A didactical electronic project for graduated students: Initiation to autonomous navigation using a small-scale model electric car.

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Abstract: Since many years, our ENSEIRB-MATMECA electronic engineering school adopted a "learning by project" strategy, to improve motivation and knowledge appropriation for our students. In this paper, we highlight first some major evolutions in the student's behaviour which justifies this didactical evolution. Then, we give a typical example of project proposed to students in second year of study: control and navigation of a small scale electrical model car. Specifications and some design details are explained. Technical results and feedback from students are described before conclusion.

Key words: Didactical experience, learning by project, Multi thematic electronic project, autonomous navigation,

1. Introduction

1.1 ENSEIRB engineer school presentation

The "Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux" is one of the oldest (founded in 1920) graduate national engineering schools, known as 'Grandes Ecoles', in France.
ENSEIRB-MATMECA has now several departments: the Electronics Department (the oldest one), the Computer Science Department (1986), the Telecommunications Department (2000), and the most recent Mathematics/mechanic Department.

1.2 The student's behaviour evolution

We have attended for a few years, a change of the behaviour students. Evolution is especially important with the "M" generation born around 2000 who is now arriving in the university. Among the major evolutions, we can extract the most important one's:

- The international origin and the diversity of social origin of our students increase the difficulties of teachin because the level dispersion and cultural diversity.
- Most of the students have a lot of extra scholar activities such as sport, internet electronic games, and other leisure's. Motivation for pure scholar activities is decreasing.
- Consequently, absenteeism rate is quite important for traditional theoretical course.
- Our students act now like consumers more than students: this "zapping" phenomenon is destabilizing for the teachers.
- Reduction of capacity of attention (inherent in human being and normally about 45 min) has also been observed.

A possible answer (among other) to this evolution is a "learning by project" approach. During concrete project work, absenteeism rate is close to 0, motivation and enthusiasm of students is higher.

2. Learning by project

2.1 Introduction

This concept is obviously not new [1], [2], [3] but the positive effects of this strategy are now more visible. Such approach avoids the abrupt and difficult theoretical courses which are often rejected by the students.
This approach improves the motivation, autonomy since students are more responsible of their work and results. This is a more personalized approach in small working group and the relations teacher-students are totally different compared to mass and anonymous courses.

2.2 Application
Up-to-date autonomous vehicle navigation thematic [4], [5] has been chosen last year to experiment this learning approach over one semester by students in second year study at ENSEIRB engineer school.

3. Description of the project

3.1 General description

3.1.1 Aim of the project
The aim of this project is to design electronic boards and embedded software to drive as simple as possible an autonomous small model electric car: It must be able to execute some basic operations: finding a direction, obstacle avoidance and car parking.

3.1.2 Mechanical characteristics of the small model car.
For this purpose, we use a mechanical frame as indicated in figure 1.

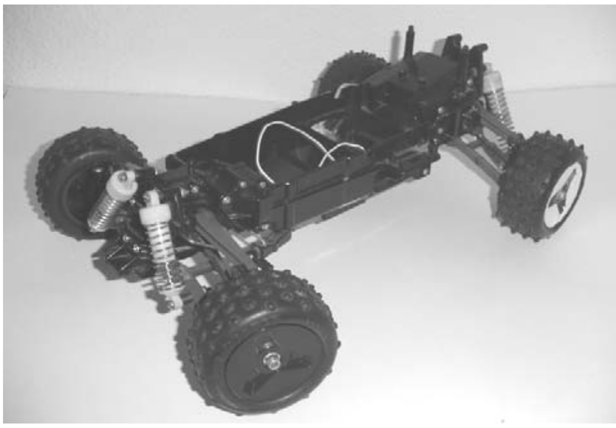

Figure 1: Small scale 4x4 mechanical frame

The main characteristics of this model are:
- 1/10 scale, Length: 441mm, Width: 185mm Weight: 1570g,
- Suspension: 4 Wheel Independent,
- Engine: Electric DC 7,2V 4A,
- Body Type: Polycarbonate Cut & Printed
- Differential Gear System: F/R 3-Bevel Diff,
- Tire Width: F/R both 27mm, Tire Diameter: F/R both 65mm.
- Steering wheel orientation: embedded servomotor

For our project, we removed the body and keep only the mechanical frame, in order to install our own electronic boards. And we disconnect mechanically the 4x4 motion option to reduce the power consumption.

