Arts et Metiers Institute of Technology
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Sorbonne Sciences University - Paris VI

Research Projects

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1 Autonomous UAV – Dassault selective project (Sept 2020/Now)

Position: Leading Artificial Intelligence development in a seven-member team
Programming language: Python (OpenCV, NumPy, Scikit-learn, pandas. . .)
Area: Mathematics, Computing, Electronics, Mechanics

Competition gathering the best students in Europe. The UAV must carry out several missions. The first one is to automatically follow ground marking to reach a target. The second one is that the UAV has to identify different targets according to the orders given beforehand (there are different forms and colors) and to deposit packages carefully. As I lead the Artificial intelligence development of this project, I must coordinate the team.

The first step was to look for a search method that provides a strong stability, and accurate results. We chose Yolo method because of the stability acquired with deep-learning logarithms instead of geometric methods. To generate data for using the Yolo method, instead of using existing data, I used an unusual method: I generated synthetic data in CATIA (CAD) to train the Yolo model. Therefore, I created different targets by each time modifying the colors and the form. Blender allowed us to import CAD models and then to create a scene, where I can modify angle, brightness, to take into consideration every parameter to train the algorithm. Therefore, we obtained a large and adaptable data base. Furthermore, I am currently working in trajectory optimization by investigating deep-learning methods based on cartography to obtain the fastest trajectory to reach located marks.

However, we faced an issue: the Yolo method provided excellent results, but the algorithm was not reactive when we used it on the streaming flow from the UAV. To resolve this issue, we are currently working on the influence of FPS in the algorithm. Indeed, the Yolo method has to process 60 images per second which is completely unnecessary due to the speed of the UAV (only 10 m/s). Wherefore, we are completing a study to obtain the perfect balance between FPS and results.

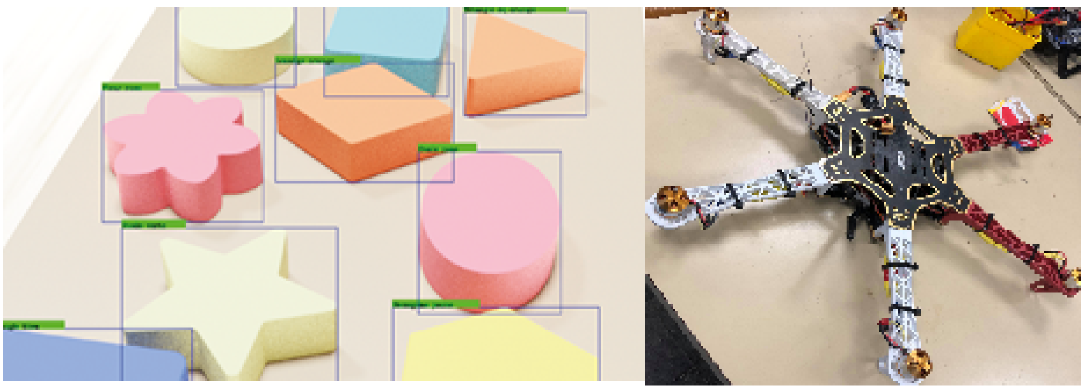

Figure 1: Yolo method application and Dassault UAV

References

[1] https://olestourko.github.io/2018/02/03/generating-convnet-training-data-with-blender-1.html

[2] J Dai, Y Li, K He et al., R-FCN: Object Detection via Region-based Fully Convolutional Networks

[3] Guillaume Bellegarda, Katie Byl: Combining Benefits from Trajectory Optimization and Deep Reinforcement Learning

2 Propeller optimization, airship UAV (Sept 2020/Now)

Position: Leading the project in a five-member team
Programming language: Python (random, NumPy, pandas...)
Area: Mathematics, Computing, Mechanics

The aim is to dimension a propeller from a dirigible-type drone intended for indoor aerial evolution, in the large ENSAM lecture hall. Initially, the drone will be a communication tool enabling images to be transmitted or carried autonomously and securely. Then, it can be modified to allow inspection or control of structures such as the vault of the large lecture hall. To respect these specifications the airship has to move extremely slowly because it will only be used as a communication tool. Due to the type of UAV (dirigible), the UAV has to move essentially thanks to the gas in the dirigible. Propellers are only here to begin the movement.

$$\eta_{mec} = \frac{P_p}{P_f}$$

η_{mec} is the mechanical efficiency, P_p is the power supplied for moving the drone, P_f is the total power supplied by the drone.

