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# Development of a Quadrotor based on an Innovative Composite Shape with Carbon and Kevlar Structure

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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 this article, the design, manufacturing and control approach is detailed.

The first part deals with the choice of an innovative shape and the research of a reliable material. The structure 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. 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.

The second part of this article talks about embedded electronics and control. First of all, a Matlab Simulink model has been developed and allows the development of the automatic level control. The control structure is implemented on a microcontroller programmed in C code. The fine adjustment of the servo control is realized in an empirical way, thanks to a first reliable prototype of the quadrotor and a test bench developed by the team.

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# 1 Introduction

This project have been developed in the INSA Strasbourg's school, a french engineering school based in Strasbourg. It began two years ago with the aim of designing and creating an innovative quadrotor. The first team was composed by six members who worked on this project as a part of the mechatronic cursus (four hours per week). A new team of five members took over the project as an internship this summer in order to participate in the IMAV competition. The following pages will presented the work done by both team without distinction.

This paper will be divided such as presented below :

1. The birth of the idea
2. The mechanic part
3. The electronic part

# 2 The birth of the idea

The main idea was first putted on paper. Then a 3D model was rapidly created :

Figure 1: The initial idea

The next step was to determinate the material and the process of fabrication of such a UAV knowing that this two aspect are bound.

# 3 The mechanic part

## 3.1 Determination of the structure material

We rapidly agree to use a composite material to create this UAV because this family of material possessed the advantage to often be light and strong. With the CAD, we did some simulation to test the best material :

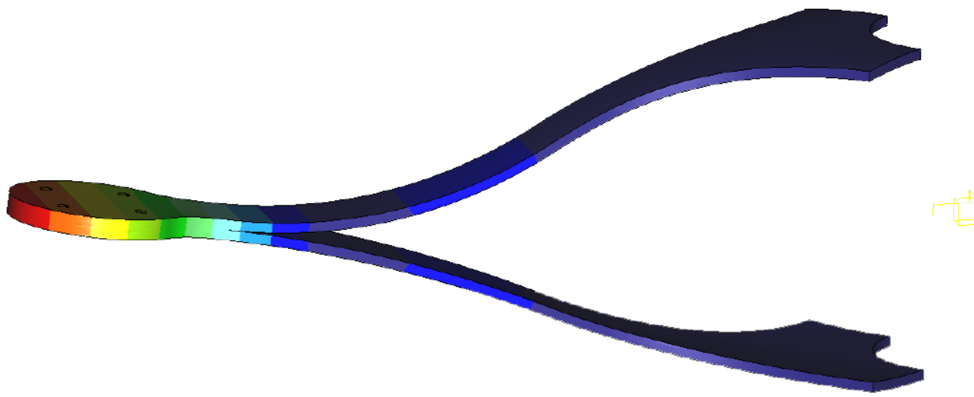

Figure 2: Deformation measurement

The major displacement (here in red) is 1.934 millimeters. So we compared this result to some that previous year had on a classic shape done with an aluminum structure. The major displacement on this previous UAV was about 4 millimeters. The displacement was reduced by 100%. This solidity is due to the fact that the two part help each other to compensate the displacement.
In conclusion, we decided to use a sandwich composite composed by a layer of Airex (a closed-cell foam) between two layers of Carbon-Kevlar.

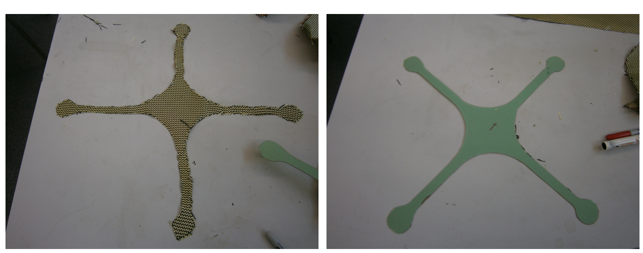

Figure 3: Carbon-Kevlar layer and airex layer

Those tests also helped us to determine the best thickness of the Airex foam and the best width for the arm.