3.1.3 Technical specifications
The electronic specifications for our project are:

- Power supply: 7,2V 2700mAh NimH battery cell
- Ultrasonic detection of obstacles
- Magnetometer sensor module BNO55
- Microcontroller: Arduino Uno [6]
- Front and back traction control (commercial board)
- Steering wheels control: servomotor FUTABA or equivalent.

3.2 Directional Servo motor
The front wheels of the vehicle are driven by a classical Futaba Servo motor powered under 5V supply. (figure 2).Movements are limited to ±40°.

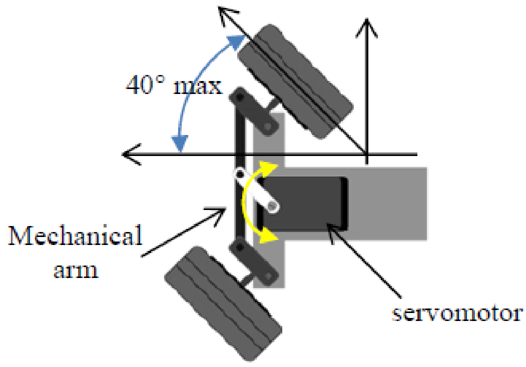

Figure 2: steering servo motor

The figure 3 shows the control signal applied to the servo and the corresponding output rotation angle.

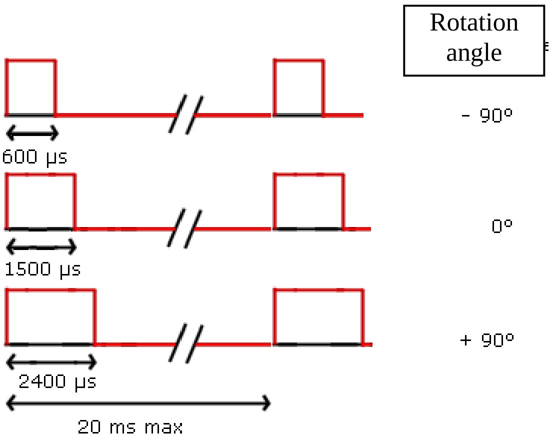

Figure 3: typical PWM control signal

Current consumption of the servo during rotation is around 150mA depending, of course, of the friction resistant couple.

3.3 Traction DC Motor and PWM driver

In order to simplify the design, we use a commercial integrated DC motor driver module 45V, 2x15A ref Lite SKU: DRI0018) (cf. figure 4) [7].This module has two channels: Each channel consists of two BTS 7960 Infineon integrated half bridge NMOS and PMOSFET with ultra-low R_{on} resistance. This smart power circuit includes current sense, slew rate adjustment, dead time generation and several protections against over temperature, overvoltage, under voltage, overcurrent and short circuit. Here, only one channel is used.

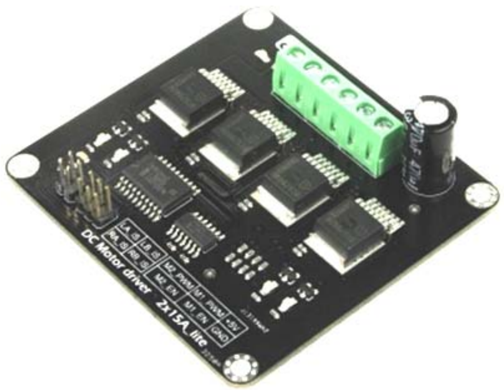

Figure 4: Motor driver board

The figure 5 shows typical waveform we obtain with this motor driver connected to the DC traction motor when no friction forces on floor (discontinuous mode). Switching frequency is imposed by PWM Arduino output.

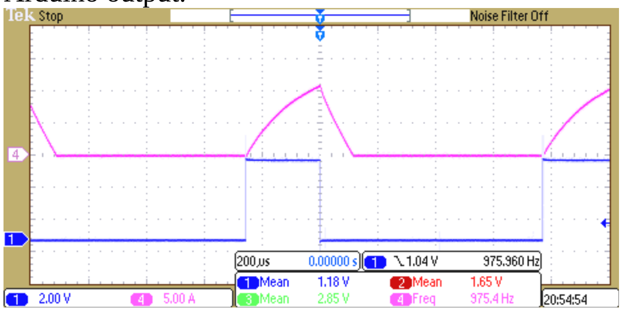

Figure 5: experimental voltage and current waveforms through the driver board

Trace 1: blue curve, logical control PWM signal (5V/div), frequency 975Hz
Trace 4: pink curve, current through the motor (scale: 5A/div) (forward and/or backward)

When the car goes forwards on the floor, duty cycle increases to fight against frictions and conduction becomes continuous.

