Modular electronic design: an alternating approach for student's projects. example of autonomous small-scale electric car design with embedded navigation module

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Abstract: In this paper, we propose some possible didactical adaptations to better fit with the new student's needs: Indeed, due to various successive evolutions in secondary schools and preparatory classes for "Grandes écoles" in France, the initial knowledge and behaviour of students is permanently changing. Lack of prerequisite in electronic and theory obliged to reconsider regularly the teaching strategy. Thus, we propose here a modified approach to student's project, oriented to a more modular electronic design. An original project is given as example to illustrate this approach. Technical specifications and design are presented. Finally, we discuss the technical differences and didactical impacts compared to the previous strategy.

Key words: electronic skills, learning by project, Multi thematic electronic project, GPS navigation

1. Introduction

1.1 ENSEIRB- MATMECA engineer school presentation

The "Ecole Nationale Supérieure d'Electronique, Informatique et Radiocommunications de Bordeaux" is one of the graduate national engineering schools, known as 'Grandes Ecoles', in France. It was created in 1920. ENSEIRB-MATMECA was initially a pure electronic school. But it has developed with the growth of information and communication technologies: a computer Science department was created in 1986 and was followed in 2000 by a Telecommunications department as well as two training in alternation departments.

1.2 Education strategy questioning

The same kind of questions appears regularly in the teaching world. For example, during the 1960's, the technological transition between electronic vacuum tubes and transistors generated a lot of questioning. Did we need to still teach tubes or replace by a totally new teaching on modern transistors? The progressive extinction of this technology gave us an implicit answer. Today, a very similar question is discussed between colleagues with the basic electronic components: Do we still have to teach transistors, diodes and basic analogue designs in 1st and 2nd year of study of our electronic department while the level of component's integration always increases and increases? The answer is not so obvious. This is not only a deep technical question (definition of the content and main required skills for students) but also a political, strategic and economic question. Several technical schools (IUT and BTS classes) in France have chosen to not teach anymore basic analogue components and to focus on more modular and integrated modules such as programmable components FPGA, PSOC or μP platform.

Moreover, technological change goes along with a change of student's behavior and new generation way of minding [1].

Among the major evolutions, we can extract the most important ones:

- Lack of prerequisite in electronic and theory due to the evolution of preparatory classes for "Grandes Ecoles" program.
- The international origin and the diversity of our students increase the difficulties of teaching.
- Recent generation of students have nowadays so many extra scholar activities such as sport, electronic games, and other leisure's. These secondary occupations are certainly positive from a personal development point of view, but they also generate a

big mental energy dispersion which is not always compatible with a rigorous school work.
- At least, the “M generation” students, born after 2000 (-M for “Multimedia”-) act now like volatile consumers: this “zapping” behaviour generates difficulties of concentration and memorization.

Looking at these questioning and evolution, we can probably guess that there is no or bad teaching strategies; But, being aware of these phenomenon leads to a necessity of permanent adaptation, adjustments and experimentation [2], [3]. Thus, we decided to test an alternating approach as indicated in the next paragraph. Advantages and inconvenient of this approach will be discussed in the paragraph 5.

2. Enseirb-Matmeca student’s project

2.1 Introduction

Historically, student’s projects in 2nd year study of electronic department were focused on analogue and digital design and practical experimentation related to theoretical courses. They are organized as weekly session of 3 hours during two semesters, pair-work, and are based on a classical “learning by project” strategy [4], [5], [6]. The teaching team insists on the basic components uses and understanding (transistors, diodes, inductances, capacitors, analogue and digital integrated circuits). Sometimes, more complex circuits (power, RF...) are also used. Finally, students design a full “medium complex” electronic system. However, because of the evolution mentioned before, we propose now to experiment another more modular approach, using “intelligent” electronic “ready-to-use” modules and open source platform.

2.2 Illustration of the new project’s approach

In order to illustrate this modular design approach, we chose a concrete example: the design of an autonomous small scale model electric car with sensors and GPS navigation module. Indeed, we already dealt with a similar subject in the past, using an “old” discrete analogue, digital components design [7]. Thus, it will be easy to compare impacts of this new didactical approach. Moreover, it is an up-to-date subject with the emergence of autonomous vehicle also called driverless car.