The aim is then to maximize the mechanical efficiency η_{mec}. I decided to develop a method to generate the most effective helix. By using using characteristic points from a blade I developed a parametric method by randomly modifying in a value interval the data of the helix. I started by generating points from a standard model.

$$A_j^i = A_0^i + F_j^i(X_j^i)$$

A_j^i is a characteristic point calculated from the standard model of the blade, A_0^i is a characteristic point from the standard model, $F_j^i(X_j^i)$ is a variable value and has to respect $F_j^i(X_j^i) < A_0^i$ to not provide $A_j^i < 0$ which is not coherent (negative length). Therefore, we were able to select a list of characteristic points with the highest efficiency, and create the blade in CATIA (CAD model).

The first step was the pre-dimensioning of the UAV by determining different forces acting on the UAV. After calculating forces that the UAV has to provide, we were able to start dimensioning by studying propellers mechanics in the literature. Then, we created a recursive python program to calculate powers supplied by the UAV as a function of our pre-dimensioning. Our aim is to provide a propeller with an extremely high mechanical efficiency because the drone as to provide a great autonomy.

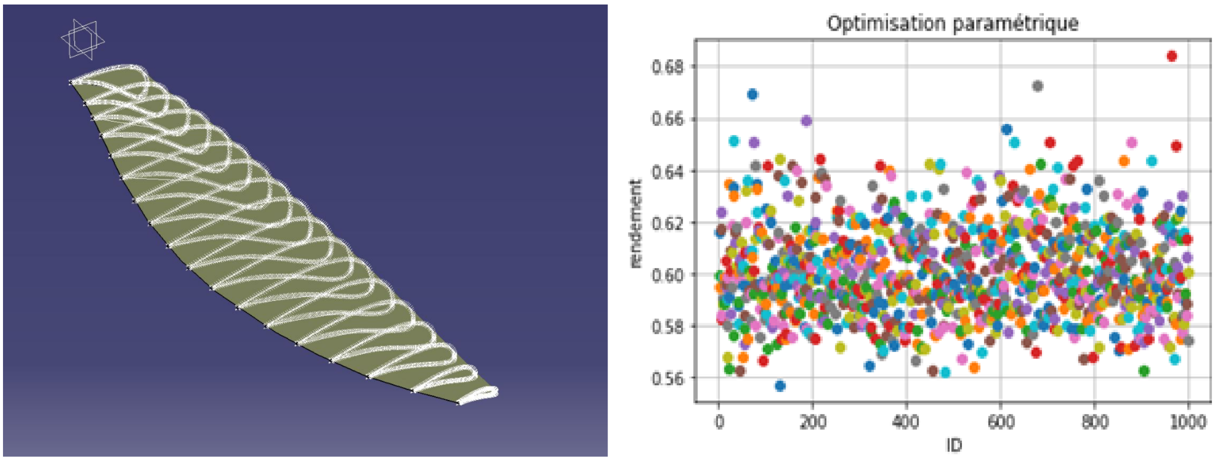

Figure 2: Blade Optimization

References

[1] http://www4.ac-nancy-metz.fr/ciras/cahierdubia/helice/helice.html

[2] Thierry Jardin, Gilles Grondin, Jérémie Gressier, Chao Huo, Nicolas Doué, Roger Barènes: Revisiting Froude's Theory for Hovering Shrouded Rotor

3 Image inpainting (Jan 2020/June 2020)

Position: In charge of mathematical optimization
Programming language: Python (NumPy, Scikit-learn, pandas. . .)
Area: Mathematics, Computing

Image inpainting focuses on the reconstruction of deteriorated images or when filling missing parts. This technique is used extremely often in images reconstitution because it allows to reconstitute historical images which have deteriorated. I principally studied the LASSO algorithm which is based on contraction of regression coefficients. and the ridge regression. The linear regression consists in resolving:

$$w* = argmin_w (Xw - y)^T (Xw - y) + \alpha\Omega(w)$$

Ω is a constraint term, α conducts the regularization.