3.4 Ultrasonic sensor HC-SR04

We use here a classical E/R ultrasonic (US) sensor (figure 6) [8] with its on board processing signal circuit. Detection range is 2cm to 4m. Distance is proportional to the pulse duration returned on "echo" pin. This type sensor is suitable to detect medium size objects such a small boxes, walls and so on.

Figure 6: emitter/receiver US sensor

The front sensor is mounted on a servomotor in order to be able to scan the front environment in a wider range angle than sensor aperture itself (around 15°). A second sensor is placed on rear the vehicle to control movement when parking.

3.5 Magnetometer

BNO055 is a multi-sensor module (accelerometer, gyroscope, temperature and magnetometer) with I2C bus interface. For a simplified approach of vehicle orientation, only magnetometer will be used.

3.6 General synoptic

The whole schematic diagram of the embedded electronic is given in figure 7.

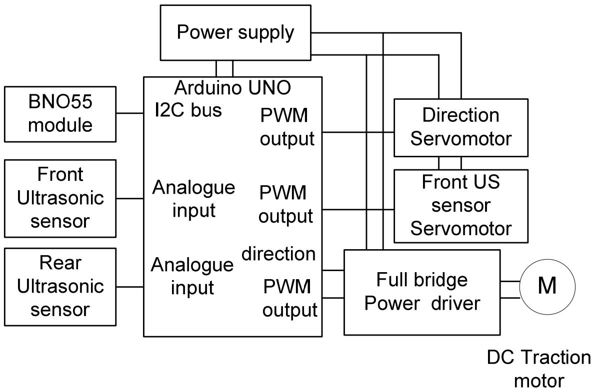

Figure 7: General block diagram

3.7 Full equipped small scale model car

The full equipped car is shown in figure 8.

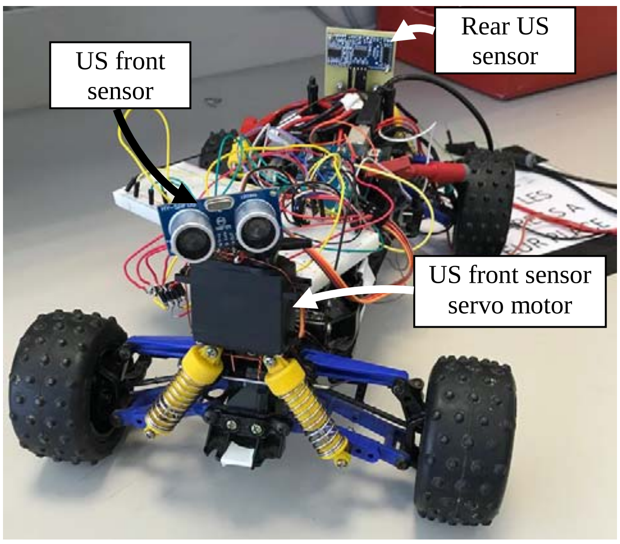

Figure 8: Electrical small model car

4. Programming the motion strategy

As it is a didactical project, a simplified strategy has been obviously adopted compared to the professional commercial embedded system. As told in §3.1.1 moving the car, avoiding obstacle, and car parking understanding the complexity of navigation were the main goal for the students.

4.1 Finding the north direction

After preliminary calibration of magnetometer, X, Y, Z components of earth magnetic field are returned. Sensor is assembled on the car so that car is oriented to north when the Y contribution is maximum. Strategy is thus quite simple and divided in two: If the north direction is within the range of the steering servo motor (i.e. between mechanical stops), the required angle of rotation of the servo is calculated and steering wheels are rotated in north direction. If it is not (north out of servo angular rotation ability), we just look if north is on the left or right side and steering wheel are turned up to the maximum corresponding mechanical limit.(figure 9).