3. Description of the project

3.1 General description

3.1.1 Specifications of the project

The aim of the student’s project is to design an embedded electronic system in order to control an autonomous electric small model car: the idea is to reach a destination point (GPS coordinates entered manually before starting) from the departure point, using GPS localisation and compass modules. The trajectory must be as short as possible. The car must detect front obstacles, and find the appropriate an avoidance strategy.

3.1.2 Mechanical characteristics of the small model car

A classical hobbyist mechanical frame is used for this case of study (figure 1). We removed the “body” and keep only the mechanical frame, in order to install our own electronic boards. And we disabled mechanically the 4x4 motion option to reduce the power consumption.

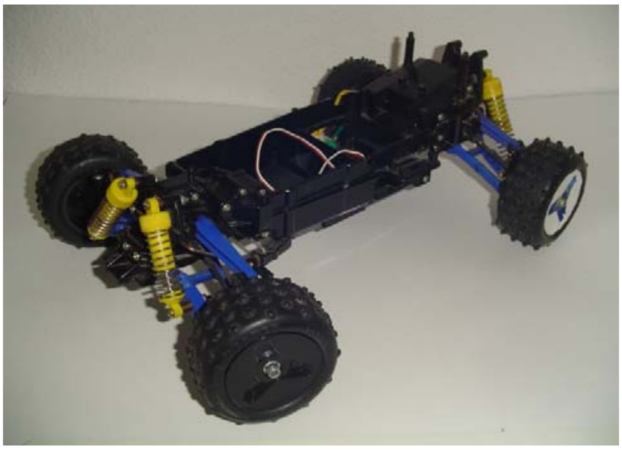


Figure 1: Small scale 4x4 mechanical frame (1/10)

The main characteristics of this frame are:
- Length: 340mm, Width: 230mm, Weight # 1000g,
- Four wheels drive,
- Suspension: 4 Wheels Independent,
- Engine: DC motor 7,2V 6A,
- Differential Gear System

3.1.3 Project’s specifications

As explained before, we will use only “built in” modules, ready to be assembled:

- Power supply: 7,2V 4500mAh NimH battery cell
- SFR05 ultrasonic detection of front obstacle module
- GPS module from Parallax Company
- CMPS11 Electronic compass tilt compensated module
- Arduino Uno as microcontroller board
- DRI10018 power module for traction motor control (Digital driver and power bridge BTS7960, 15A)
- FUTABA hobbyist servomotor for steering wheels control, controlled by classical 5V, PWM signal.

3.2 General architecture

The whole schematic diagram of the embedded electronic is given in figure 2.

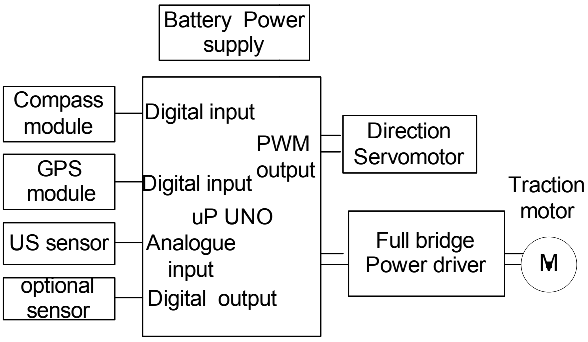


Figure 2: General block diagram

3.3 Processing board

We chose to use here a classical ARDUINO UNO module [8] based on a micro controller ATmega328 (ATMEL) to process inputs from sensors and outputs (figure 3).

Voltage supply is 5V. The clock Frequency is 16MHz. 14 digital I/O pins and 6 analogue input pins are available. Some of them can deliver directly a PWM signal (suitable for driving servomotor). Programming requires only Arduino freeware platform and USB connexion. Programming language is adapted from C language with many built-in libraries. The board can be powered from USB or external supply.

Figure 3: Arduino UNO board

3.4 The GPS module

This Parallax GPS module [9] is one of numerous available modules on the market, with an easy access to the localisation data’s. This is a fully-integrated, low-cost receiver module with on-board passive patch antenna and a serial 4800 baud interface to transmit data to any processor. Supply voltage is +5V DC.

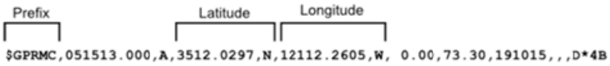
The other important characteristics are:

- Receiver sensitivity: -152 dBm in search mode, -139 dBm in acquisition mode.
- Data refresh time : 1 time per second
- Average accuracy: plus or minus 5 m in position, and +/- 0.1 m/s for the speed.

