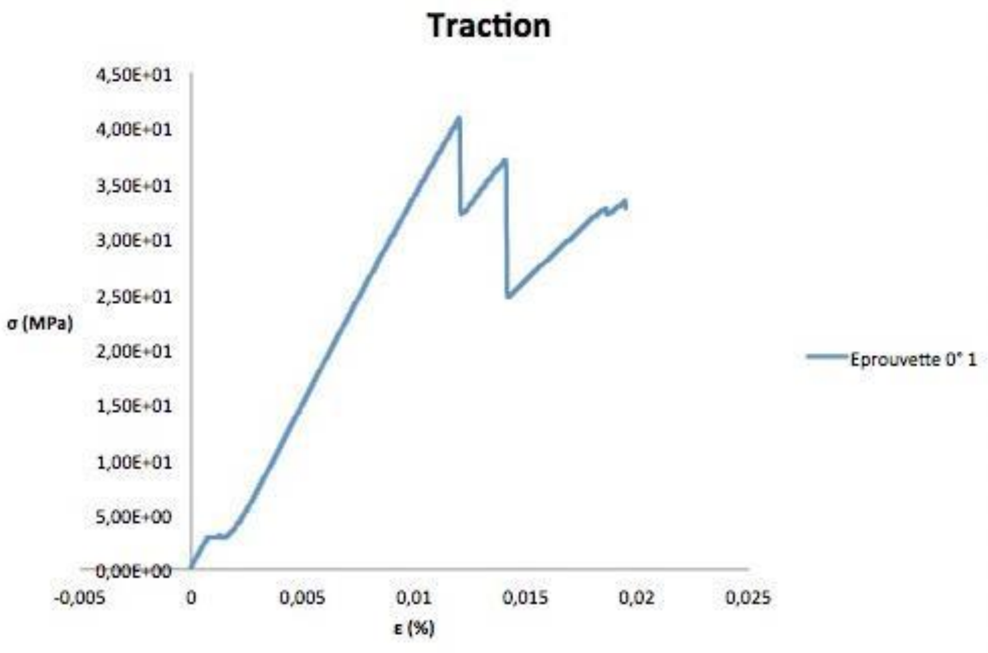

Figure 6: Example of tensile results on 90° carbon composite sandwich. The mean Young modulus obtained on 3 samples is E= 3832 Mpa

Finally after multiple measurement we obtain an average Young's modulus of E= 3832 Mpa with 90° oriented carbon fibers (longitudinal direction of arms). The density of the specimen is 0,4971g/cm3. This composite specimen is a stratified material and has an orthotropic behavior: the Young modulus in 1 and 2 direction (in plane modulus) are E1=E2 = 3832 MPa.

The tensile tests below (Figure 5) is performed on two different types of plates we found efficient. The test have been made on four samples of 2C-A-A-2C and on four samples of 2C-A-C-A-2C, at 0° and 45°. Details about each curve can be found in the table below. Then, the two Young's moduli have been extracted in the plane of the plate (E1 and E2) to calculate the stress.

