# Teachings using microcontrollers of the STM32 family

## Department of Electrical and Computer Engineering

December 2017

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES TOULOUSE

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|---|---|
| **Title**: | Algorithms and programming, in ADA (Gameboy) |
| **Year**: | 2nd year Materials, Components and Systems Engineering (IMACS) |
| **Teacher(s)**: | Guillaume Auriol |
| **Development:** | Sébastien DI MERCURIO |

**Description:**
The first two years of engineering at INSA are an opportunity for students to learn algorithmic and programming languages through ADA, reputed to be a rigorous language.

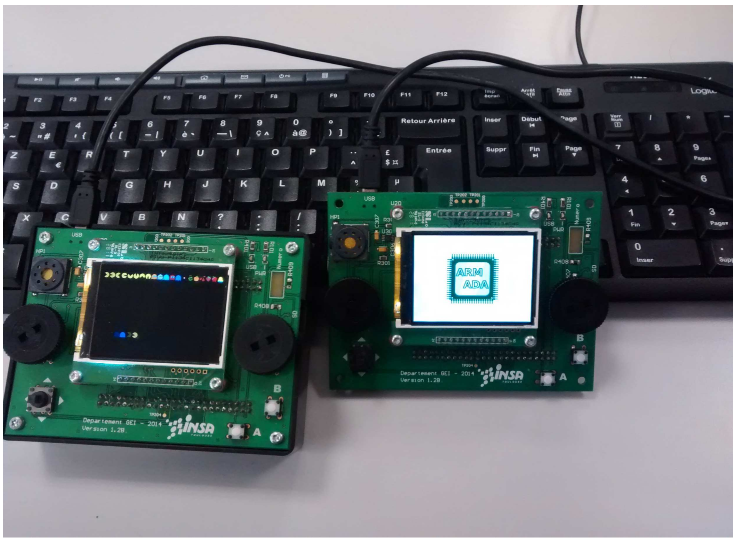
The disadvantage is that ADA language is generally practiced on PC and the resulting image is that this language is only used to develop on PC.

It was decided, in the 2nd year, to break this image by doing a series of labs where the program runs on an embedded target, in this case a console based on the STM32F3DISCOVERY board.

The device integrates sensors provided by the discovery board (accelerometer, gyroscope and magnetometer) and adds a 320 * 240 pixel color screen, an audio amplifier with a loudspeaker, buttons, directional cross, two potentiometers and an SD card reader.

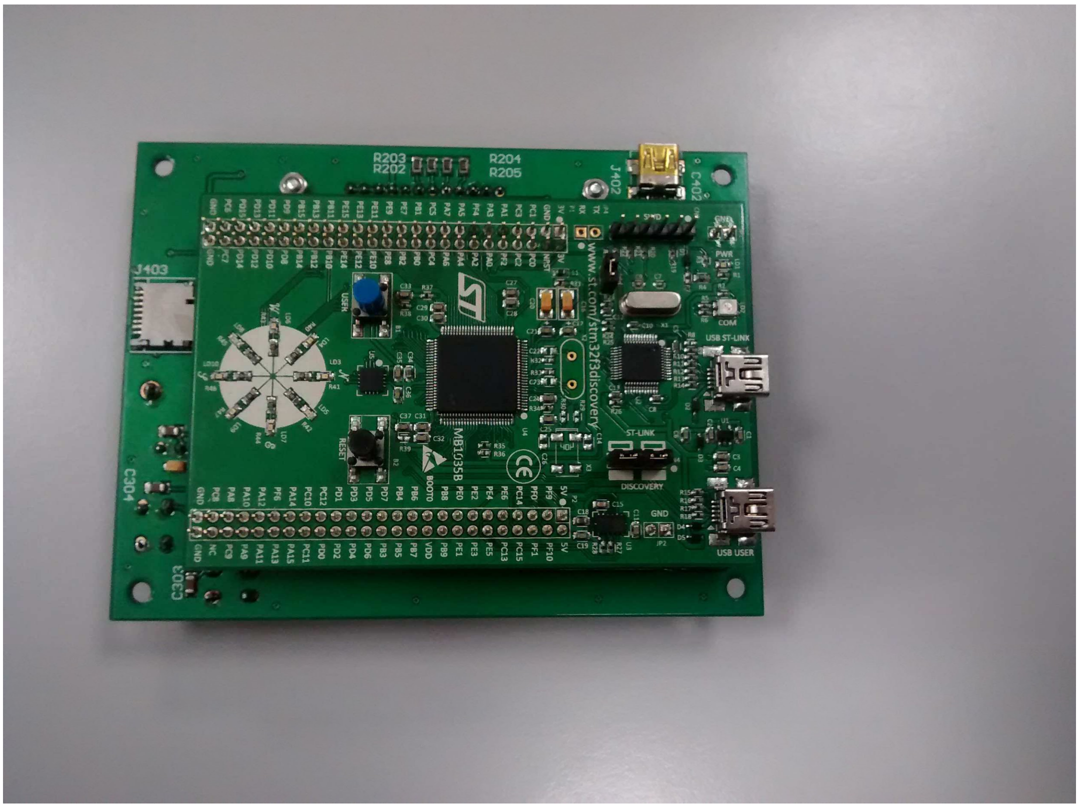
The ecosystem around this box has been developed within the department: patch and recompilation of the GCC compiler for our needs, development of a bootloader and a resident OS as well as ADA libraries and tools for the support of the labs. The student develops and compiles his ADA program on PC and then transfers the program to the flash memory of the STM32 for execution.

The labs are progressive and allows the student to become familiar with different algorithmic structures and programming objects, in a more playful setting. Moreover, he becomes accustomed to problems related of a limited system in therms of debug and resources.



**Picture 1:** The Gameboy, with and without its cover


**Picture 2:** The Gameboy, front view




**Picture 3:** Rear view, which shows the STM32F3DISCOVER board

**Title**: Assembly Language (Magic Wheel)
**Year**: 3rd year Materials, Components and Systems Engineering (IMACS)
**Teacher(s)**: Vincent Mahout
**Development:** José Martin

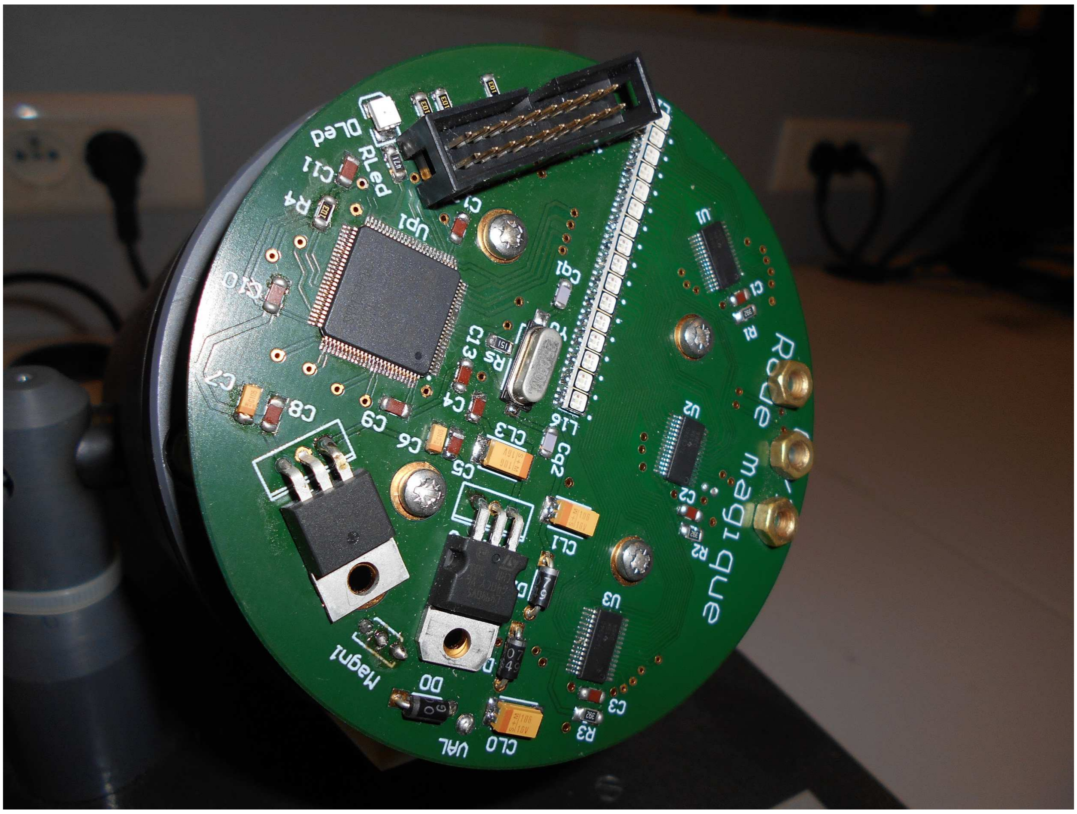
**Description:**
This model serves as a fun medium to train students in assembly language programming.

Already having substantial foundations in hardware architecture, students discover the architecture and specificities of the heart of STM32 (ARM Cortex M) and learn the fundamentals of an assembly language (instruction set, addressing modes, management system stack, classical algorithmic structuring, ...).

During this lab, the student aims to achieve a stable display on a bar of rotating LED (wheel). The lab is an opportunity to introduce for the first time peripherals such as timers, GPIO, SPI as well as the interrupt controller and internal and external interruptions.

The purpose of this teaching of about 40 hours and very practice-oriented is not to encourage students to develop in this rudimentary language but to assimilate the principles to better understand the work of a compiler, to know how to debug delicate situations and to have the necessary prerequisites allowing students to address STM32's advanced C programming (peripherals, interrupts, bare metal, ..).