Figure 4: GPS Parallax Module

Data’s are returned according to NMEA format [10] as ASCII character chain.

An example of pattern data’s returned by the module is given below:



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$GPRMC,051513.000,A,3512.0297,N,12112.2605,W, 0.00,73.30,191015,,,D*4B
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Using predefined software library compatible with Arduino, it is quite simple to process this frame and to sort the useful data. Among all the received fields, we need here for our navigation strategy, only latitude, longitude and heading (direction of movement).

3.5 Directional Servo motor

Angular direction of the front wheels of the vehicle is controlled by a classical hobbyist FUTABA servomotor. Basic principle is given in Figure 5.

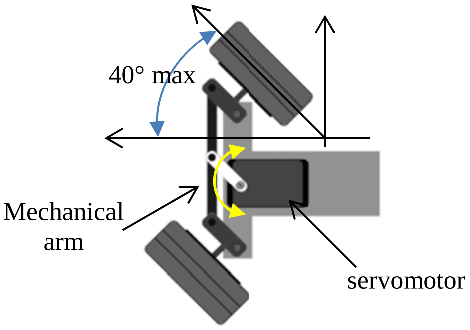

Figure 5: steering wheels servo motor principle (top view)

The figure 6 shows the range limits of control signal applied to the servo and the corresponding output rotation angle which is proportional to pulse width D.

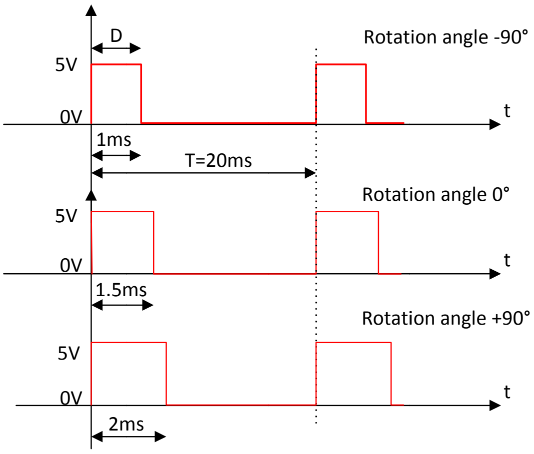

Figure 6: Typical PWM control signal

When rotating, the power consumption of the servo is around 200mA depending, of course, of the friction force between wheels and floor. Since the wheels rotation is limited to ±40°, the range of pulse width is obviously reduced according to this mechanical limit.

3.6 Traction DC Motor and Power driver

The DC traction motor has been first characterized with impedance meter Agilent 4263B, in order to check the correct voltage and current waveforms observed during later experimentation:

DC maximum voltage: 7V
Internal resistance: 1.2Ω
Inductance @ 1kHz: 100µH

In order to match our modular didactical approach, we decided to use a commercial integrated DC motor driver module 45V, 2x15A ref Lite SKU: DRI0018) [11].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 intelligent power circuit includes current sense, slew rate adjustment, dead time generation and protection against over temperature, overvoltage, under voltage, overcurrent and short circuit. Here, only one channel is used.

Figure 7: Motor driver board

An input on the logical gate allows stopping the car in case of emergency or front obstacle detection during the motion. In order to simplify the design, as our “playing area” is supposed to be flat, we did not add any feed back loop for speed or torque control.

3.7 Ultrasonic sensors

We use a classical SFR05 Ultrasonic module (Figure 8) for front large obstacle detection. (Detection range is between 10cm up to 4m). It includes a 40 kHz emitter/receiver sensors and a processing circuit. Measured distance is proportional to the pulse width of the output signal.

By programming, we will be set up the threshold detection level to 1 m which is widely sufficient to decrease the speed and stop the small car before the obstacle.

Figure 8: US sensor SRF05

3.8 Compass module

Because of the relative “low” precision of GPS compared to the small size of the electric model car, we included a tilt compensated compass module CMPS11 to help navigation. This compass module is based on a 3 axis magnetometers and an embedded processing unit that can be interfaced by I2C bus.

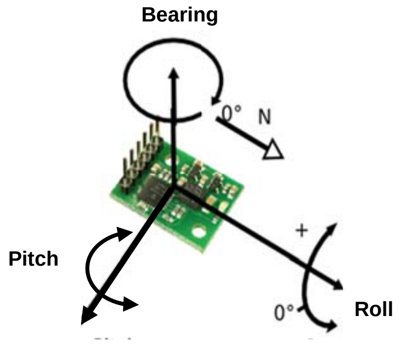

Figure 9: 3 axis compass module CMPS11

The compass module returns angle referenced to north as a serial data coded on 8 bits.