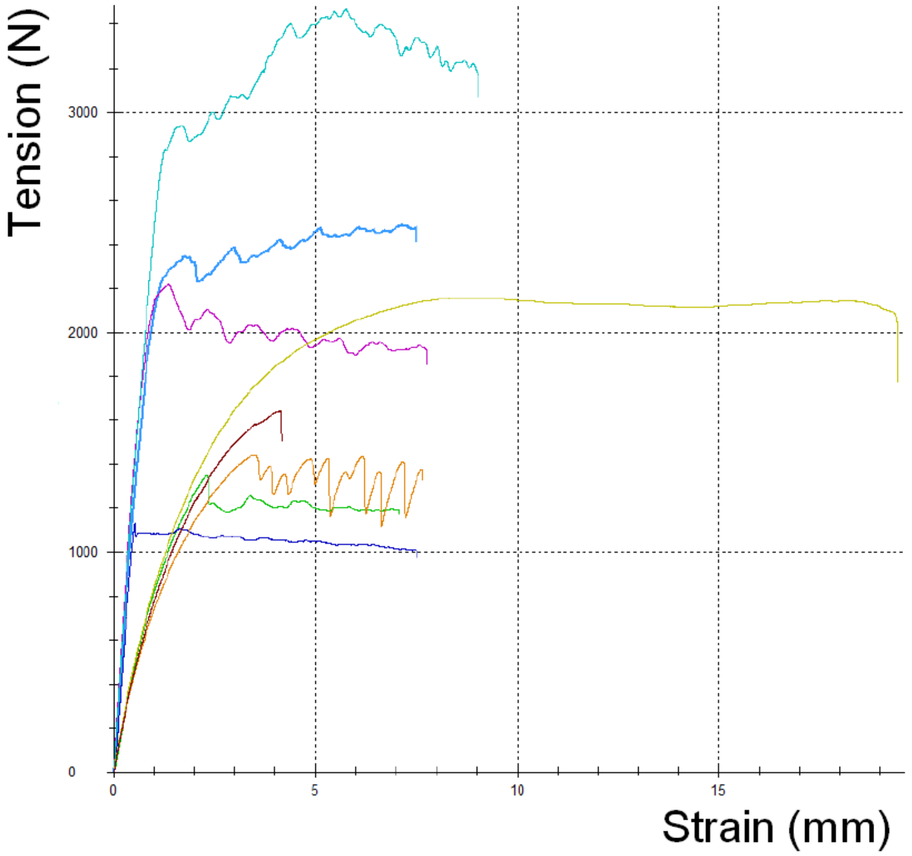

Figure 7: Tensile tests made on the arms

	0°	45°	Young's moduli
2C-A-A-2C	Blue, Dark blue	Green, Orange	E1=E2=3879.5±348.5 MPa
2C-A-C-A-2C	Violet, Red	Clear blue, Yellow	E1=E2=4353.5 ±83.5 MPa

The test below was performed over a frequency range from 0 Hz to 200 Hz on the material we decided to use. After the solicitation, we observe two resonance modes, one at 14Hz and one at 180Hz.

A resonance of 95dB is observed at 14Hz and 85dB at 180Hz. Knowing that traditional propeller frequencies propeller are between 70Hz and 120Hz, we can assume that there is no resonance problem with this structure.

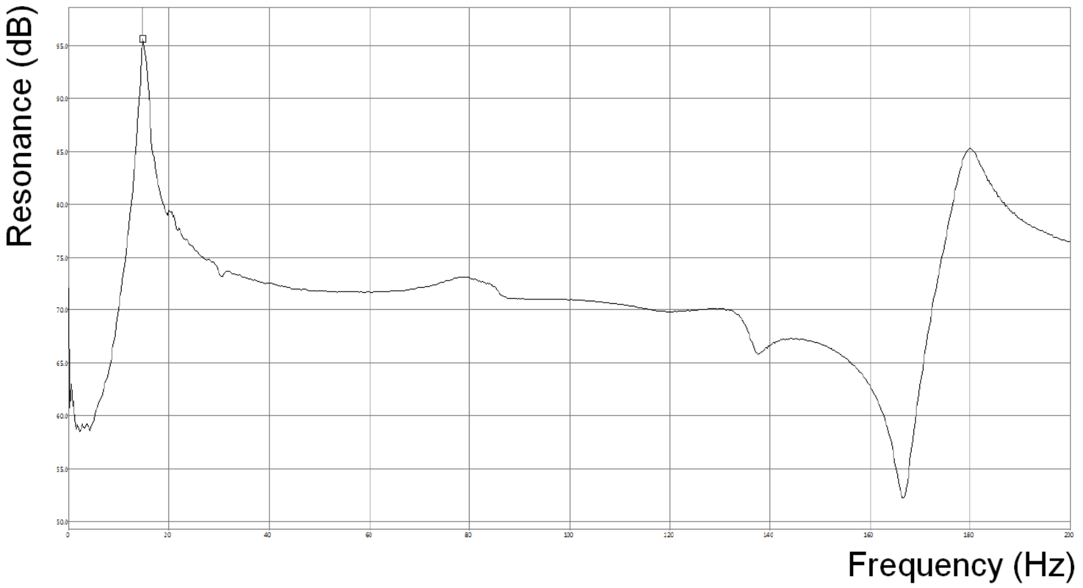

Figure 8: Resonance test made on an arm

Static analysis have also been carried out, with a load corresponding to the resultant of the motor weight and thrust (10 N, which is the worth case) to determine the arms structure behavior.

More details concerning arms design and characterization are described on this paper: [4].

Figure 9: Photography of the MAV we are continually improving

3 A MAV from a far fully controlled

1) Global electronic design

The control board is an APM 2.8. It controls the stabilization of the MAV in flight and the auto piloting through the APM:Copter (formerly called the ArduCopter). Basic parameters are configured via the software Mission Planner. However, we are trying to completely integrate configuration in a stand-alone program which we will explain later. For the autopilot, as usual we use GPS, barometer and IMU. These sensors are completed by a network of ultrasonic sensors and an Odroid board for image processing. An XBee module pair is used to communicate the orders from the ground control station (GCS) to the drone, and also the feedback in the opposite direction.