## 3.2 The fabrication process

As the material was determined, we decided to create the structure by using a vacuum lamination process. The mold needed have been modeling in 3D. This 3D model have then been used with a CAM software in order to machine the mold on a CNC Milling Machine. The material of the mold is HDF (High-density fiberboard), an engineered wood product. The mold is then covered with gel-coat and is ready for molding.

The following pictures show the different steps of the fabrication process :

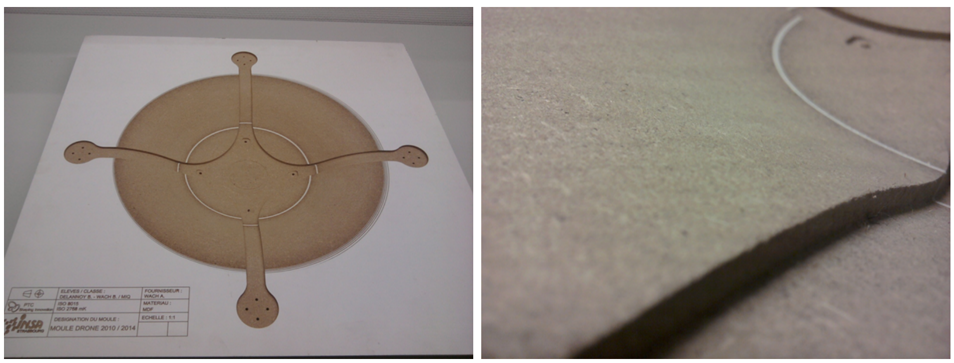

Figure 4: The mold after machining and its surface state

After the application of a release wax, some epoxy resin is applied and the first layer of carbon-Kevlar

Figure 5: The different steps of the fabrication process

is putted on it. Between each layer, the epoxy resin is applied. After the first layer of Carbon-Kevlar, we apply the Airex foam and some Carbon to solidify the weak point. Finally the last layer of Carbon-Kevlar is applied. A microporous membranes and some felt are putted on it to absorb the epoxy excess. Then the vacuum is made to give the shape. After approximately 24 hours, the structure is ready.

## 3.3 The landing gear

The landing gear was designed the same way of the rest of the structure :

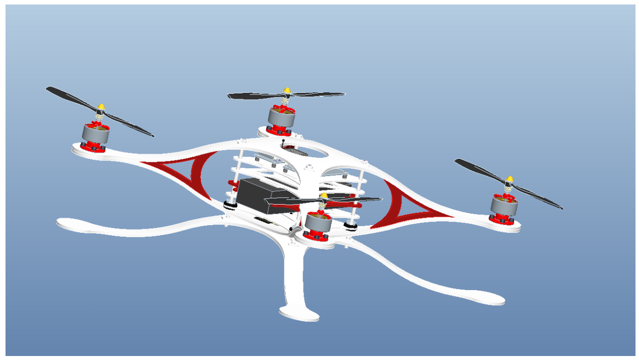

Figure 6: The UAV with its landing gear

But a problematic rapidly appeared after the first flights. The material used to build the structure is to easily deformed and become too rapidly plastic. The problem appear due to the fact that this structure was initially created to be a two-pieces structure with the two pieces supporting each other. We decided to change the material but not the shape, so we could keep the same fabrication process.