3.9 Programming the motion strategy

For didactical reasons and project duration, a very simplified strategy has been adopted, compared to the true commercial embedded powerful GPS system. Complexity is enough for the students to deal with some geometrical considerations and to understand the principle of navigation systems.

Since the driving distance is very short (A few hundred meters), we assume the earth to be locally “flat”.

At the beginning of the run, the coordinates of arrival point are entered in the program. Then, the GPS get the initial position and the processing board computes the initial heading.

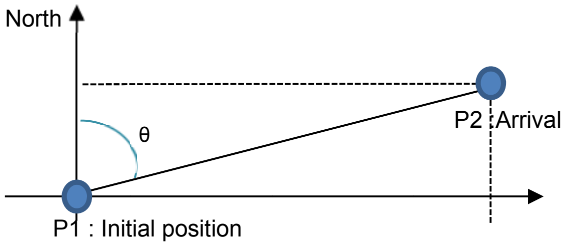

Figure 10: Initial heading

Comparing the initial orientation θ of the car to the computed heading, the car turns first on itself until the compass module gives the correct value and then follow the required direction (figure 11).

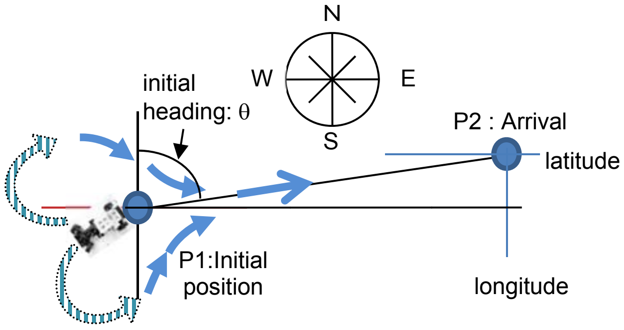

Figure 11: Moving strategy

Then, during the run, a periodic real time acquisition from GPS is done. A comparison between header calculated θ and the angle ϕ given by the on-board CMPS11 compass allows correcting the instantaneous heading. Depending on the quadrant where the car is, an angle offset should be or not added. To avoid too much workload of servomotor, correction is applied to steering wheel only if the difference (θ - ϕ) becomes greater than a threshold acceptable value set up at 7°.

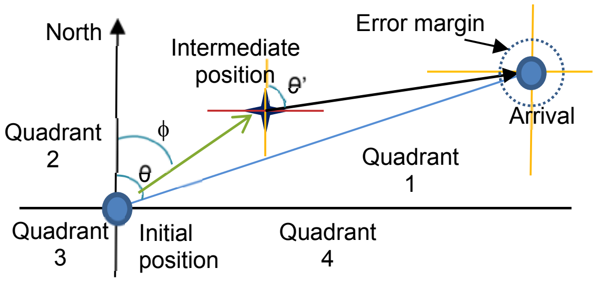

Figure 12: Intermediate heading recalculation

So, the trajectory is not exactly linear as indicated in figure 12 but looks like a “broken” line between final and departure positions.
In case of front obstacle detection, the car first slow down, stops, moves backwards and turns around to avoid the object and computes a new correct heading.

The whole strategy is summarized in figure 13.