**Picture 1:** Magic wheel in action



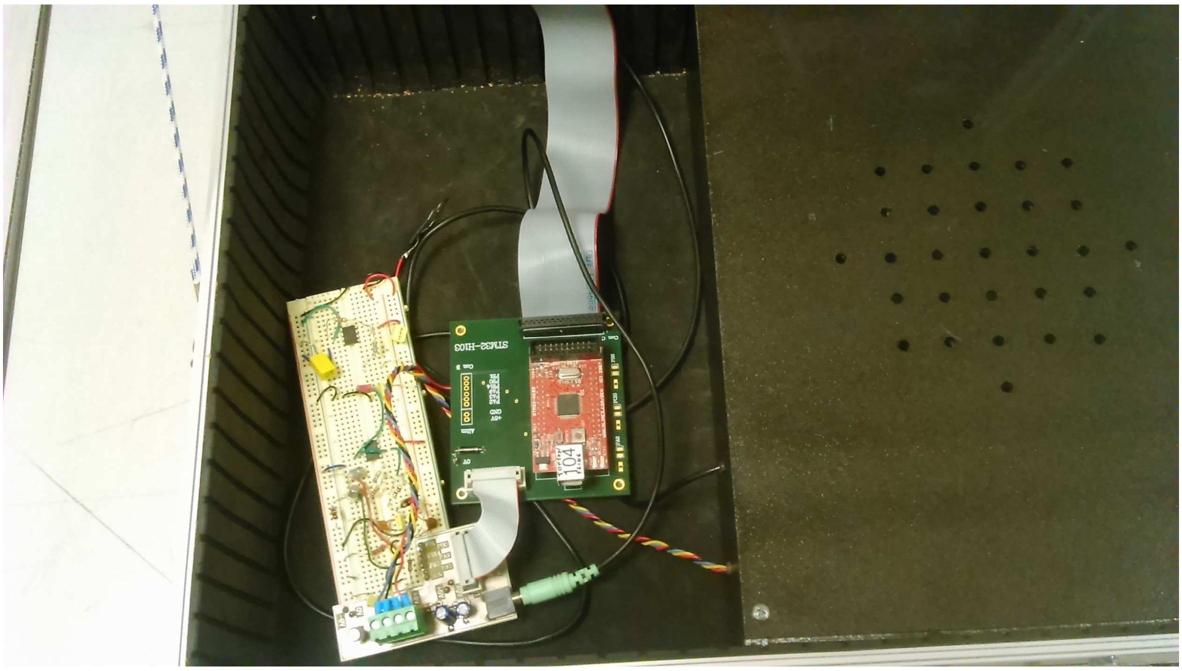
**Picture 2:** Zoom on the PCB (showing STM32F107 MCU)

**Title**: Laser Shooter
**Year(s)**: 3rd year Modeling, Computer Science and Communication (MIC)
Concepts and Hardware for the Transmission of Information
**Teacher(s)**: Thierry Rocacher
**Development:** José Martin

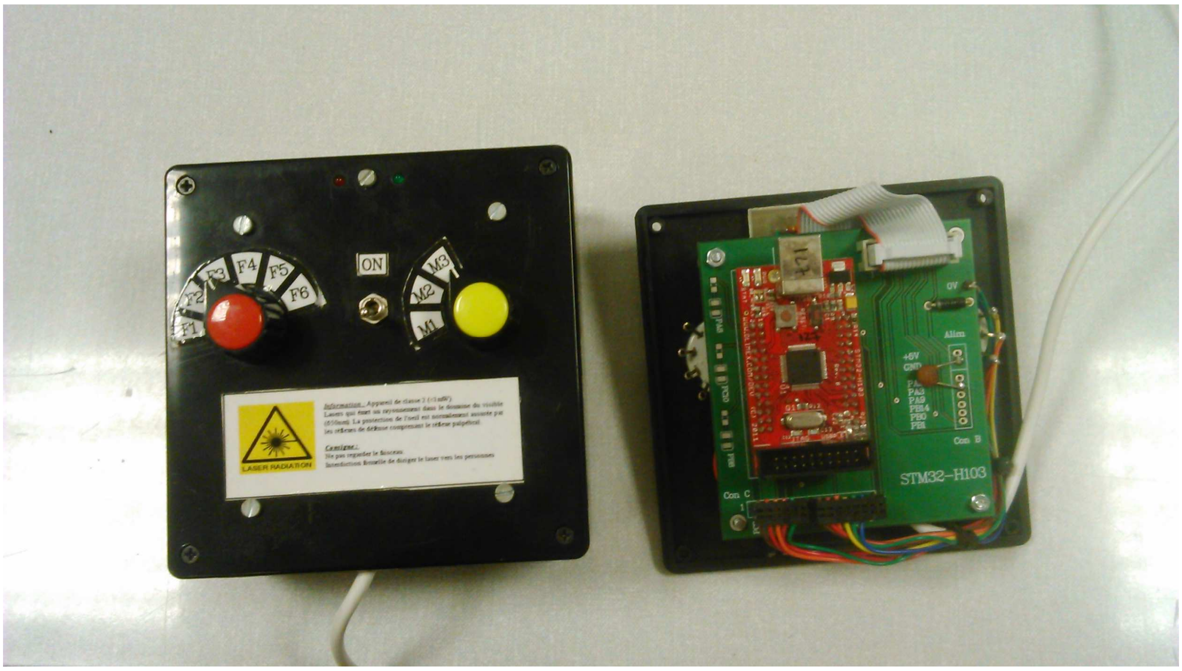
**Description :**
The manipulation consists of developing a Laser shooter, namely designing the hardware and software part. The software includes a lot of features such as Discrete Fourrier Transform (DFT) analysis of received signals, sound generation, score management ...

It is a STM32F103RB, mounted on an Olimex board, which embeds the code.

**Picture 1** : Global view of the system, including guns and target.



**Picture 2** : Zoom on target hardware: heart is an STM32F103RB



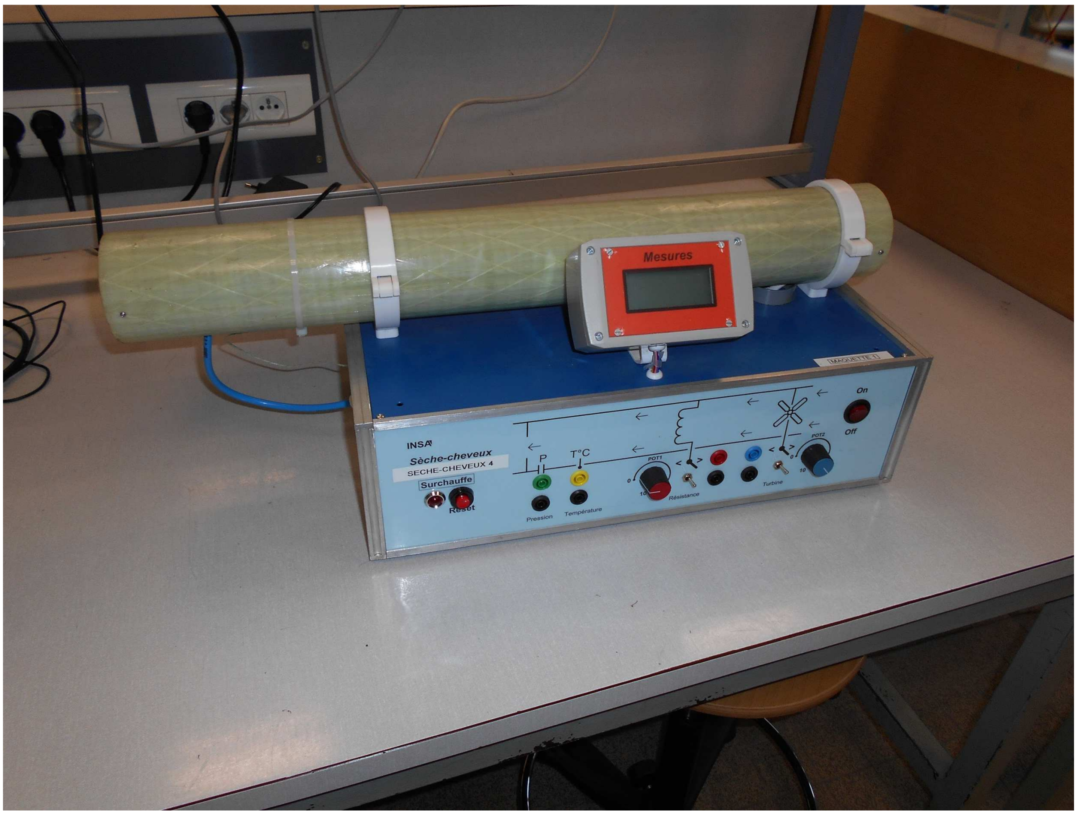
**Picture 3** : Inside view of a gun: management is also done using and STM32F103RB

**Title**: Thermal and Pressure Regulation
**Year**: 4th year Automatic and Electronic (AE)
**Teacher(s)**: Gwendoline Le Corre
**Development:** José Martin