We did some tests to determine the best material to create the landing gear. To do so, we made different test specimens :

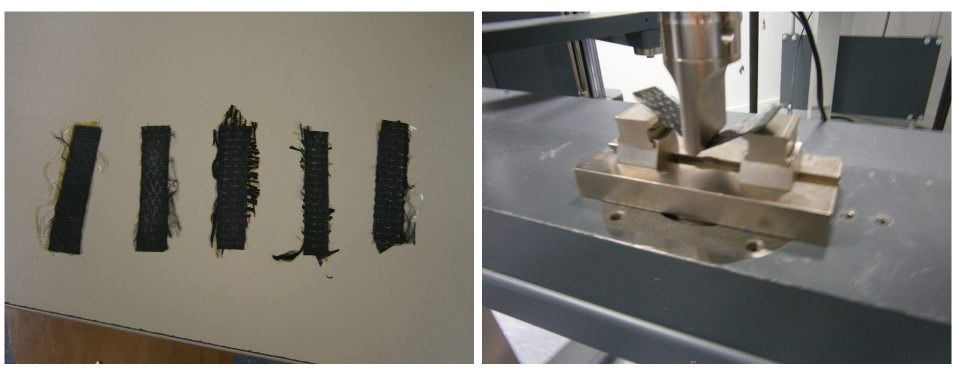

Figure 7: The test specimens and a specimen during the test

This test have been made to determine which material must be used and the number of layers to have a landing gear strong enough to not be deformed after the shock but flexible enough to amortize the shock.

The results obtained led us to the conclusion that we should use Carbon only because the Carbon-Kevlar present less advantage for what we need for the landing gear. We also obtain to use four layer of Carbon for the optimization.

### 3.4 The electronic support

The shape of this UAV also present the advantage to have all the electronic inside the structure in order to protect it while keeping the ability to change it rapidly.
Each board is cut with a CNC Milling Machine and is design for different purpose while keeping the same shape. The first board, called "the command board", supports all the command electronic. The second part, called "the battery boards", are all the boards that support and block every movement of the battery. The last board supports the different components necessary for the competition.