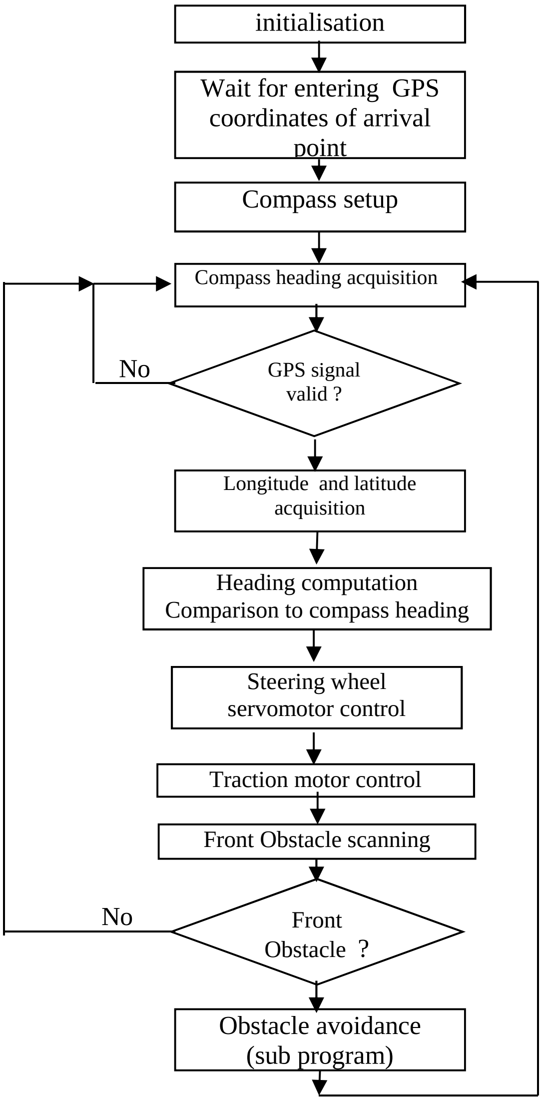

Figure 13: Software organisation

Programming code represents around 40% of the total memory capacity of Arduino uno. And 41% of the dynamic memory is used for variable and constants declaration.

3.10 Full equipped small scale model car

The full equipped car is shown in figure 14.

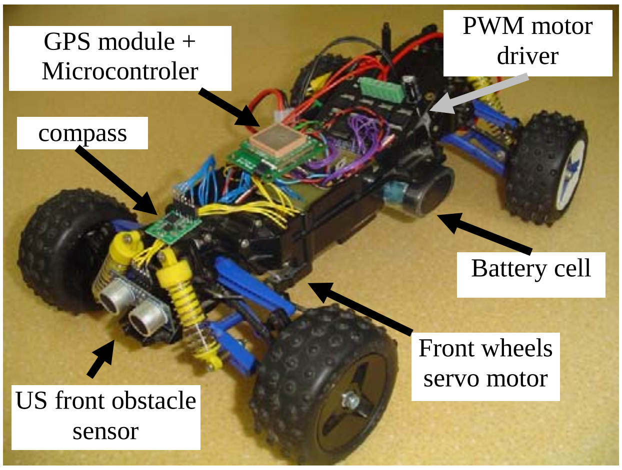

Figure 14: small scale car and electronic system

When the car is in action, the motor generates some electromagnetic perturbations, so we added a copper shield and we put the compass module as far as possible from the DC traction motor.

4. Validation test and technical results

Tests are performed in three ways: In door Electrical and electronic tests, Outdoor navigation algorithm validation, and finally global tests (vehicle and navigation system.

4.1 Electrical Validation tests

Behaviour of H Bridge in discontinuous mode was first predicted by Spice simulations (figure 15):
Trace 1: (green upper trace) PWM control signal (duty cycle 40%, switching frequency 10 kHz, vertical scale 5V/div, horizontal scale 50us/div)
Trace M: (red middle trace) Voltage across the engine (vertical scale: 5V/div)
Trace 2: (blue lower trace) Current through the engine (vertical scale: 5A)

Three phases can be observed:
- “ON” state: current increase almost linearly ①
- “OFF” state: free wheeling ②
- “OFF” state: current cancelled, voltage across the engine equals to the internal e.m.f. ③

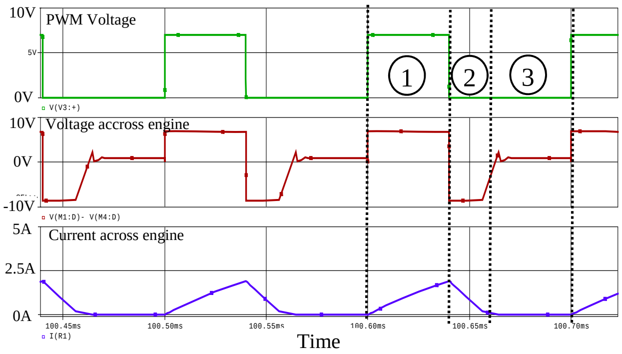

Figure 15: Spice simulation

This simulation can be easily compared to the following experimental curve in figure 16a (same conditions and scales).