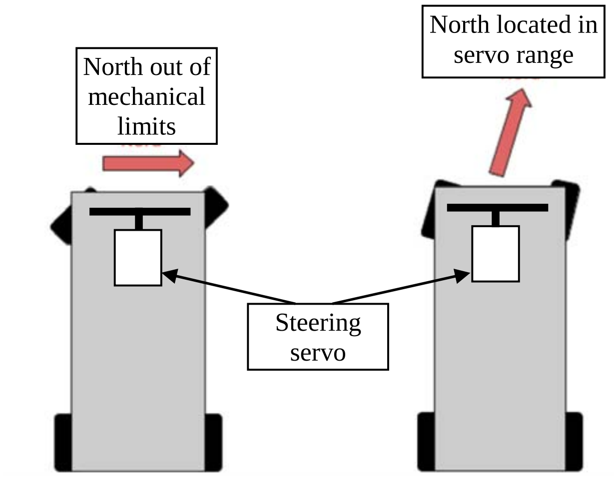

Figure 9: Finding the north

4.2 Obstacle avoidance

When the car is moving forwards, the front US sensor looks straight ahead. In case on obstacle detection, the car first stops then, the servo rotates the sensor from right to left (figure 10). As shown example figure 11, obstacle is rather on left side, an empty path is located on the right side, so the car first moves slightly backwards, and turns to the right. As obstacle can be wide, the strategy is repeated until to find a significant empty path.

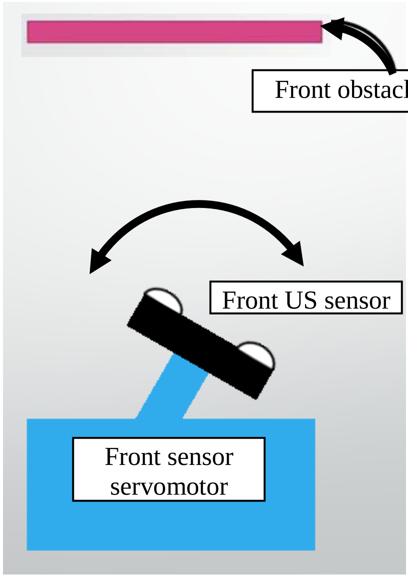

Figure 10: Scanning front obstacles

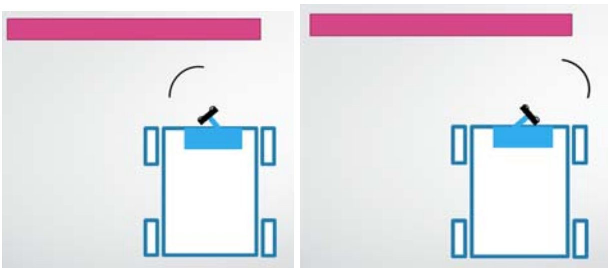

Figure 11: Obstacle avoidance

4.3 Parking the car

Parking a car is a complex task to do for human but also for an automatic system. Here, we choose to do “parallel to pavement” parking. Two already parked vehicles are symbolized by red boxes side to the pavement (figure 12). The small car (grey box) must find a place between them and park correctly.

Strategy we used is greatly simplified but enough to understand the principle of operation. It is described and summarized in figure 13.
Programming this strategy represents a few hundred lines of C language code.

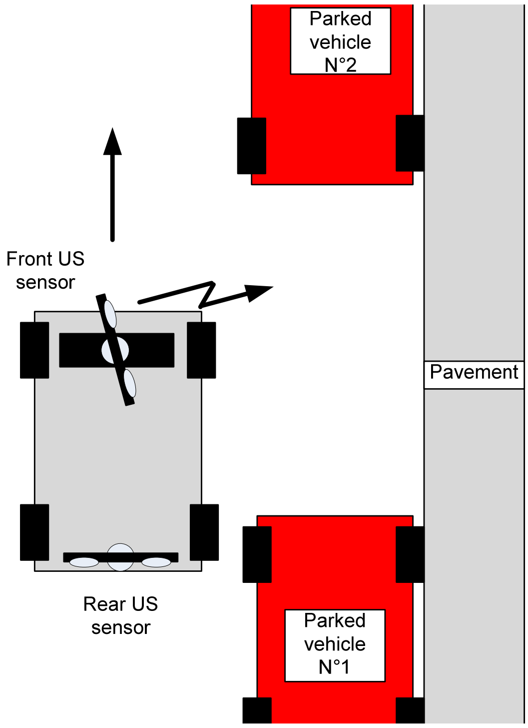

Figure 12: Car parking.