To study the effect of ridge and Lasso penalization, we trained three versions of regression to distinguish even numbers and odd numbers in the USPS base. I optimized each parameter on these methods to obtain an image without penalization. Ridge regression, compared to regression without penalty, does not produce weight of which the amplitude is high in relation to the other weights (the weights have the same scale). The Lasso regression, on the other hand, assigns to several weights the null value, it is also the only to give zero weights (157 zero weights out of 256). Lasso thus makes it possible to build a linear regression model that depends only on a subset of the initial variables.

Figure 3: Image sample

References

[1] Bin Shen and Wei Hu and Zhang, Yimin and Zhang, Yu-Jin: Image Inpainting via Sparse Representation Proceedings of the 2009 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP ’09)

4 Heat Exchanger Optimization (Jan 2020/June 2020)

Position: Individual project
Programming language: VBA, C++
Area: Mathematics, Computing, Mechanics

The objective of this project is to find a solution to recuperate the warmth coming out of a system which produces fumes at high temperature. The solution I found, was a creation of an exchanger to recuperate fumes to warm the air which entered another system. The other system required air at the temperature of $T = 800K$. I had to dimension my exchanger to respect size-specifications.
The objective is then, to achieve the most efficient exchanger possible. In a first step, I calculated the different coefficients governing the thermal transfer (DTLM method, NUT...) to complete a pre-dimensioning. To obtain an efficient thermal exchange between air and fumes, I created an exchanger geometry with the highest exchange surface between air and fumes. I developed my solution in CATIA. I finally simulated my model and analyzed our results under StarCCM+ (CFD software). According to results, we had to complete the dimensioning by determining the perfect dimensions, materials, and architecture to obtain the most optimized heat exchanger.