**Description:**
In automatic, this model illustrates a temperature regulation of a heating process.

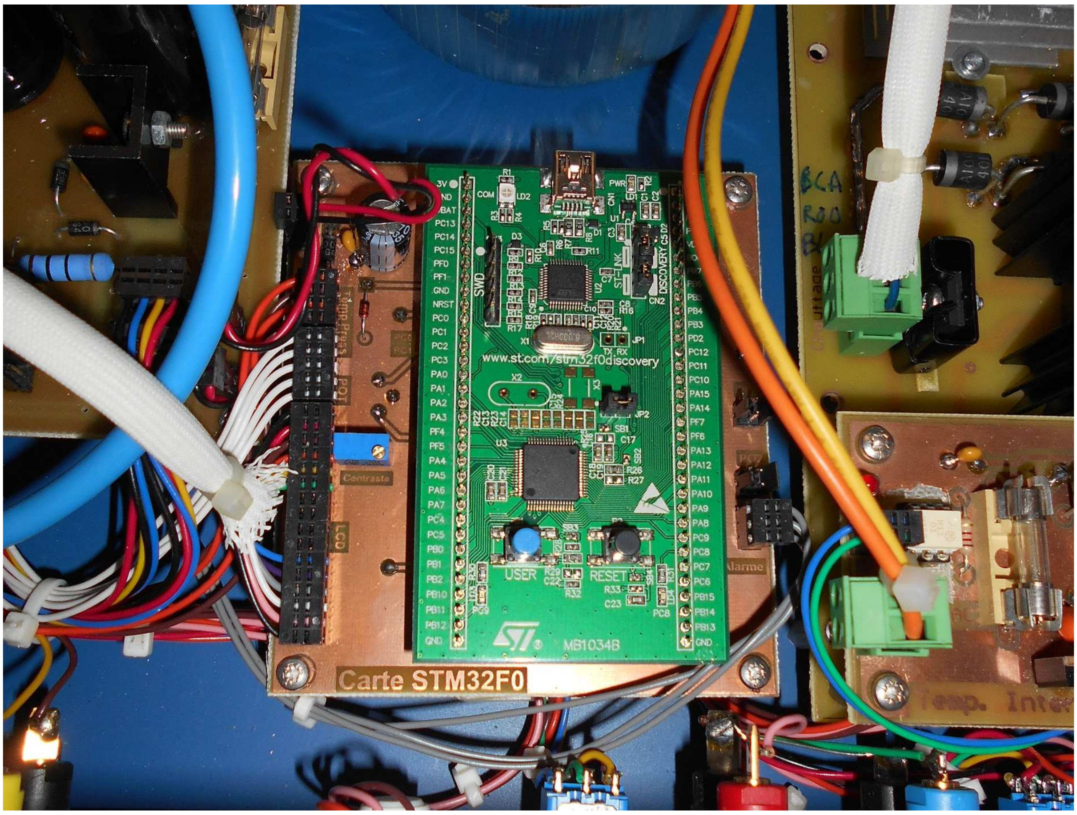
This device allows the implementation, by the students, of a ventilation control (blower and measurement of pressure) and heating power (heating resistance and thermocouple).

The set is made from the elements of a real hair dryer. The whole is integrated in a tube placed on a box which contains the power electronics and an STM32F0 microcontroller used for management of sensors measurement, analog inputs, potentiometers, display ...




**Picture 1:** Global view of the device

**Picture 2:** Inside view




**Picture 3:** The main part is a Discovery F0 board

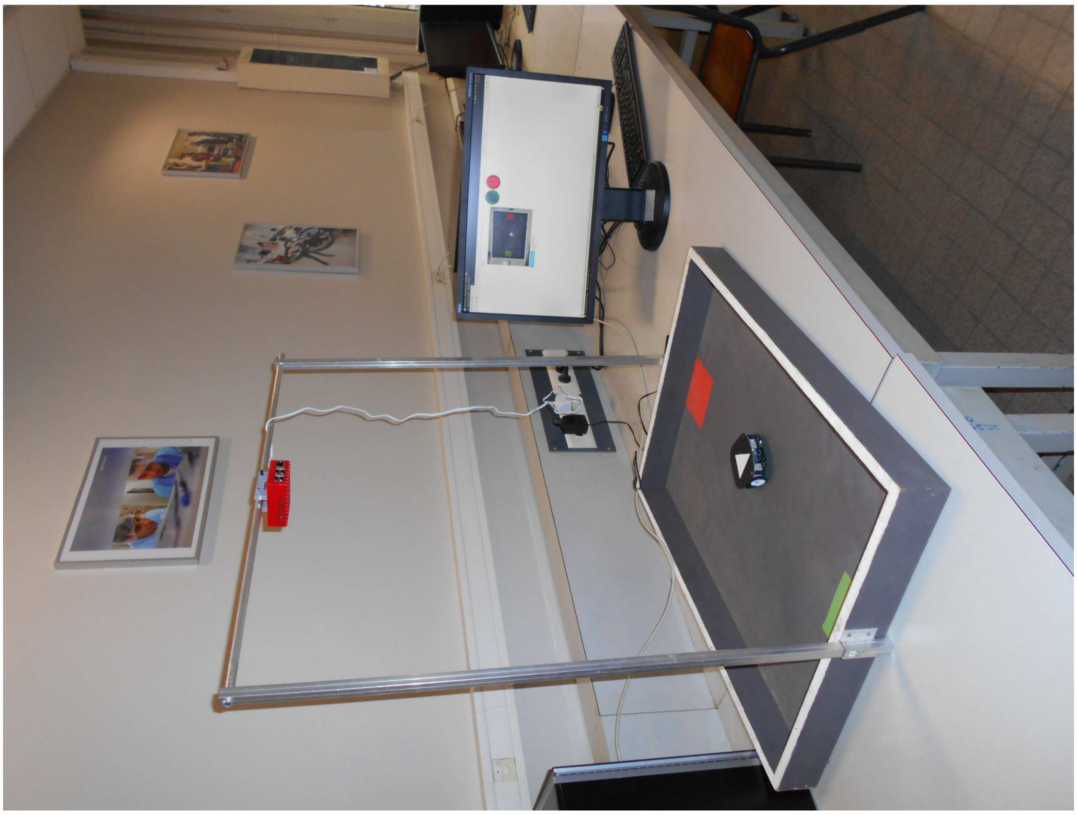
**Title**: Real Time Systems "Controlled Robot"
**Year(s)**: 4th year Automatic and Electronic (AE)
4th year Computer Science and Network (IR)
**Teacher(s)**: Pierre-Emmanuel Hladik
**Development:** Sébastien Di Mercurio, Lucien Senaneuch

**Description:**
As part of teaching on real-time, 4th year students of Automatic and Electronics and also Computer and Networks are led to develop the control application of a two-wheeled mobile robot.

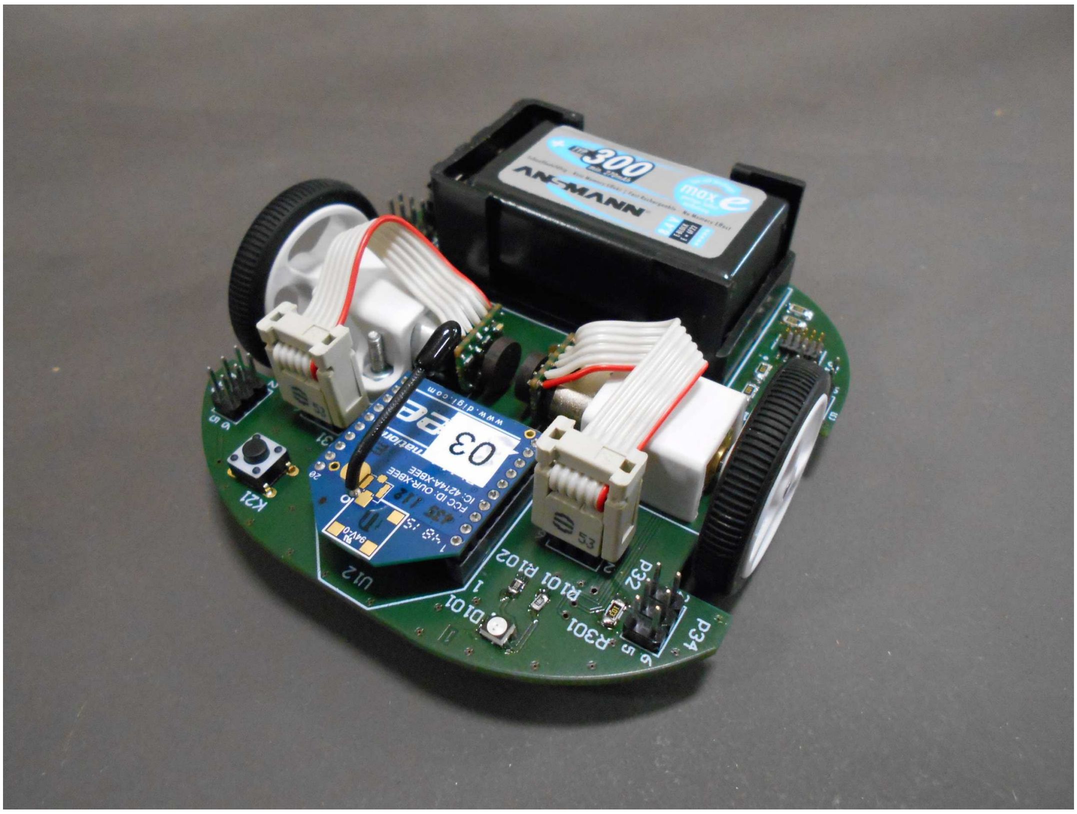
The educational model consists of a robot that evolves in an arena. It is equipped with an Xbee module to communicate with a Raspberry. The Raspberry is equipped with camera allowing to have a global view of the system in order to locate the robot in the arena.

The first version of the robot used an ATMEGA 8 but since 2015, a refurbished and miniaturized version based on STM32 has taken its place. This is accompanied by its charger also developed internally and based on STM32 to finely manage the battery charge.