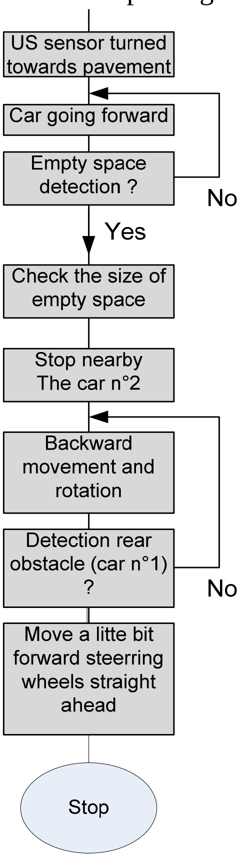

Figure 13: Software algorithm

5. Experimental test

Indoor test and some video clip were recorded. For these tests, the car is powered by external power supply equipment wiring can be seen on the following pictures. The presented photos are captured from the videoclip.

5.1 Front obstacle avoidance

A red box simulates a wide front obstacle. Firstly the car stops (figure 14a). Front ultrasonic sweeps and scans the front environment (figure 14b). Here, an free path is found on right. Then, the car move shortly backwards. Steering wheels are turned in the right direction and the car move forwards to avoid the obstacle (figure 14c).

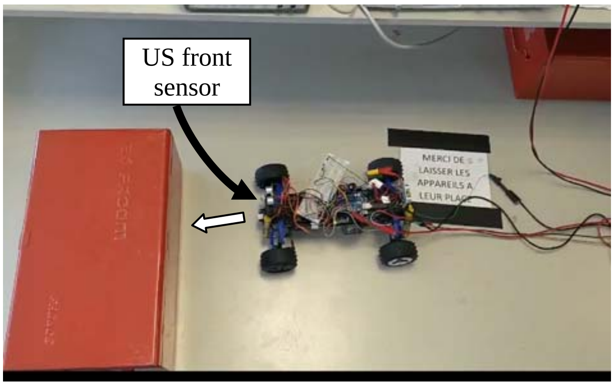

Figure 14a : Stop in front of obstacle

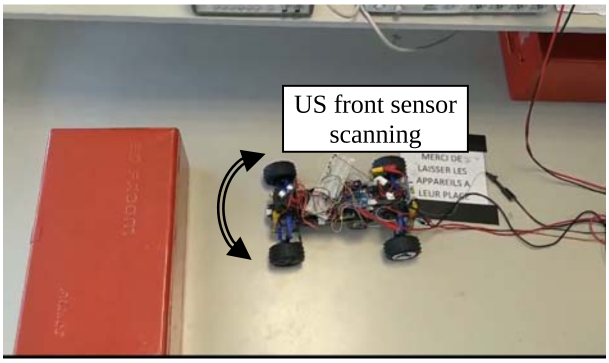

Figure 14b : Looking for exit

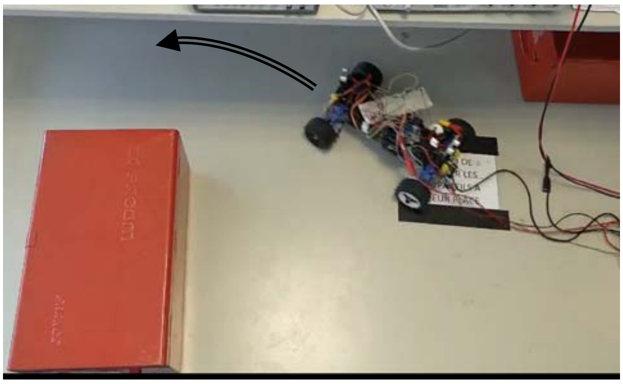

Figure 14c : turning around obstacle

5.2 Parking the car

The most impressive test was parking the car: The small model is placed on the test table. Two red boxes simulate two cars parked near a sidewalk.

The front ultrasonic sensor is first oriented perpendicular to vehicle main axis to detect right lateral obstacles. Coming from right, the car detects an empty space, stops at the beginning of empty space.