The embedded camera, a Mobius 1080p, is mounted on a 2-axis gimbal stabilizer allowing it to counterbalance roll and pitch rotations and therefore having a better image. The gimbal is also able to rotate towards specific angles by putting offsets to the commands. Images from the embedded camera are transmit by specific analog emitter to the GCS. A newly developed ability concerning the drone's vision is the target tracking. The drone will be able to follow a mark on the ground and land on it. The image processing will be done thanks to an on-board ODROID, which will simply return the relative movements of the drone to follow the target.

Several electronic boards are currently designed to add some functions such as the Bambi-bucket controlling. The function of this board simply consists in commanding the servomotor that drives the pulley in rotation. When the APM sends a certain signal to this board, the bambi-bucket will have to go down until a fixed distance or go up until the cable is totally rolled up. Similarly, we consider to develop a motorized hook to automatically drop a life belt, which also comes with its own controller board.

Finally, to make the drone able to see its environment, a sensor board will be developed to gather distance measures (such as ultrasound or infrared sensors) and send it to the APM. A measure of the distance to the ground will also enable a better precision of the altitude servoing.

Here is a recap of all the electronic systems interacting with each other:

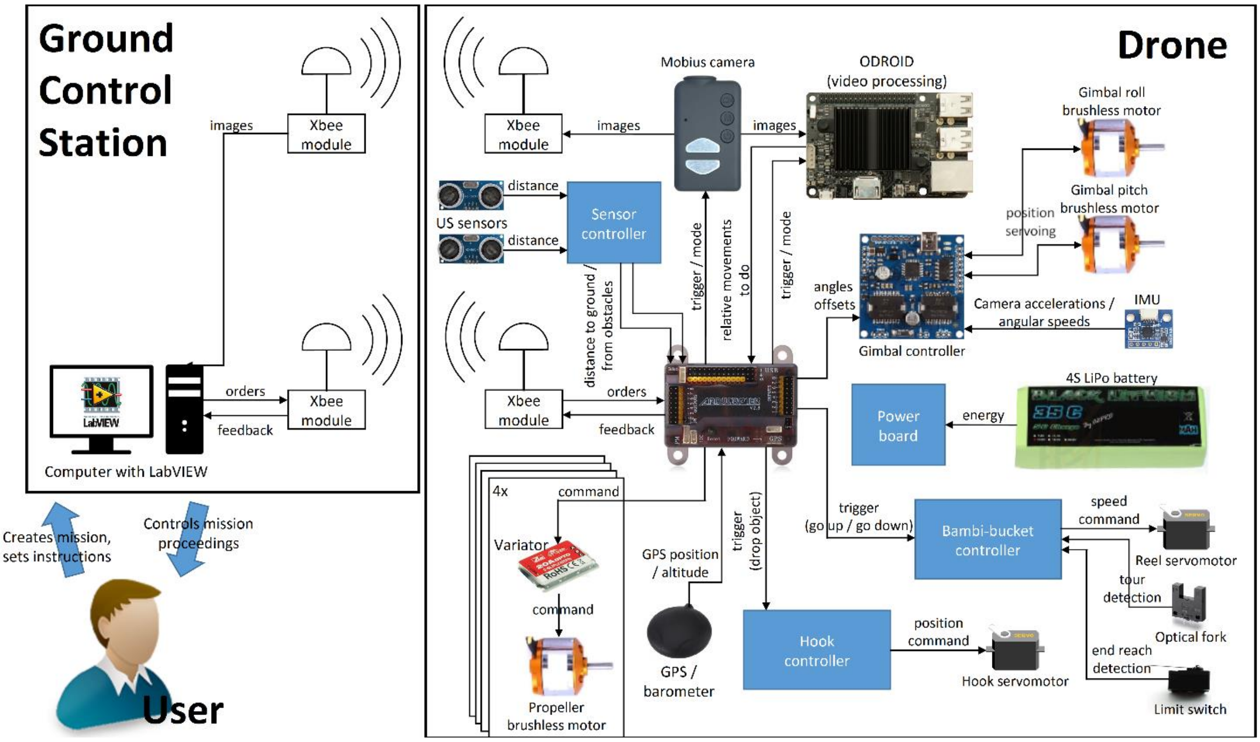

Figure 10: Overview of the electronic of the MAV

2) Description of the programming part

The goal of the main control program is to allow a user to create and send a mission to a drone equipped with an APM control board, so it can fly autonomously. While there are already some open source interfaces or software such as Mission Planner to communicate with the APM, their capabilities are sometimes limited in order to deal with the kind of mission that our drone will have to face during the competition. Thus, the development of a new interface gives us the possibility to integrate all capabilities needed. A LabVIEW interface has been set up since this platform offers an easy environment of development for engineering applications while keeping quality and robustness