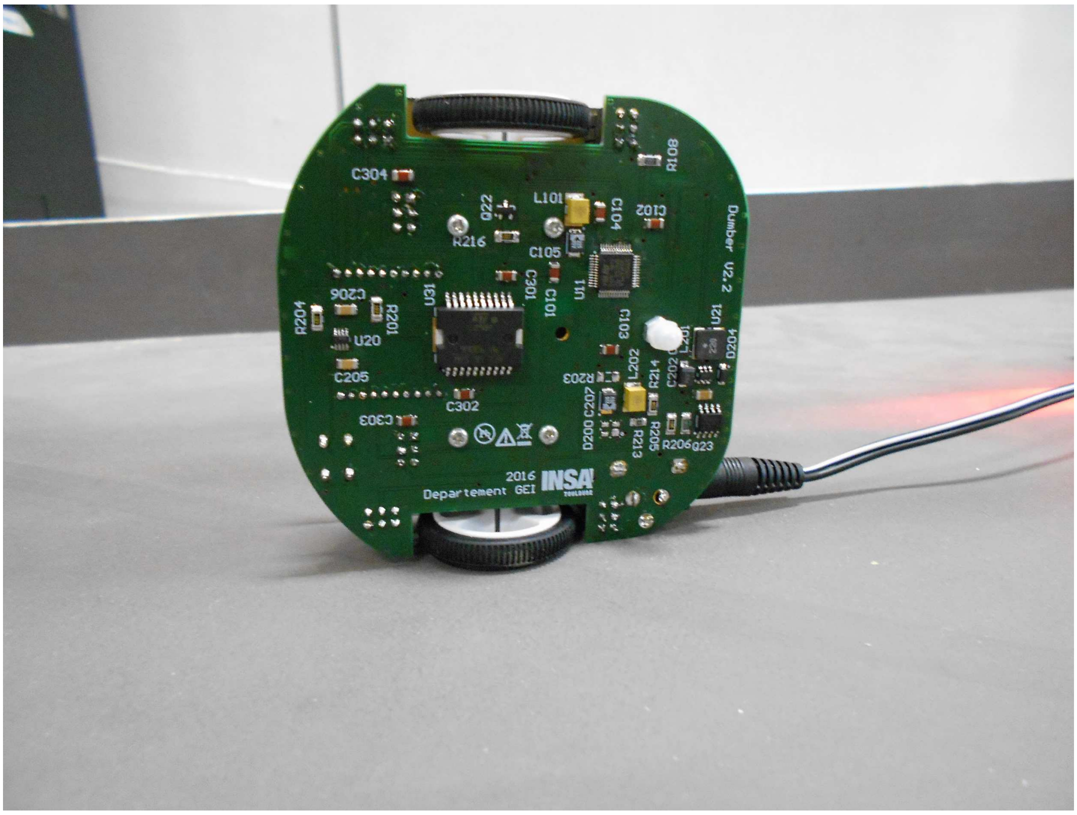
<u>Details of realization:</u>
- Raspberry Pi3 - Image Analysis, Network Communication, Real Time Xenomai.
- Mini Robot running under STM32F103RB
- Robot loader under STM32F103RB



**Picture 1:** Global view of the lab




**Picture 2:** Zoom on robot




**Picture 3:** Behind view of robot, showing and STM32F103C6T6 (upper right)

|  |  |
|---|---|
| **Title**: | Position control (SEGWAY) |
| **Year**: | 4th year Systems Engineering (IS) |
| **Teacher(s)**: | Claude Baron |
| **Development:** | Emmanuel Lombard, José Martin, Lucien Senaneuch |

**Description:**
Developed by INSA and studied as a mechanical system and electrical system, the segway is an important project of the 4th year Engineering System.

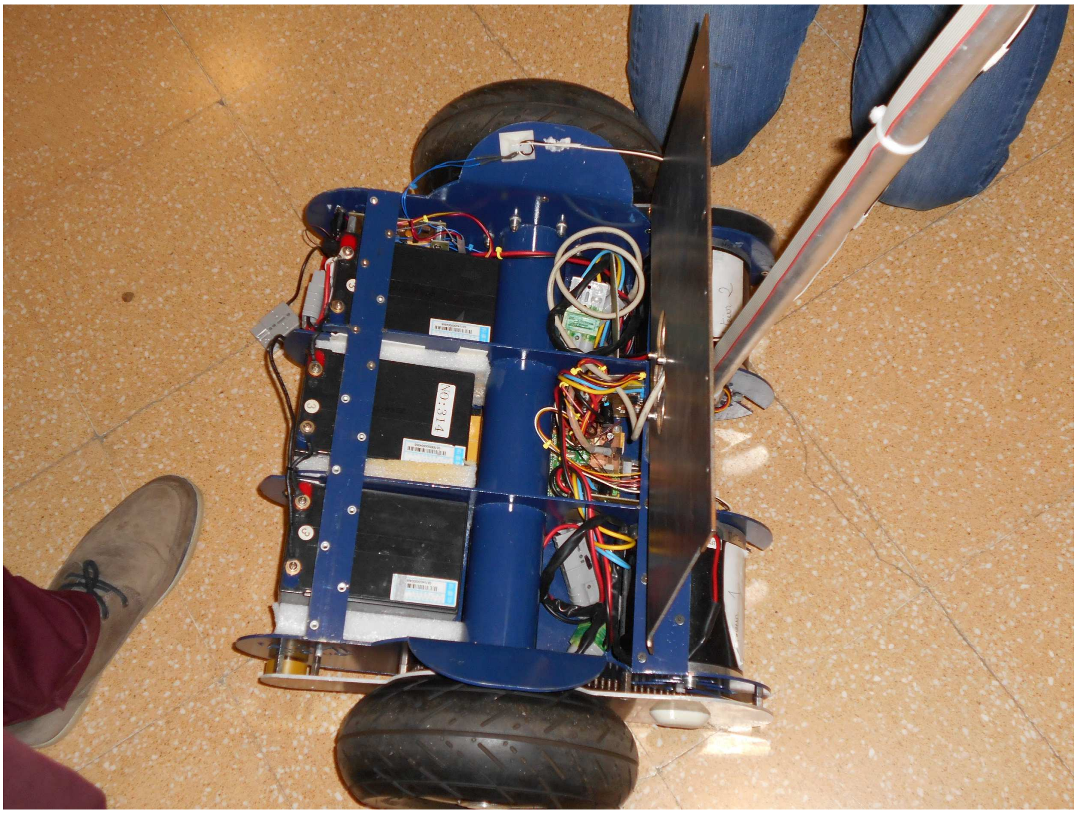
Electronically built around a STM32F303VC card with an integrated inertial unit, students developed portion of code both on STM32 (data fusion, motor servoing) and on Raspberry Pi (HMI, Real Time, ...).

A support for simulating Segway was also realized on the basis of a STM32F303VC. It serves as a test bench to the student code before transferring it to the real version.

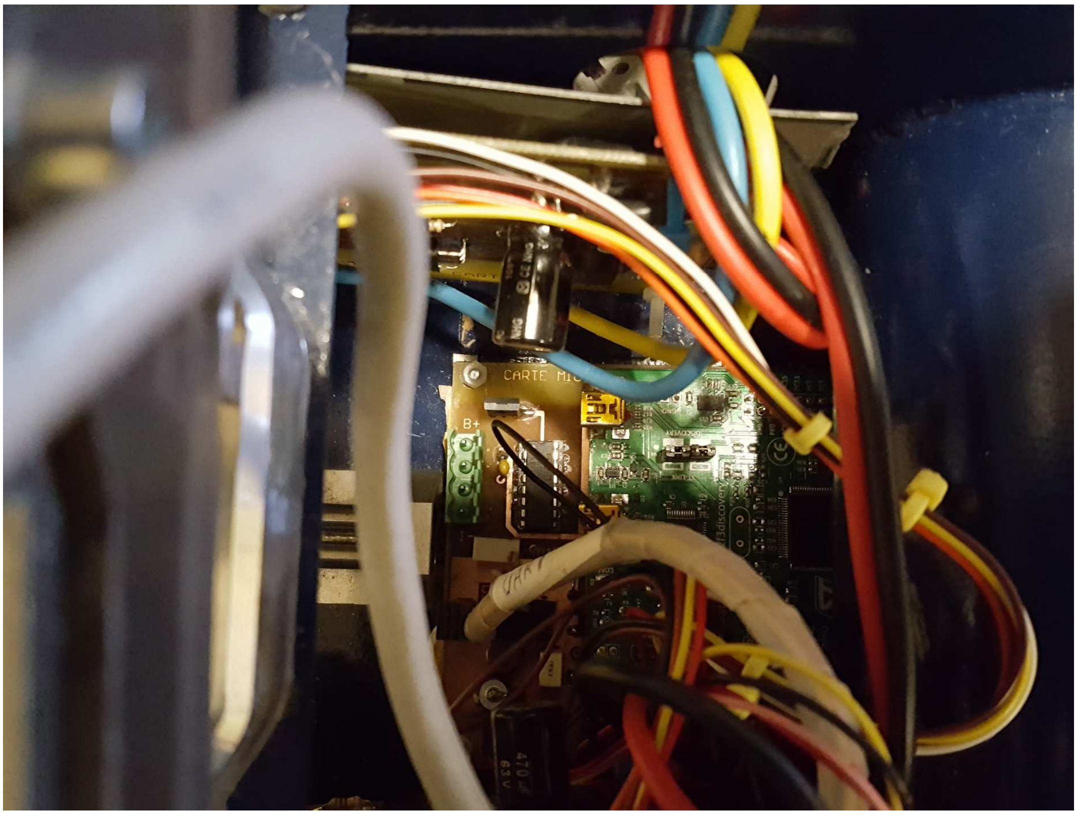
Details of realization :

- Raspberry Pi3 - HMI, Network Communication, Real Time Xenomai.
- Hardware control, data merge via STM32F303VC
- Segway simulator on STM32F303VC