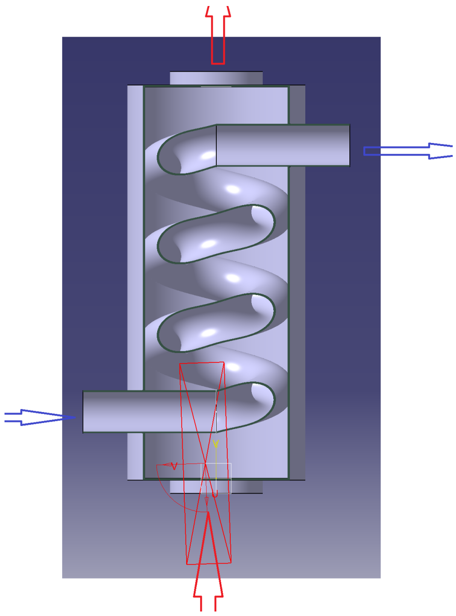

Figure 4: Echanger Model

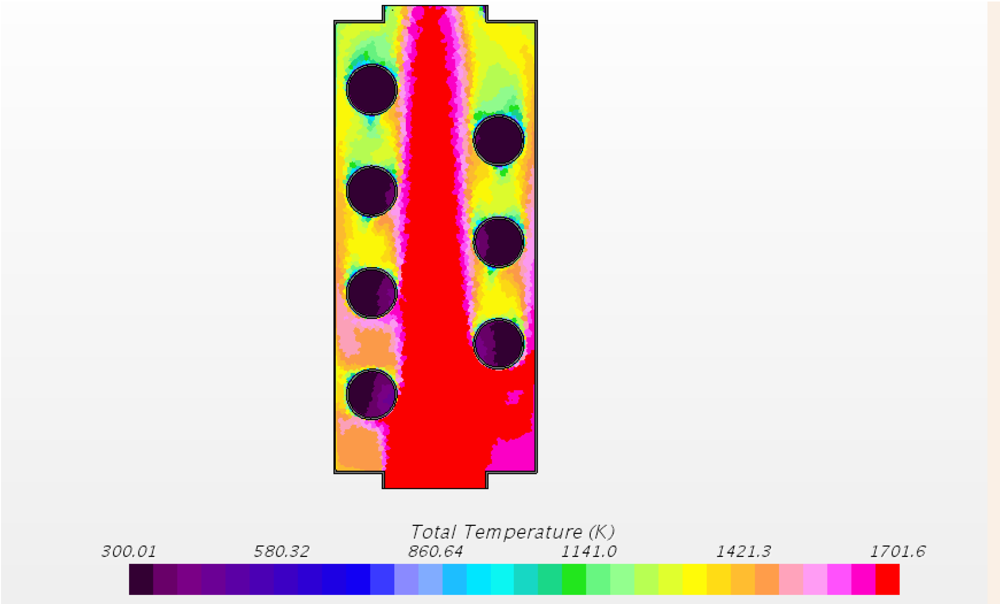

Figure 5: Thermal transfer

References

[1] Mathieu Legay: Intensification des processus de transfert de chaleur par ultrasons, vers un nouveau type d'échangeur de chaleur : l'échangeur vibrant

5 Film Data Analysis (Sept 2019/Jan 2020)

Position: Head of the project of a three-member team
Programming language: Python (NumPy, pandas, pickle, iads...)
Area: Mathematics, Computing

Using a large database of films, we analyzed these data via optimization methods. The objective of our analysis was to predict the average grade of the film, the profitability, the category of the film, the next film category of the actor. To complete objectives about the grade of the film and the predicted film category depending on the actor, we developed a supervised regression. The interest of this method is generalization to other data. To predict the category of the film we developed a method based on supervised classification to define rules to automatically categorize those films.

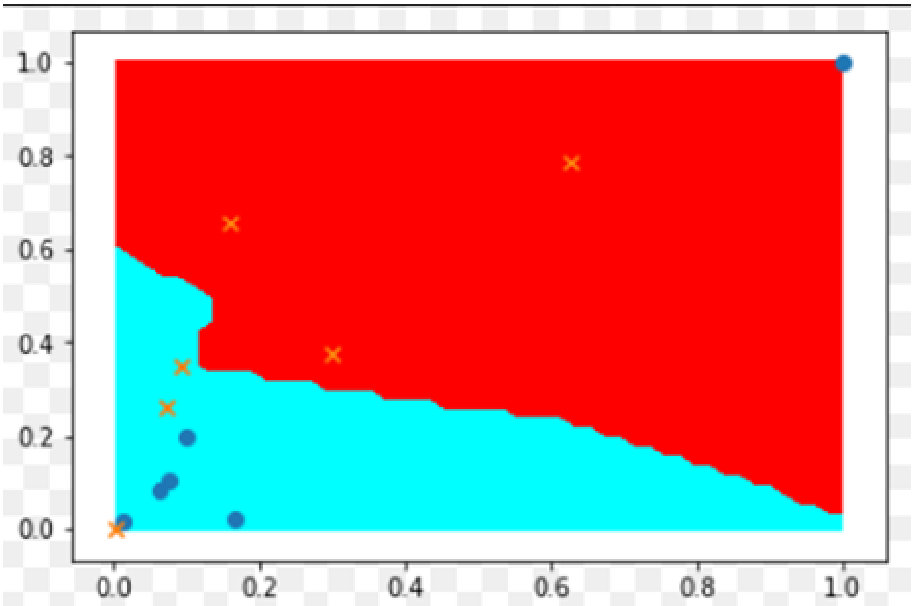

Figure 6: Profitability decision frontier – KNN algorithm

References

[1] Lijun Wang, Xiqing Zhao: Improved KNN classification algorithms research in text categorization

6 Particle Tracking (Jan 2019/June 2019)

Position: In charge of the mathematical optimization and resolution.
Programming language: Python, MATLAB
Area: Mathematics, Computing, Mechanics