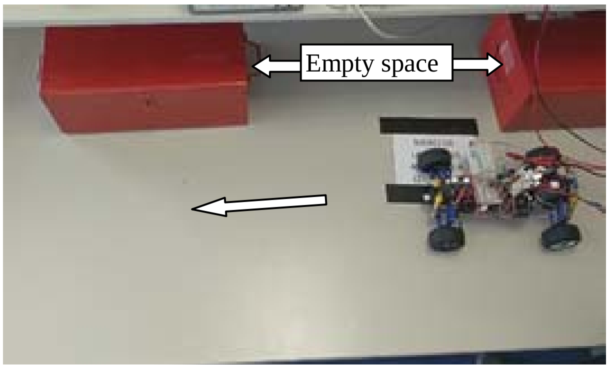

Figure 15a: Looking for empty space

Then it starts again towards left, to evaluate the size of free space. it stops side by side to the second red box and moves backwards to do a parallel park. The rear sensor avoid touching the first red box. Finally, the steering wheels are straightened up.

Figure 15b: Parking operation

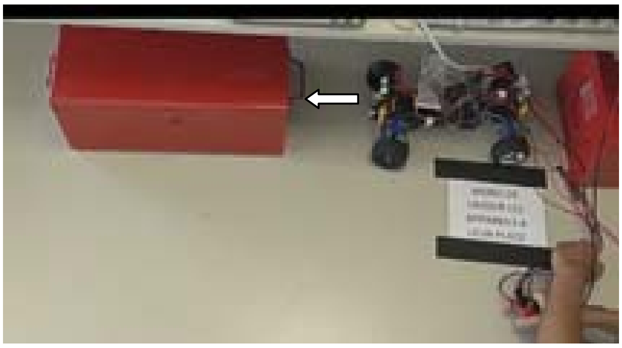

Figure 15c: Last movement

6. Comments

As explained before, this student project was only a simple initiation to autonomous navigation. Indeed, within a 40 hours framed project, it is obviously totally impossible to design a so complex and safe system as the private companies do presently on some vehicles. However, our didactical goal was reached. Students were so satisfied to see their small car moving and parking on the test table; a great performance for them.

6. Possible improvement

Adding other sensors to investigate multi sensors fusion concept could be studied in a future project.
For example, we could include:
- a light sensor for automatic turn on/off of headlights,
- a GPS module,
- a embedded camera
- a line tracking system,
- Battery management and control system.

Presently, optimization of power consumption is probably one of the most important criteria we could investigate. It requires an automatic control of PWM signal width for the traction motor. In our first program, duty cycle is constant to simplify the design. It has been oversized to fight against friction when starting up. One of possible idea would be to add a accelerometer sensor and adapt the duty cycle value looking at accelerometer/inclinometer data.

7. Positive Consequences of “learning by project”

7.1 Technical aspects

- Our practical approach gives the opportunity to teach some difficult fields of electronic as simply as possible.
- Our modular and system approach allows mixing different fields of electronic (analogue, digital, sensors, programming and power electronic). It focuses on global understanding more than design details. Thus, we obtain significant results within the relatively short duration allocated to student’s projects.

7.2 Human aspects

- These kind of “open” project gives some freedom to the students into the design. So, they have impression to be actor and creator. The funny aspect of the project amplifies the student’s motivation.
- Complexity of the design is better received by the students through a practical approach.
- The project is also a time for a human experience, a pleasant team work. Each student can discover his own preferences, profile, and personal interest.

7.3 Collateral effects

This kind of project is an opportunity for our students, to become aware of the complexity of the real electronic systems. They understand the necessity of team work, they see the gap between scholar project and industrial products design. It also, restores in their mind a “scale of value” regarding research, design and production times and energy required. Indeed, the very low commercial prices of high added value consumer's electronics such as GPS, mobile phone, IoT and other embedded systems founded in the super market, often gives a distorted idea of the true value electronic objects.

8. Conclusion

An example of student's project given in our electronic engineering school was presented. Basic control of the autonomous small scale model car was successful. Technical aspects and learning by project strategy were discussed. Since the students were enthusiast and motivated by the subject, we probably will go on next year, with similar thematic project.
Permanent adjustments and adaptation between student's needs, industrial needs and didactical project offered by our ENSEIRB School are probably the key points to make our scientific curriculum always more attractive in the future.

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