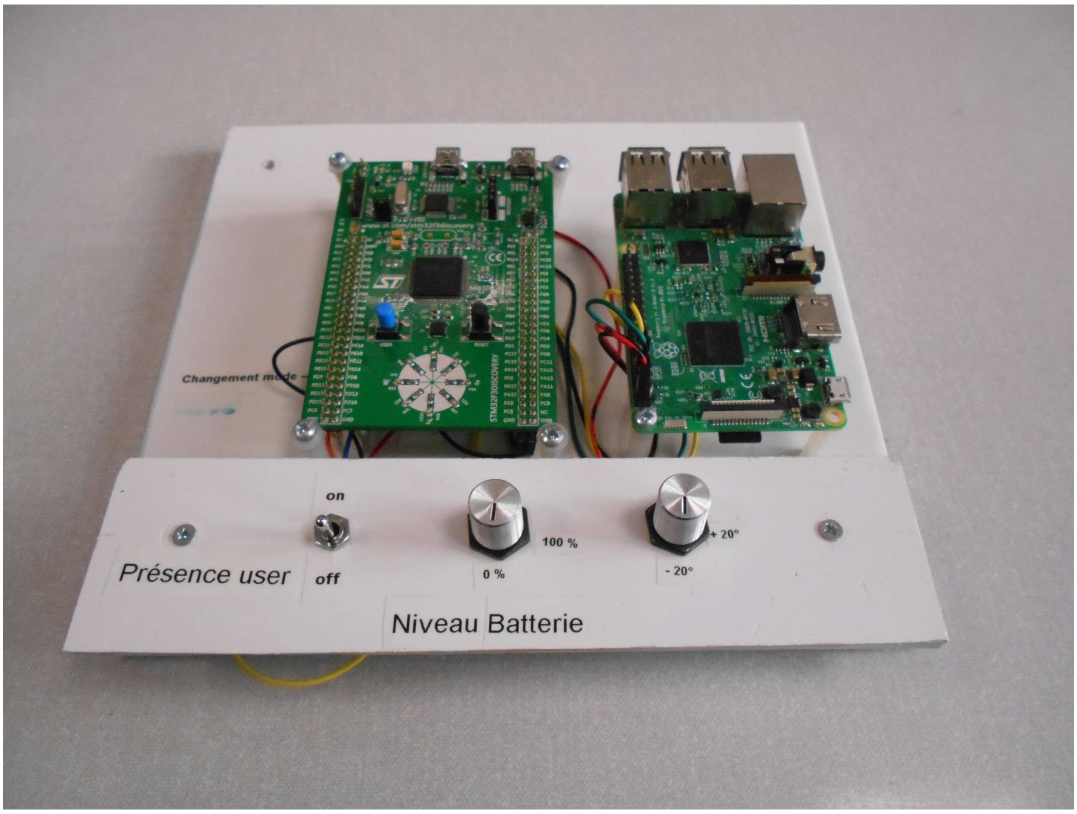
**Picture 1:** Segway, in action




**Picture 2:** Inside view of Segway




**Picture 3:** Zoom on the STM32F3DISCOVERY board.



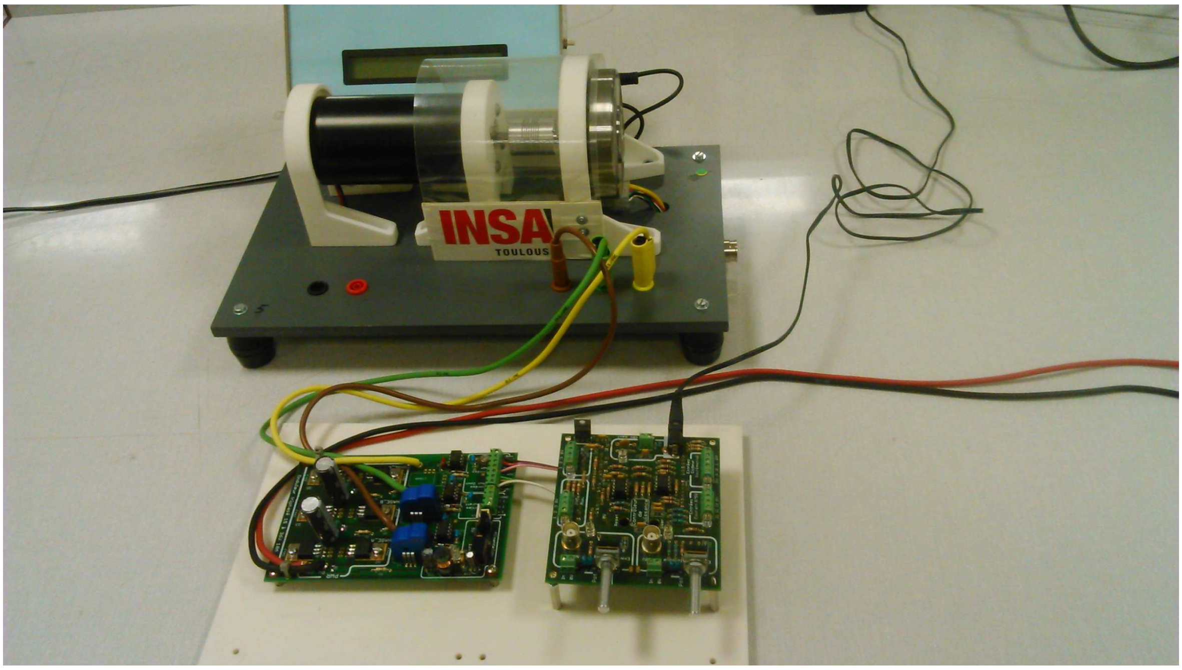
**Picture 4:** Segway simulator

**Title**: Brushless motor control
**Year(s)**: 4th year Automatic and Electronic, Embedded System
5th year Energy Conversion
**Teacher(s)**: Thierry Rocacher
**Development:** Sébastien DI Mercurio, Emmanuel Lombard, José Martin

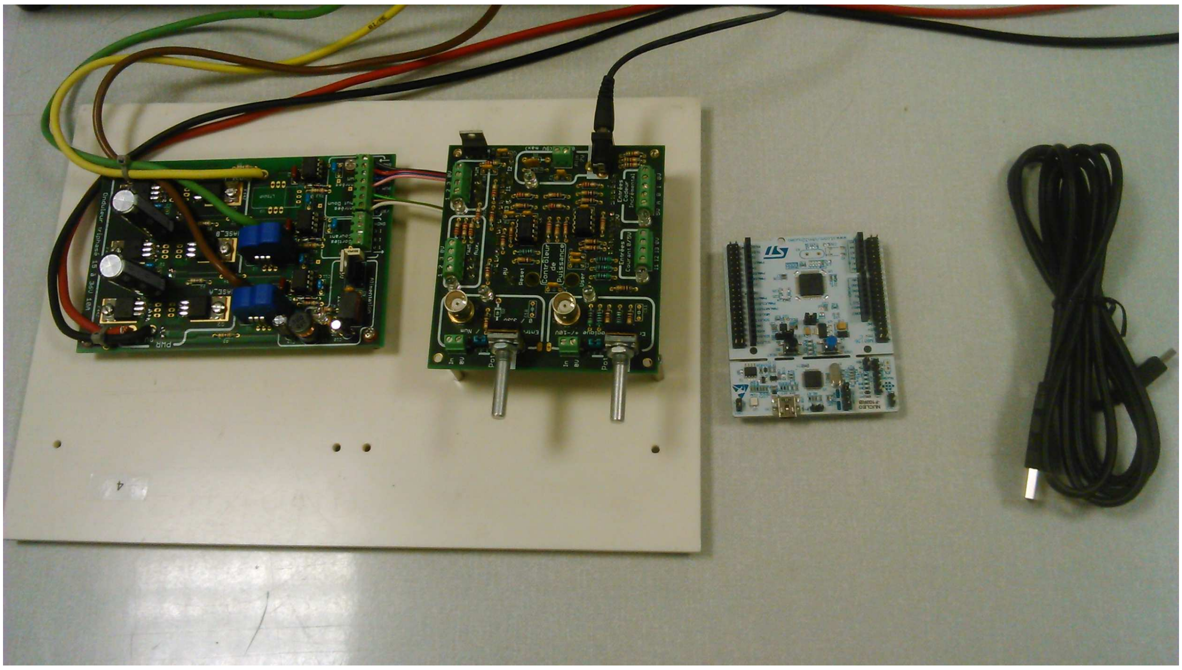
**Description :**
The lab consists in speed control of brushless motor. More precisely, it involves generating the three-phase PWM control signals in synchronization with Hall sensors. The controller uses a STM32F103RB mounted on a NUCLEO board. The latter takes place under an analog / digital interfacing card.

The set allows also other possibilities such as:

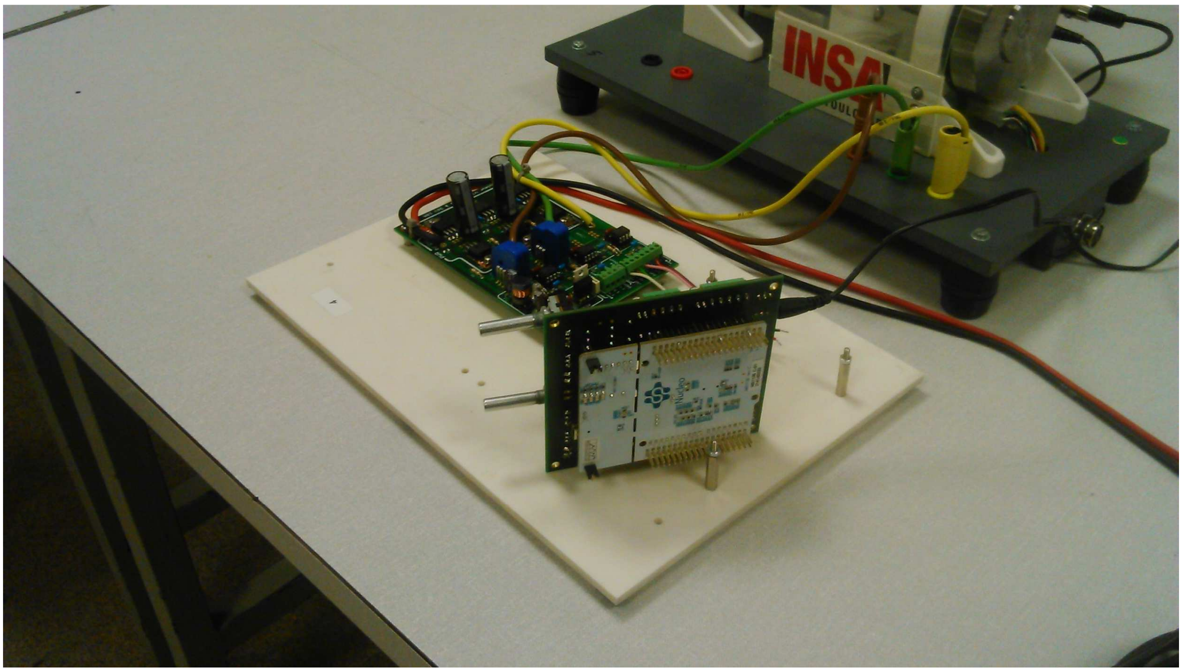
- MCC steering
- Single-phase inverter, three-phase
- …