Figure 16a: horizontal scale: 40us/div
Trace 1: (upper trace) PWM control signal scale 5V/div)
Trace M: (middle trace) Voltage across the motor (scale: 5V/div)
Trace 2: (lower trace) Current through the motor (scale: 5A/div)

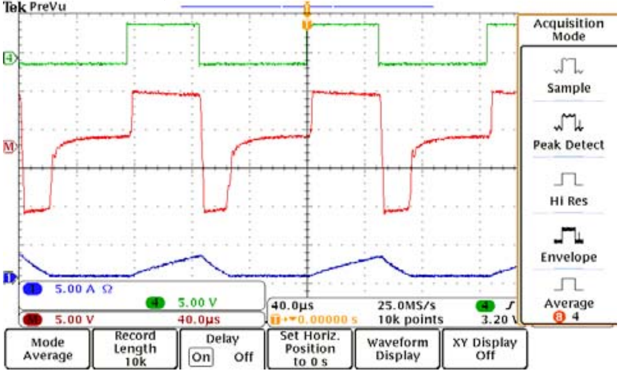

Figure 16a: Experimental voltage and current waveforms across the traction motor (discontinuous mode i.e. with a freewheeling phase)

Finally, figure 16b shows experimental curve in continuous mode:
Duty cycle 70%, resistant friction torque on floor,
Trace 1: (upper trace) PWM control signal scale 5V/div)
Trace M: (middle trace) Voltage across the motor (scale: 5V/div)
Trace 2: (lower trace) Current through the motor (scale: 5A/div)

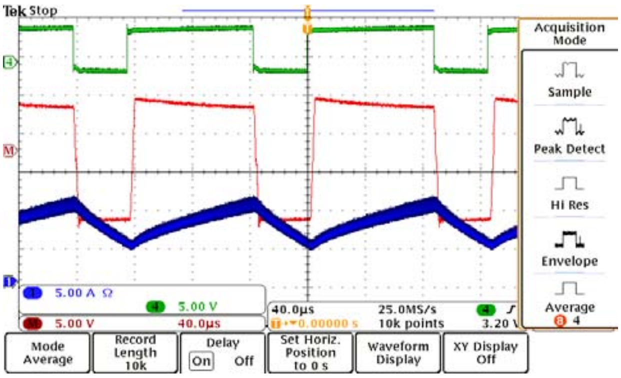

Figure 16b: Experimental voltage and current waveforms across the traction motor (continuous mode)

Thus, with these experiments, students get a didactical, visual and concrete illustration of the switching frequency, duty cycle and friction torque impacts.

Then correct addressing and I2C data transfer of the compass module CMPS10 is checked separately.

4.2 Validation of navigation algorithm

Our GPS module was preliminary checked by acquiring the local coordinates (latitude 44.806498, longitude -0.606047) of our school. Then, the acquired position (red flag) is reported on “google earth” to check the accuracy of our module (Figure 17).
According to specifications, accuracy is around 10m.

Figure 17: GPS initialisation (google earth image)

Then, the navigation strategy is checked "manually" as follow:
The full navigation electronic system (Arduino+ GPS) is first carried by a pedestrian equipped with a PC computer. An arrival point is set up, Then, the pedestrian starts to walk and follow the 5 simplified orders returned by the system, on the PC screen: "Turn to the right, turn slightly to the right, straight ahead, turn slightly on the left turn to the left". Instantaneous latitude, longitude during the ride are recorded in a text file.
Then, it is converted in a typical *.gpx file format used for GPS localization [12], Thus, the ride is reported on a map with a GPS visualizer [13] (blue broken line between the two roundabouts close to our school, in figure 18). It allows to check the correct motion and to evaluate amplitude of "zig zag" inherent to navigation strategy, which is less than 10m.

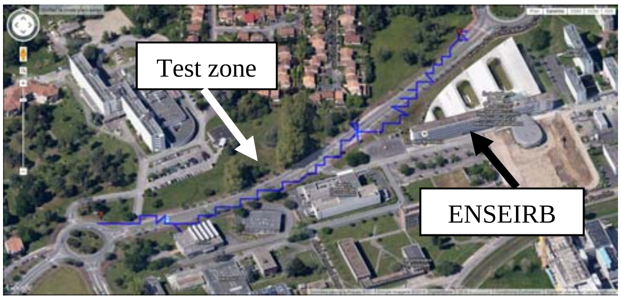

Figure 18: Preliminary test ride

During the test, some disturbances may occur in GPS signal capture, due to proximity of high buildings and probable wave reflection. So, we did it several times.
Once validated, our electronic system is embedded on the small scale autonomous vehicle powered by the battery in an open space area.