The objective of the project was to study and numerically represent a flow around a cylinder using the principle of PTV. A camera with a laser was placed in front of the cylinder, the flow contains particles which do not influence the characteristics of the flow. Our role was to use images from the camera. By using the flow of the particle around the cylinder, we can use our mathematical and computing knowledge. The first step was to identify particles on each image from the film. The background being totally black, we can identify particles which are white. The second step was to find the center of each particles. Therefore, we assumed that the light follows a Gaussian distribution.

$$f(x,y) = I_{max}\exp(-\frac{1}{2}\frac{(x^2+y^2)}{\sigma})$$

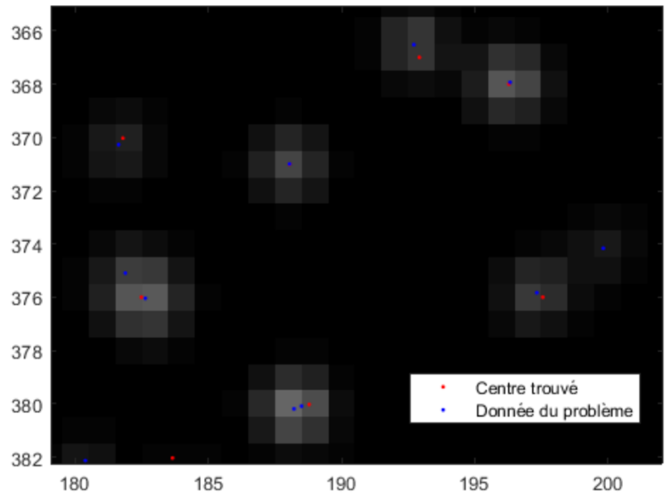

Figure 7: Particle center identification

We filtered images to have particles with an ideal Gaussian distribution, we were able to identify the center. Thereafter, the most complex task was to associate a particle from image 1, in image 2. We used a correlation method based on neural networks. By means of weights, the method identifies the particles that resemble each other between two images. Then we infer vector fields.

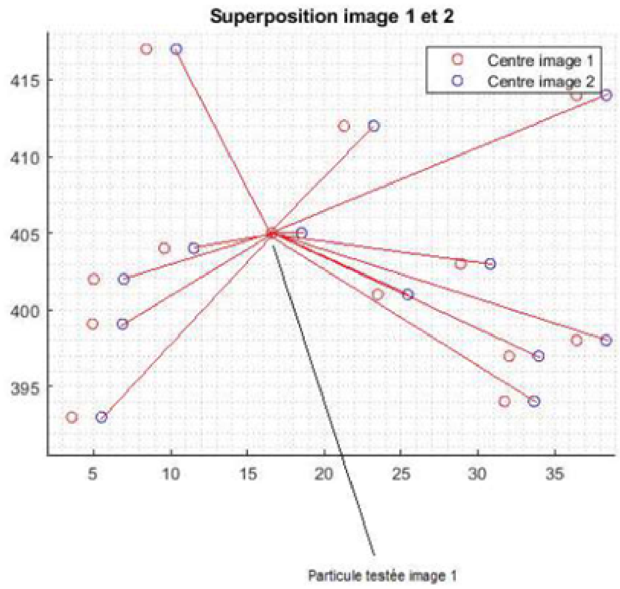

Figure 8: Particle correlation

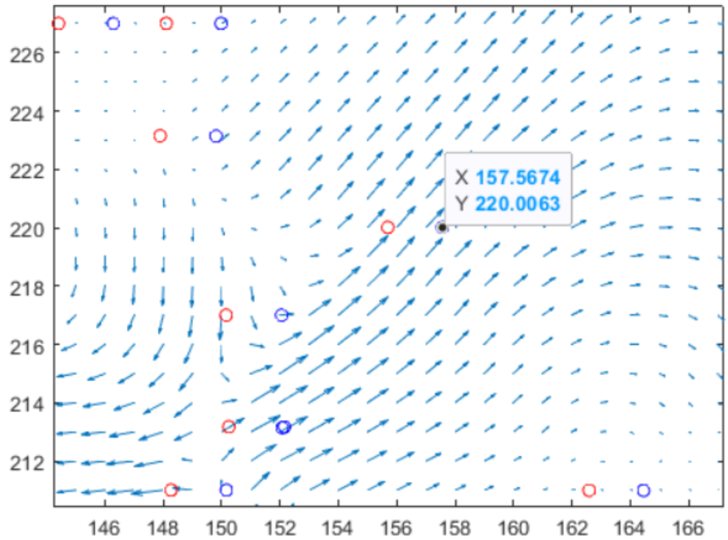

Figure 9: Vector fields

References

[1] https://fr.mathworks.com/help/matlab/ref/corrcoef.html

[2] T.HadadR.Gurka: Effects of particle size, concentration and surface coating on turbulent flow properties obtained using PIV/PTV