**Picture 1** : Global view of controller and 3 phases bridge



**Picture 2** : Focus on controller, with Nucleo board removed




**Picture 3** : Controller view, with Nucleo board mounted

**Title**: Labs “MCU Peripherals” (Boat)
**Year**: 4th year Automatic and Electronic, Embedded System
**Teacher(s)**: Thierry Rocacher
**Development:** José Martin

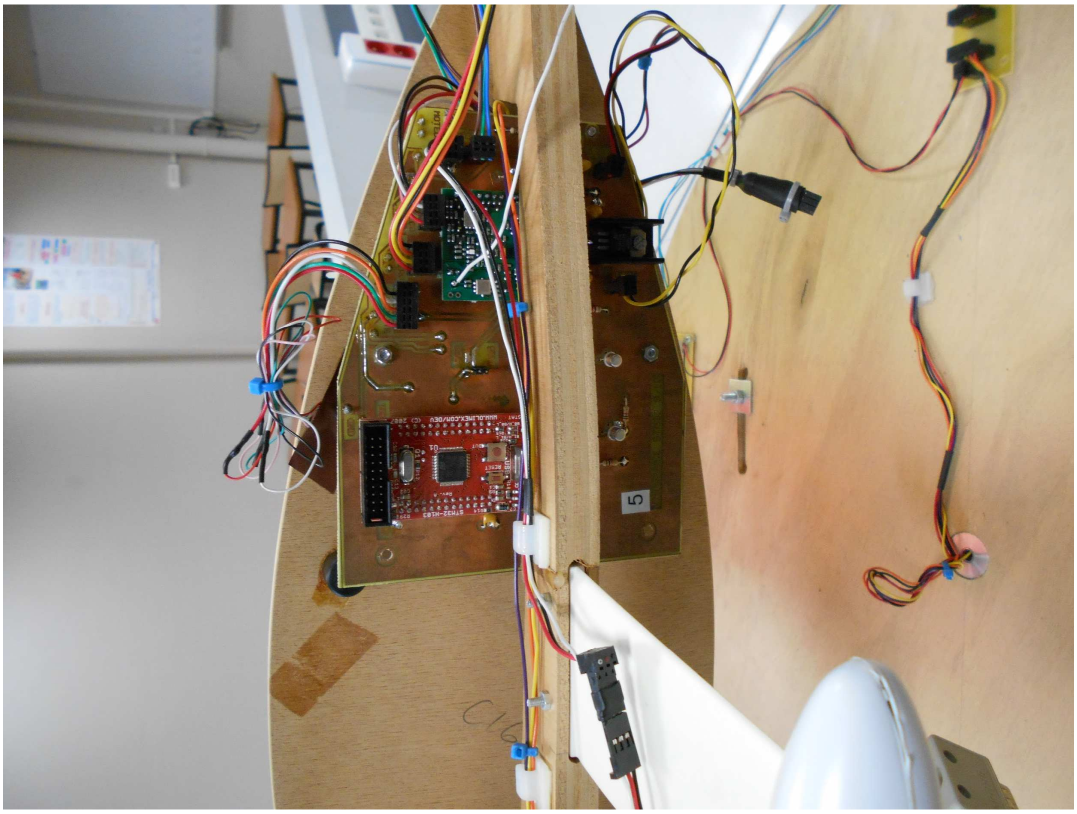
**Description:**
During 4th year, in order to learn classic peripherals of a microcontroller and UML design, students work on a sailboat model.

The model consists of a sailboat that can pivot on its axis of heel, which can be oriented to the wind (rotating base), whose sails are controllable (servo motor), with an accelerometer to calculate the heeling angle and a radio transmitter. In addition, you can connect a model radio receiver to remotely control the boat.

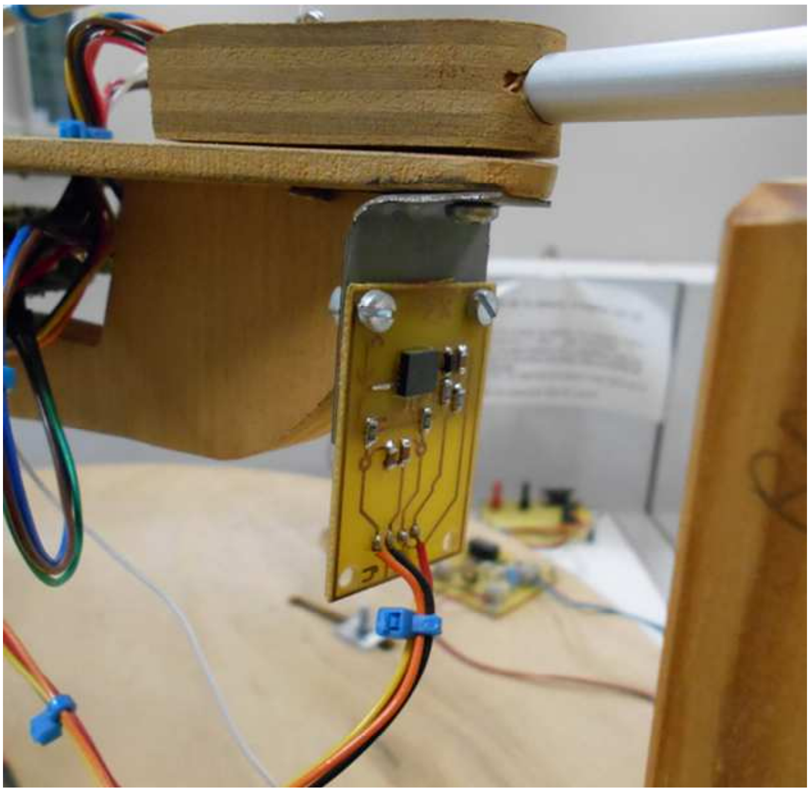
This forces students to understand and master programming of devices such as timers, ADCs, serial link, ...

As students work in groups of 4, sharing the work, they will also have to correctly specify the needs of each part of program and their interfaces in order to succeed during integration phase.

**Picture 1:** The ship model



**Picture 2:** Zoom on controller board (STM32F103RB)



**Picture 3:** Zoom on accelerometer for measuring heel

**Title**: Coupled Multivariable System (Helicopter)
**Year**: 4th year Automatic and Electronic (AE)

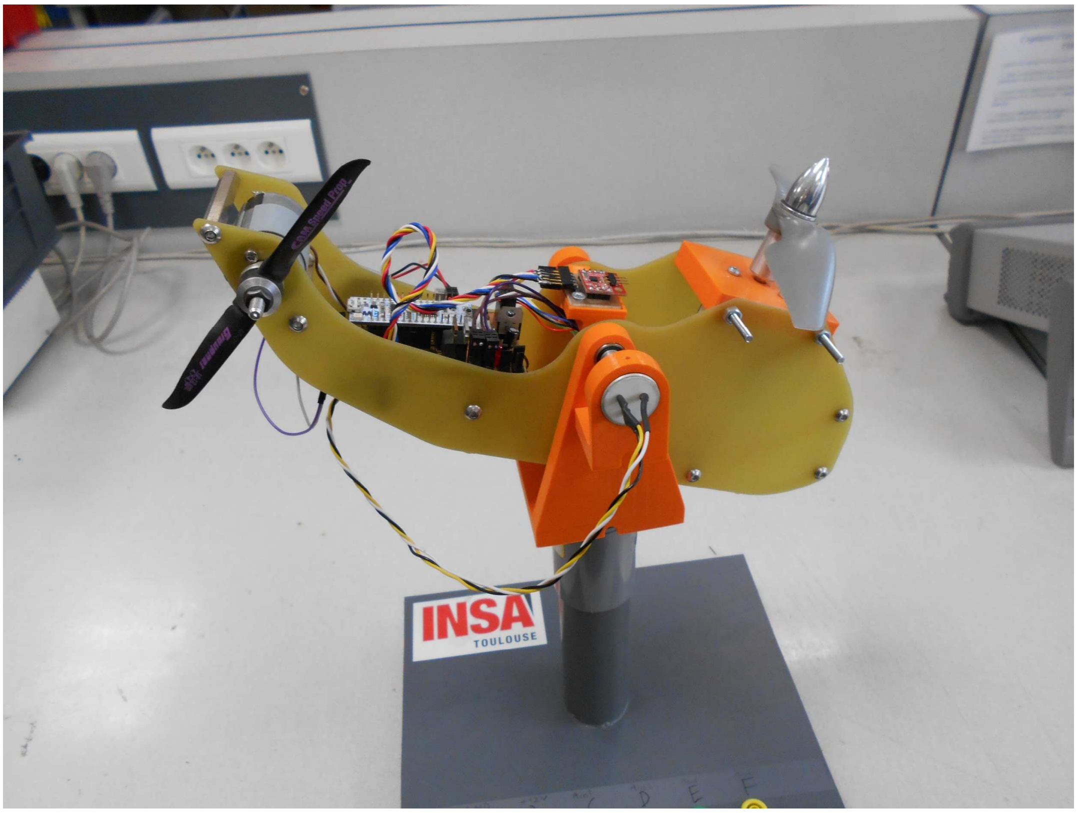
**Teacher(s)**: Élodie Chanthery, Gwendoline Lecorre,
**Development:** Sébastien Di Mercurio, José Martin

**Description:**
In automatic, to illustrate coupled multivariable systems, an helicopter has been developed inside the department. Composed of two propellers (a rotor and a tail rotor), the helicopter can evolve along two axes: yaw (rotation around the pole) and pitch (rotation around the pivot between the two propellers).