4.3 Final outdoor test

A "live" test was done on the square "car parking" (around 100m x 150m) (figure 19). The speed of the vehicle was first set up at around 5km/h. That is slow enough to have a human action in case of any problem.
When GPS was correctly locked, it took around 5 minutes to reach the arrival point after two obstacles avoidance and turn around [14].

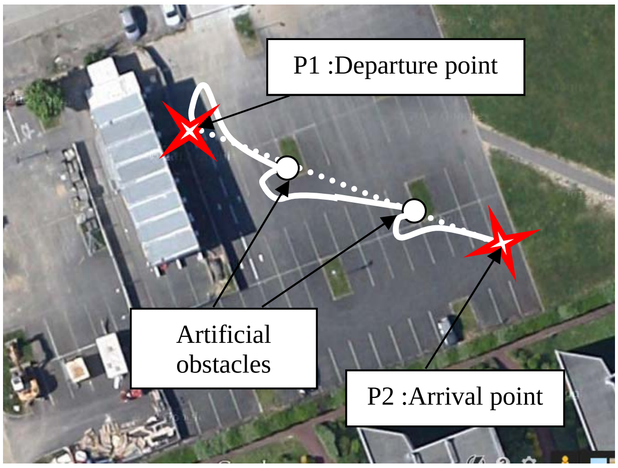

Figure 19: Test area

.... wished trajectory (dashed line)

▬ Practical run of the car

4.4 Technical results analysis and comments

Looking at the outdoor small car motion and practical behaviour, students became aware of the complexity of a true GPS guidance system: Indeed, performances of the small car model were far from the ones of a true in-board GPS we find in modern vehicles. But becoming aware is a good way for the students to understand the necessity of a good theoretical and practical knowledge appropriation.
From a technical point of view, many improvements could be done. For example, we could add tactile whiskers for very near obstacle detection. We could also take into account the Greenwich meridian for optimizing the trajectory calculus. (For departure and arrival points situated on the both side of the meridian). An Arduino XBee module could be also used to transmit parameters from the car to a host computer, in order to check behaviour of the vehicle in real time.
However, the complexity must be compatible with the project duration and adapted to the basic knowledge of students.

5. Didactical strategy assessment

This sample project was performed by two students in 2nd years of study at ENSEIRB-MATMECA. In parallel, several similar projects with modular design based on Arduino platform were tested to check all the steps of this alternating didactical approach during two consecutive years. All of these projects were globally completed in time and technical specifications were satisfied. However, we point out in table 1 some positive and negative points.

Modular design

Advantage	Inconvenience
- Soldering operation almost suppressed, - Hardware wiring mistake suppressed, - No hardware debug waste time, - "easy to use" modules internally protected against over currents and voltages, - No more electronic components destruction by students, - Reusable modules for the next academic year. - Project completed in time	- Board size and volume not optimized, - No more concrete printed board realization - No time to look deeper inside the electronic and thermal behaviour of components - Loss of basic knowledge: using a module do not mean knowing how it operates inside and it is designed. - When it do not operate, higher difficulty to find the error because lack of fine understanding. - Higher project cost

Table 1: Pro and con of modular design

5.1 Other comments on didactical approach

This alternating approach allows mixing different fields of electronic (analogue, digital, sensors, programming, and power electronic). It ensures a better cross connection between them, and causes a global interest for the technical and theoretical lessons. It is also an opportunity for our students, to become aware of the complexity of the electronic systems, duration and difficulties of design. And consequently, restoring in their mind a "scale of value" too much devalued by the very low prices of high added value consumer's electronics such as GPS, mobile phone, tablets and so on.

5.2 Student's feed-back

Even if it is always difficult to quantify the efficiency of a didactical strategy, we can quote first a strong implication of the students involved in the projects. After the experimentation, we did an opinion poll and report among the students in order to get some feedback about this strategy. It shows a global satisfaction rate up to 80% for this project strategy:

- Thanks to this approach, they declare to be more satisfied while their projects were completed in time, they obtained results and reached a fixed goal.
- They better feel complexity of the electronic design through a practical approach.
- They highlight the positive emulation between working-pairs inside the student's group and the pleasant environment of work.
- Lastly, they notice that 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.

However, we must be careful. There is no absolute truth : correlation of opinion poll results and ranking of students, shows that the new project approach is extremely well perceived by the best students but do not solve the difficulties and lack of average students.

5.3 New educational questioning

As said before, this new approach does not solve the problem of fundamental lacks of the students.