[3] Kendall, M.G. (1948). Rank correlation methods. Griffin.

7 Satellite trajectory optimization (Sept 2018/Jan 2019)

Position: Individual project
Programming language: C
Area: Mathematics, Computing, Mechanics
Prize: Best results

The numerical project consisted in putting a satellite in orbit around the earth. The objective was to study the impact of numerical methods, choices of parameters in relation to the stability of the problem and search for resolution method to solve the problem. The first step was to understand mechanically the way the system operates to put in an equation the 2D problem. The satellite must cross several orbits to reach the geostationary one. I had to first, calculate the speed and the amount of energies that the satellite has to spend to leave different orbits (Low Earth Orbit, Medium Earth Orbit and High Earth Orbit). Then, I searched methods to resolve the EDO system.

$$\begin{cases} \frac{d^2x(t)}{dt^2} = \ddot{x}(t) = -GM\frac{x}{(x^2+y^2)^{\frac{3}{2}}} \\ x(t=0) = 0 \\ \dot{x}(t=0) = U_0 \end{cases}$$

$$\begin{cases} \frac{d^2y(t)}{dt^2} = \ddot{y}(t) = -GM\frac{y}{(x^2+y^2)^{\frac{3}{2}}} \\ y(t=0) = 0 \\ \dot{y}(t=0) = 0 \end{cases}$$

With G the gravitational constant, and M the mass of the system.

I used several resolution methods to compare results. After a complete study of the residual error, I used the Runge-Kutta method to resolve the EDO. However, these equations are coupled. I had to use the Newton-Raphson method in two dimensions by calculating the Jacobian Matrix and resolve the Cramer System. Moreover, with an energy analysis, I had to implement some conditions in the position to make the satellite accelerate to leave the Low Earth Orbit, and the Medium Earth Orbit to reach the geostationary orbit. Moreover, to reach this orbit in an optimized way (fuel consumption, time and high speed), I calculated strategic points where the satellite had to accelerate to benefit from the elliptic trajectory.

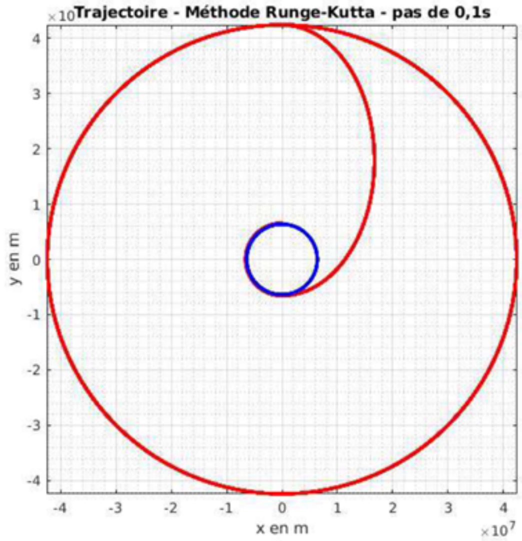

Figure 10: Satellite trajectory

References

[1] John T. Betts: Survey of Numerical Methods for Trajectory Optimization

[2] Christophe Louembet: Génération de trajectoires optimales pour systèmes différentiellement platsApplication aux manoeuves d'attitude sur orbite

[3] Zdeněk Kopal: Perturbations of the orbits of artificial satellites by an attraction of external bodies

8 Romarin2, a submarine project – selective project for MIT Submarine (Jan 2018/June 2018)

Position: Head of mathematics and computing
Programming language: Arduino, C, MATLAB
Area: Mathematics, Computing, Mechanics, Electronics
Prize: Best contextualization and ideas