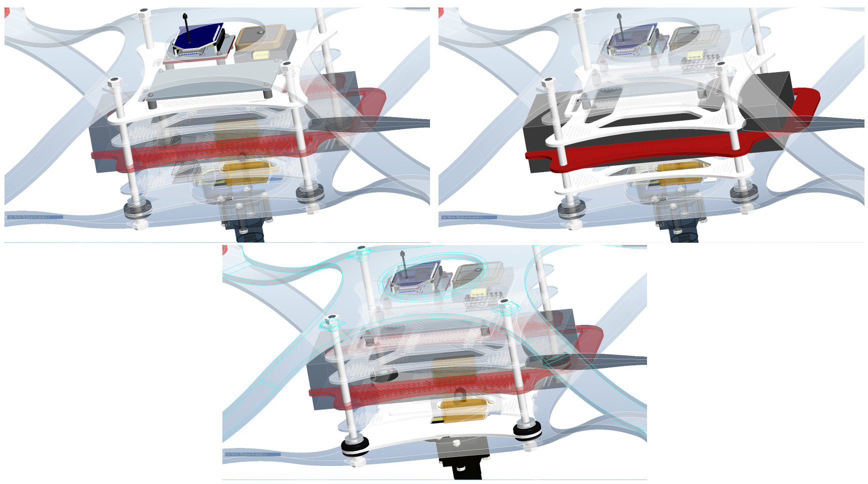

Figure 8: The three different boards inside the UAV

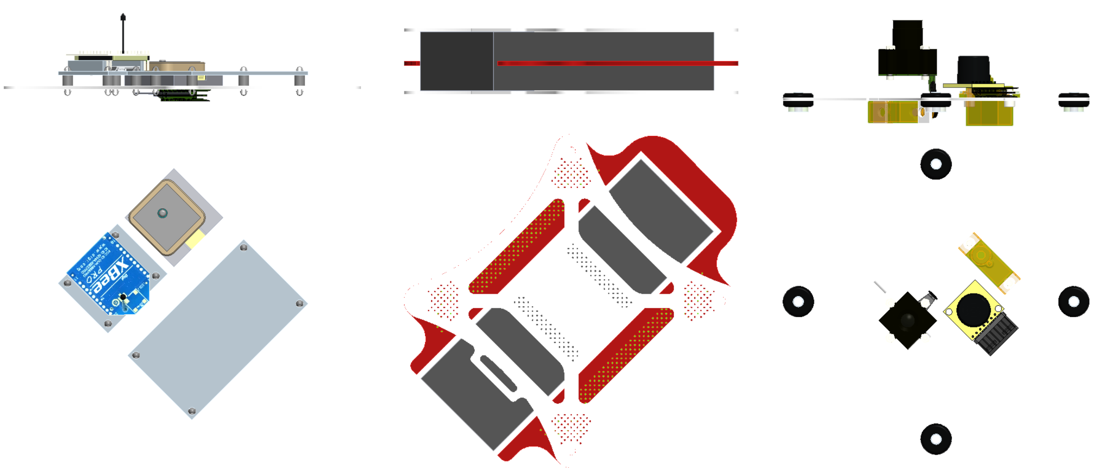

Figure 9: The three different boards

# 4 The electronic part

## 4.1 the electronic architecture

The electronic part has the following structure:

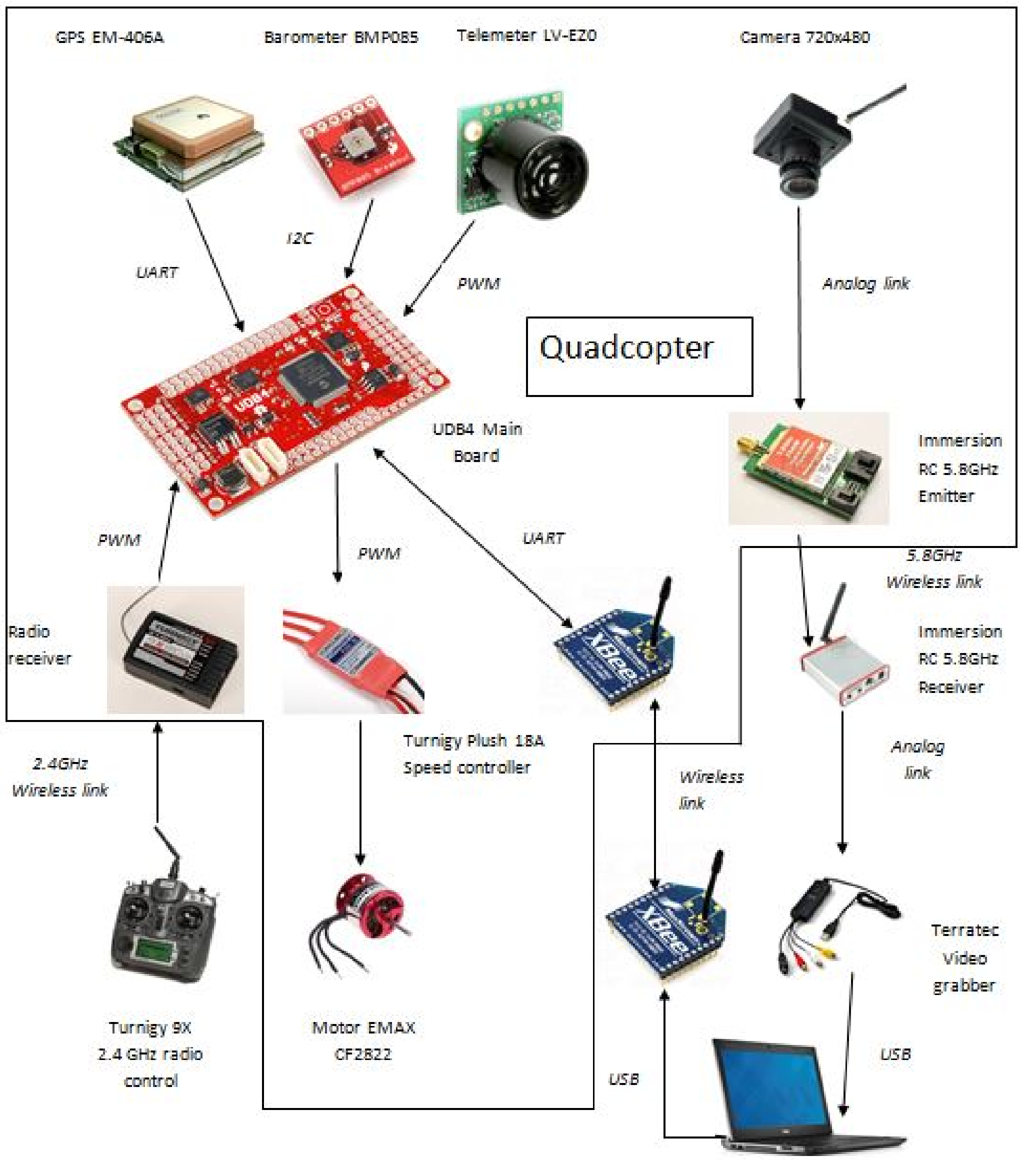


Figure 10: The electronic architecture

The central element is the UDB4-board. It contains accelerometers and gyroscopes to compute the UAVs orientation. The microcontroller used is a dsPIC33FJ256GP710. To this board are connected three other sensors: A GPS module, a barometer and an ultra-sound telemeter. GPS is used for navigation. Barometers measures are used to compute the altitude of the UAV (+/- 50cm). The telemeter is used on take-off and on landing to have a better altitude control. Telemeter is also the altitude sensor for low-altitude flying (under 2 meters). The motors are brushless motors. They need a specific controller which converts DC current from the battery into 3 phases AC current. The controller receives PWM signal from the UDB4. 1ms pulse width means no rotation and 2ms pulse width means maximum speed. The frequency of the current in the motor controls the speed. Control of the UAV is made in 2 ways: First, an 8-channel radio-system allows user-control of throttle, roll, pitch and yaw. An additional channel enables or disables the automatic flying. Second, a XBee link between the UAV and a ground PC is implemented to receive information from the UAV (GPS-Position, altitude, mission state ). The embedded camera sends images through a 5.8 GHz video emitter. The ground computer receives and processes images to detect and decode QRCodes for example. The vision part uses the XBee link to send to the UAV information about a target position, so that the UAV places itself on it. The power source is a 3S LiPo battery with 5Ah Capacity. Flying time is between 5 and 10 minutes depending on flying condition like wind.

## 4.2 The program

The program running on the USB4 is the gentlenav program with some modifications. The main part of the program is the stabilization of the UAV. It is made through a PIDD regulator on the position. We added functions to tune the coefficients from a PC through the XBee link. The correct coefficients have been found by tests first on a test platform and then by flying. We added altitude regulation with the ultrasound telemeter. It consists in 2 steps: First, a position error computes a vertical speed. Then, regulation of the vertical speed applies correction on the speed of all the 4 motors. We added also the barometer by using the provided I2C driver. Temperature and pressure measures are used to compute the altitude.

## 4.3 The vision system

Vision part needs an independent computer on the ground station. Image from the camera are transmetted through a 5.8GHz radio system and sampled through an analog video grabber. For the image processing, we use the open source image processing library OpenCV. The analog grabber is recognized by OpenCV as a webcam. QRCode decoding implements the ZBar library.

# 5 Conclusion

In this paper, we have tried to synthesize the work done by the two teams presented in the previous pages. The main point of our UAV is the innovative shape and the innovative use of the Carbon-Kevlar in this kind of UAV. After all the tests and all the reasoning, an UAV is now ready to fly and all the results are satisfying.

*Thanks :*

*The team wants to specially thanks the IMAV 2013 edition to allow us to present our work.*

*The* INSA Strasbourg *'s school, for its support in this project and more particulary M. Kiefer, supervisor of the project.*

*All those who have contributed to this project.*