In order to communicate with the APM, a set of LabVIEW functions allowing to send and receive different type of messages has been developed based on the standard communication protocol known as MAVLink. These modules enable for example to send a mission item to the memory of the APM. Once the drone starts the mission, it executes each command saved on its ROM and performs an autonomous flight. The basic commands that can be saved in a mission are commands to take off over a specific altitude, navigate to a specific GPS location and land. In addition, the communication functions allow the interface to read and decode messages sent by the drone in order to display a feedback of its status and location on the screen. Likewise, there are commands to set PWM and relay outputs of the APM, which can be used, for example, to control the angle of the camera gimbal or to close and open the water tank (Bambi-Bucket). As a result, these functions can then be easily integrated into the main LabVIEW interface.

3) Mission creation and transmission strategy

In order to create a mission, the graphical user interface has a list where the user can add new instructions for the drone. Thus, each instruction is ordered and described in the list. It will be possible to pick instructions from a toolbox, edit it and then place it wherever we want in the program.

To make the mission creation more intuitive, the user is able to click on a map generated from a public API (GMap) to automatically add new waypoints to the list of instructions.

Moreover, a mission can be saved and loaded from the computer. As all mission instructions are stored in objects, an XML structure is used to convert them into text data.

In order to send instructions to the drone, two different strategies are considered. The first, the simplest, acts like Mission Planner. That is to say, it sends all instructions at the beginning to the drone, so the latter can store them in its memory and then execute them one after the other. However the instructions are limited to the simple mission items provided by the MAVLink protocol. Impossible then to make the drone perform complex decisions during the flight. This mission mode is currently the first priority in development.

Then comes the other mission mode, which enables the interface to send new instructions during the mission execution. That way, the drone can send its situation to the GCS and the latter can make the complex decisions or treatments and send new orders according to the results. This includes for example QR-code reading during a mission.

4 A Quadrotor adapted for rescue missions

1) **Take-off (and landing) from a moving and rocking platform.**

The take-off and landing is aimed to be done fully automatically through the LabVIEW interface described upper.

2) **Do a fast mapping of the accident area to evaluate the whole situation and then find designated targets, like the location of the people in the water**

The mapping and the finding of the targets will also be made through the LabVIEW interface using the Google Maps module, as described earlier. The image processing will be made coupled with the APM Card.

3) **Deliver lifebuoy to the person's vicinity**

The lifebuoy delivery will be made thanks to a hook designed for the IMAV2015 parcel delivery. This hook will be fitted to the specifications of this test once more information will be released.

4) **Sample water around the oil rig and then release the water into a specified water container.**

For the « Sample water around the oil rig and then release the water into a specified water container » mission, a system of water recovery inspired from the fire-fighting planes ones, namely the Bambi-bucket has been imagined.

Below is a picture of the MAV taken in flight during a water sampling test:

Figure 11: Bambi-Bucket attached to the MAV

The system chosen is reputed simple (one servomotor and no pump used) and lightweight. This system is set in the shell of the two plates.

The principal rope, controlled by a pulley/servomotor system stretches to lift the background of the bucket. The purpose of the other small rope in the inside of the bucket is to open the bottom for the water sampled to be relieved. Through gravity the water pushes the bottom to fill the bucket, there is no need for an actuator in this part.

Currently, the winding system is regulated through a temporization. This system is not optimal and the team is working on building a standalone electronic-card for the Bambi-Bucket, matched with ultrasound sensors for the control to be the more autonomous as feasible. These sensors are aimed to measure the altitude of the MAV above the water. This system should be ready by the end of the summer.

5 Conclusion

In this paper, we have tried to synthesize the work done by the teams presented in the previous pages. The main goal of the UAV is the innovative shape, the Bambi-Bucket and the LabVIEW interface. The optimal design of such structures in order to fit given specifications is not easy as mechanical as well as electronical parts have to be optimized together, and this remains a topic of research [5].

After all the tests and the reasoning, the team UAVs are now ready to fly and will still be improved until October.

6 References

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