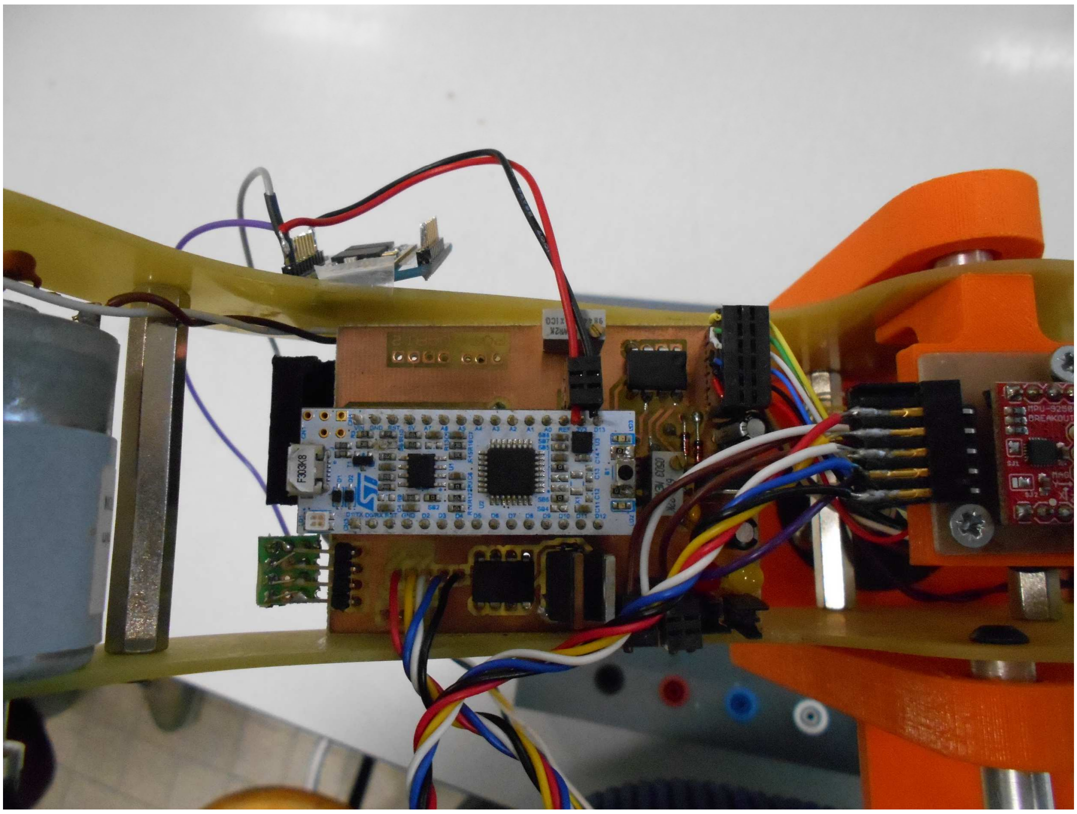
The objective of the student is, by a controller law, to maintain the machine according to a given angle and cape.

The device is made entirely of PVC, 3D printing and digital cutting.

The STM32 microcontroller is used to acquire analog command signals from both motors, convert them to PWM to drive motors and return analog values corresponding to the two axes. In addition, a bluetooth module transmits useful data during system identification phase.




**Picture 1:** Helicopter used in coupled systems labs



**Picture 2:** Focus on controller board, a Nucleo-32 F300

**Title**: Autonomous Rolling System
**Year**: 5th year Critical Embedded Computing Systems (SIEC)
**Teacher(s)**: Pascal Acco, Elodie Chanthery, Pierre-Emmanuel Hladik
**Développement:** Emmanuel Lombard, José Martin, Lucien Senaneuch

**Description:**
As part of the 5th year Critical Embedded Computer Systems, students work in groups on an autonomous rolling system. Each group develops new functionalities of vision systems, diagnostics, communication, etc... ensuring its safety.

The system currently used is an electric car. The model was based on a child transport car. The low-level control computer system used a STM32F103 coupled to all actuators and sensors in the system. The software libraries were produced by the students.

Some projet examples :

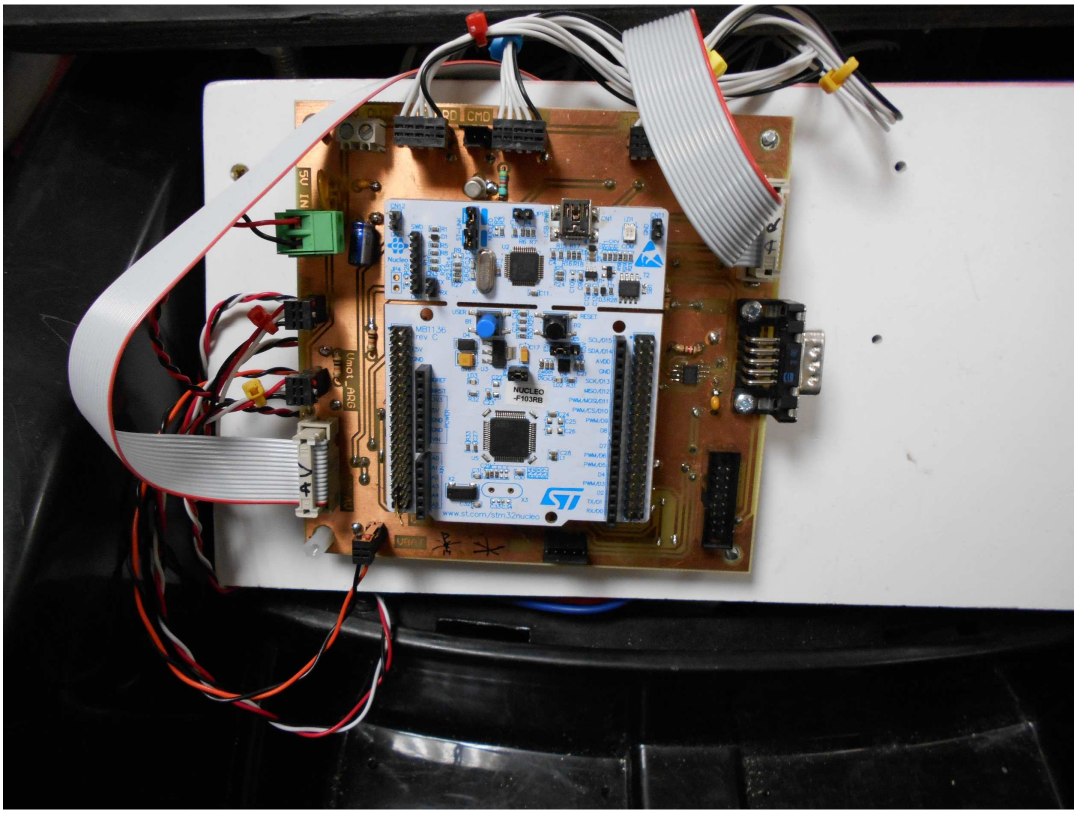
- Autonomous parking system
- Collision detection
- Independent movement

Realization :

- Instrumentation of a child's electric car
- Architecture NUCLEO F103 - Raspberry Pi3
- CAN communication bus
- Servo control and recovery of sensors by STM32
- HMI, Image processing, Wifi, Bluetooth via Raspberry Pi3

**Picture 1:** Global view of the car


**Picture 2:** Nucleo F103 board integration



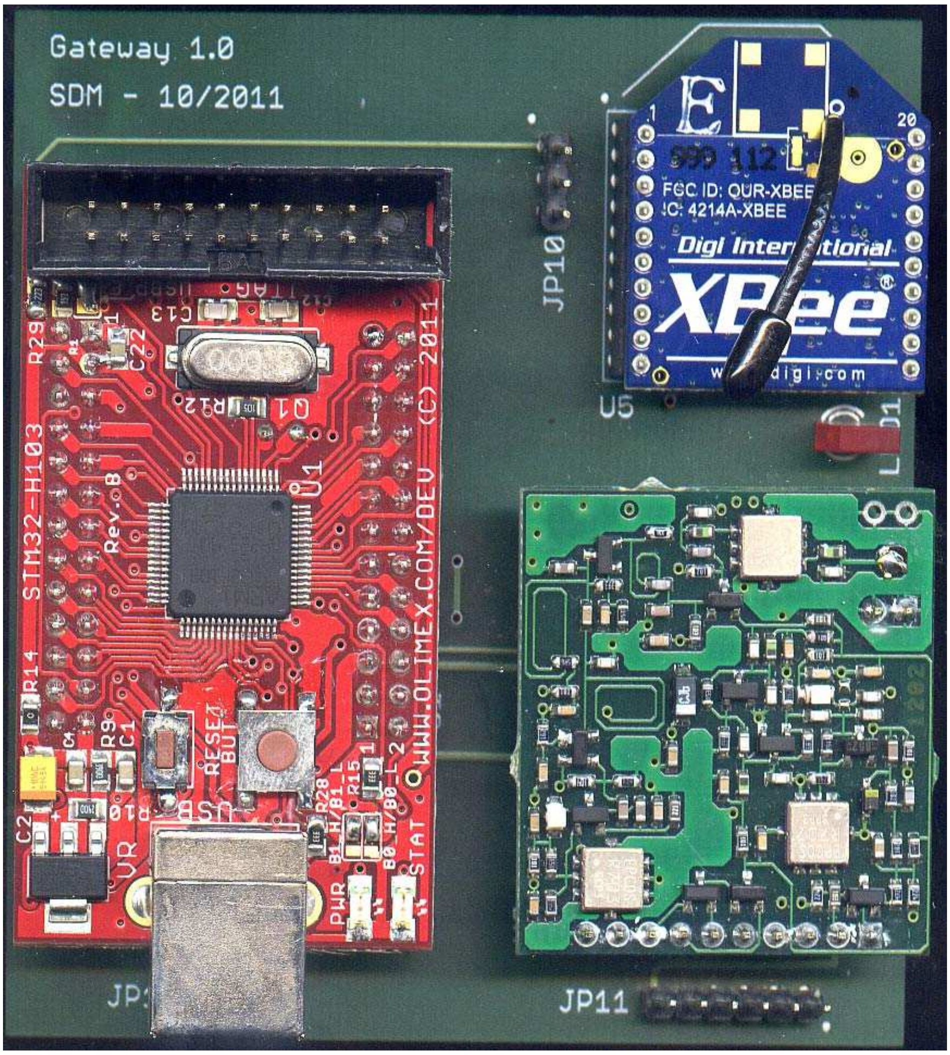
**Picture 3:** Zoom on Nucleo F103 board

**Title**: Communicating Systems Labs (BESC)
**Year**: 5th year Electronics and Embedded Systems (ESE)
**Teacher(s)**: Jean-Louis Noullet (noullet@insa-toulouse.fr)
**Développement:** Jean-Louis Noullet