This project is based on an MIT project for a submarine. As a pair, we had to build a submarine entirely on our own. We focused on controlling and enslaving it using the Arduino environment. Indeed, we had to carry out various studies beforehand (robot design, dimensioning...). The first step was to study the equilibrium of the system to dimension the submarine (number of floats…). To refocus and find a purpose to our research I proposed to the evaluation committee to build a submarine with as the main objective locating oil slicks at the surface of the water. To do this, we used a luminosity sensor (darkness under the slick), pressure (to stay at a certain distance from the water surface and therefore not lose brightness), and a GPS module (to transmit the position of the slick in an SD card). The most complex part was to manage interference between GPS module and motor. Indeed, the motor created a magnetic field which disrupted the signal from the GPS. To resolve this problem, we positioned the GPS at the top of a mast. With this solution, the signal was not disrupted anymore. We had to present the submarine to a large committee of industrialists and professors. We won the prize for the best ideas and context-setting.

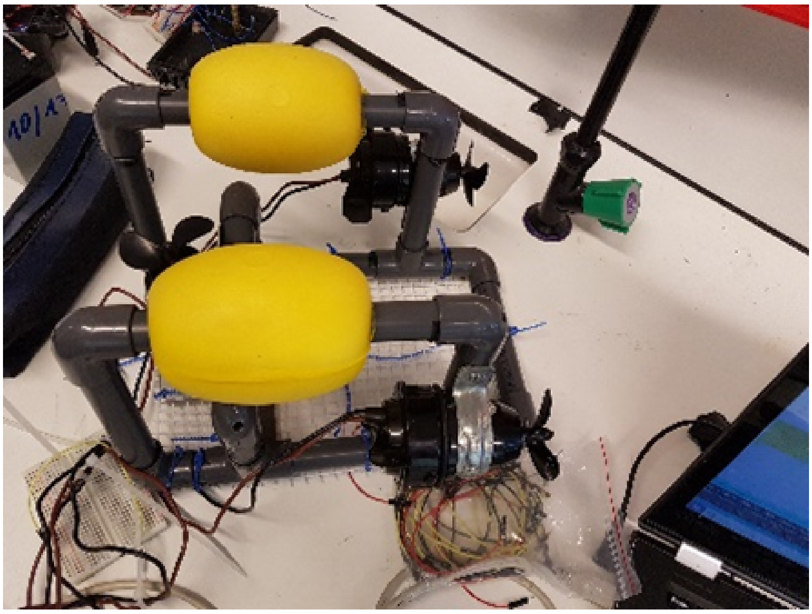

Figure 11: The submarine

References

[1] Michel Bensoam: Notions d'asservissements et de Régulations

[2] http://licence.meca.sorbonne-universite.fr/fr/modulesdenseignement/la-mecanique-en-l2/a112-romarin-un-vehicule-teleguide-pour-l-observation-sous-marine.html

9 Smart Tennis Racket (Sept 2015/June 2016)

Position: Head of project of a three-member team
Programming language: Arduino, C++, VBA
Area: Mathematics, Computing, Mechanics, Electronics

As I am passionate about Tennis, and I saw that some brands were developing their connected rackets, I wanted to create my own smart racket. We created a module that can be adjusted to all rackets. The objective was to improve our skills in tennis by having statistics, and advice. The first step was to think about where sensors have to be placed. As I am a tennis player, the most practical solution was the “racket throat” of the racket, because it does not influence the balance of the racket. We wrote specifications for the weight and the size to not disturb the player. Secondly, to provide advice we analyzed the play-style of pro players to infer their gestures to obtain a model. We deducted the trajectory of the racket and the distribution of the speed. Thereafter, we built a movable box with accelerometer, gyroscope, and a SD card. During the movement, gestures were saved into the SD card with values of positions and speeds. In Excel, I developed a tool to interpret these values (trajectories, speeds). I provided a grade based on differences with the model. Moreover, according to the grade, some advice was given to the player to improve his/her gestures.