By definition, an electronic engineer must be able to design circuits and systems, to understand, to innovate, to calculate and to give a technical support to technicians working with him.

So, our future engineers must acquire progressively deep theoretical and practical abilities, as well as good common senses and of course others human qualities.

In that way, to make our modular design project strategy in 2nd year of study more efficient, some discussions are now in progress [15] about 1st year electronic program content: some adjustments should be done in the early 1st year of study: In particular, to focus on the ground level and roots of electronics and to improve the ability of the students to follow a mental reasoning in order to be creative. Indeed, teachers and researchers often prefer to give high level lectures and complex practical projects which are more funny and flattering. But, it is necessary for all to understand that teaching (too much) complex aspects is not efficient while the students did not have assimilated all the electronics basics.

8. Conclusion

We proposed in this paper an alternative approach to the traditional teaching methods. Indeed, we noticed in our electronic department that classical courses do not match anymore with the actual pedagogical needs for environmental, individual, and society evolution reasons. As we can not change the students, we only thing we can do, is to adapt our pedagogical approach to them: “Learning by project with a modular design approach” seems to be a good way among others, to increase the efficiency and the quality of our teaching. We illustrated this method with a concrete example of small scale autonomous electrical car design project. Student’s feedback shows that it is necessary to make permanent adjustments and adaptation between students’s needs and teaching strategy. It is probably one of the best way to make our scientific curriculum more attractive in the future.

References:

[1] N. Howe & W. Strauss, «*Generations: the history of America’s future, 1584 to 2069*» Perennial Harper Collins publisher, 1991 ISSN 0-688-11912-3

[2] M. Avila, JC. Bardet, S. Begot, P. Vrignat, N. Stride «La pédagogie par projets » CETSIS 25-27 octobre 2005 Nancy France

[3] M. Johnson, M.J. Hayes, A comparison of problem-based and didactic learning pedagogies on an electronics engineering course *International Journal of Electrical Engineering Education* Vol: 53 issue: 1, p. 3-22 July 23, 2015

[4] N. Boutin, D. Dalle, G. Lachiver, Ph Mabilleau, L’apprentissage par problèmes et par projets pour le développement des compétences professionnelles de l’ingénieur: l’exemple des programmes de génie électrique et de génie informatique de l’université de Sherbrooke CETSIS EEA 29-31 October 2007 Bordeaux France

[5] J. Macias-Guarasa, J.M. Montero, R. San-Segundo, A. Araujo, O. Nieto-Taladriz, A project-based learning approach to design electronic systems curricula, IEEE Transactions on Education Vol 49, Issue: 3, Aug. 2006

[6] Ph. Dondon, P. Roman, B. Mouton, A motivating pedagogical approach: “learning by project” with an electronic design, example of ultrasonic tracking radar WSEAS/IASME 16,18 dec 2005 Tenerife Spain

[7] Ph. Dondon- T.Tsing, F. Sandoval " Initiation to GPS localisation and navigation using a small-scale model electric car: An illustration of "learning by project" for graduated students: " WSEAS EDU'09 17-19 octobre 2009 Genoa Italy

[8] Arduino open source web site: www.arduino.cc/fr/

[9] P. A. Chevalier, GPS courses, Web site http://www.gpsy.com/gpsinfo/gps-faq.txt Ecole d’ingénieur de Bienne, Suisse 2002

[10] National Marine Electronics Association, NMEA Web site: http://www.nmea.org/

[11] DFrobot web site: http://www.dfrobot.com/wiki/index.php/DC_Motor_Driver_2x15A_Lite_(SKU:_DRI0018)

[12] GPS localization Web site: http://www.gpsvisualizer.com/

[13] Web site gpx file format: http://fr.wikipedia.org/wiki/GPX_(format_de_fichier)

[14] V. Vaillant, J. Pastre, vehicule miniature autonome, ENSEIRB internal internship report 2015

[15] Project managers internal meeting report, ENSEIRB 2017

[16] Darya Bulelukova ; Michael Kramer ; Harald Wahl ; Susanne Schwanzer Gender-inclusive laboratory design for teaching electric vehicle components, Global Engineering Education Conference (EDUCON), 2017 IEEE25-28 April 2017Athens, Greece

[17] F. Soares, C.P. Leão, P. Moura Oliveira, A student-friendly approach in teaching/learning theoretical concepts in automation MED 2017, 25th Mediterranean Conference on Control and Automation 3-6 July 2017 Valletta, Malta