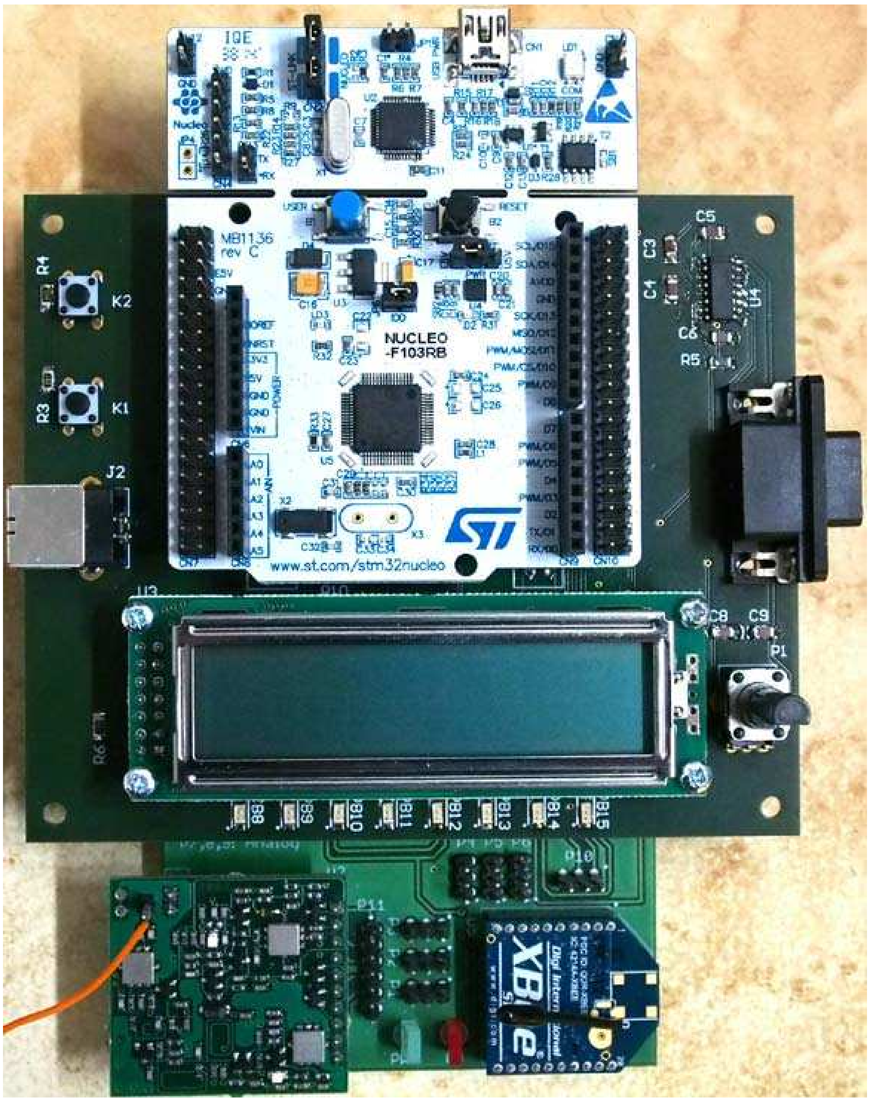
**Description:**
The purpose of this design office is to put the students in a situation of designers on a problem of communicating sensors (IoT).
This BE comes in addition to the BE "Electronic Sensors" which deals with the physical and analog aspects of the sensors, thus in this BE the essential development of the door on the embedded software.

The students have at their disposal a collection of modules equipped with various means of radio communication. At the heart of each of these modules is a STM32 microcontroller.

A first generation of modules that comprise :
- A minimal module including a STM32F103RB, an X-Bee transceiver and a 433 MHz FSK transceiver (picture 1)
- A heavy module including an LCD display and an RS232 interface for external modem (picture 2)

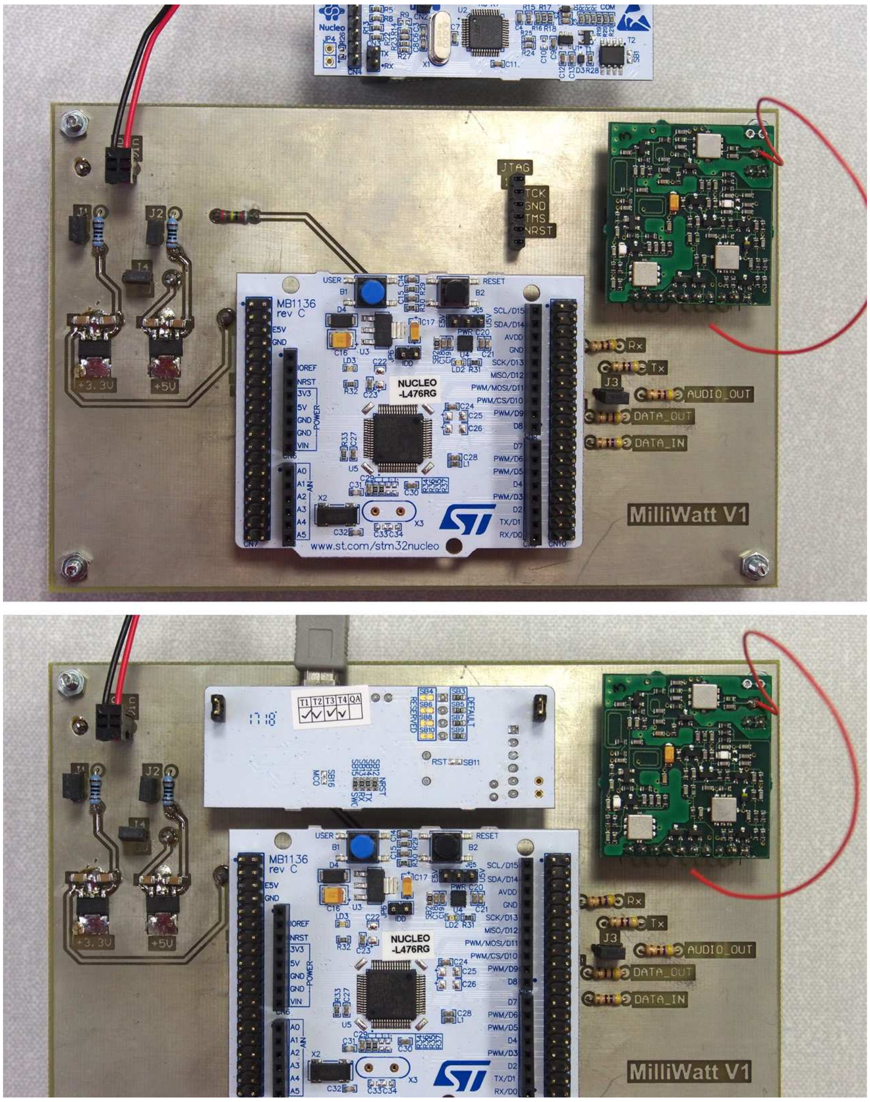


**Picture 1**: XBee transceiver and 433MHz FSK transceiver




**Picture 2:** LCD display and RS232 interface

In 2015 was introduced the "milliwatt" module which hosts a Nucleo STM32L476RG card (picture 3).




**Picture 3:** Milliwatt board, with and without debugger part

Its particularities are the following :

- 433MHz FSK transceiver
- power supply device to facilitate fine consumption measurement, separately for the microcontroller and the radio, with special regulators (the Nucleo regulators are not used)
- use of a Nucleo cut, with connections for the ST-Link part which becomes removable

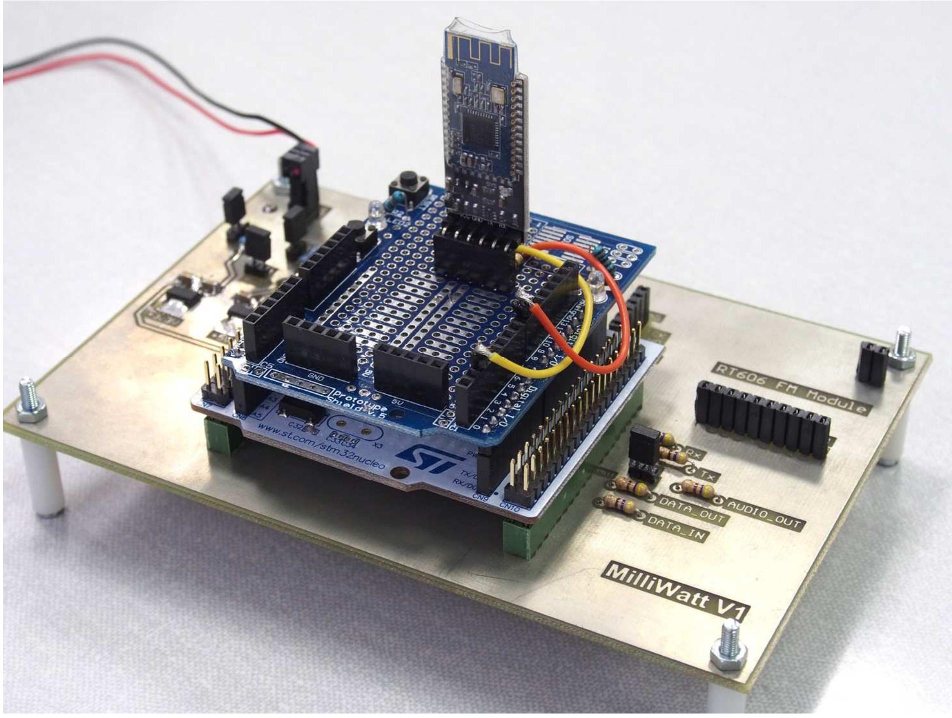
From that moment, labs priority became energy saving, with a specific programming style :

- no queuing, all devices in interrupt mode
- sleep (sleep) of the CPU with periodic wake-up by the system timer (typical duration 10ms)
- put in standby (complete stop of the microcontroller) (typical duration 10s) and alarm clock by RTC

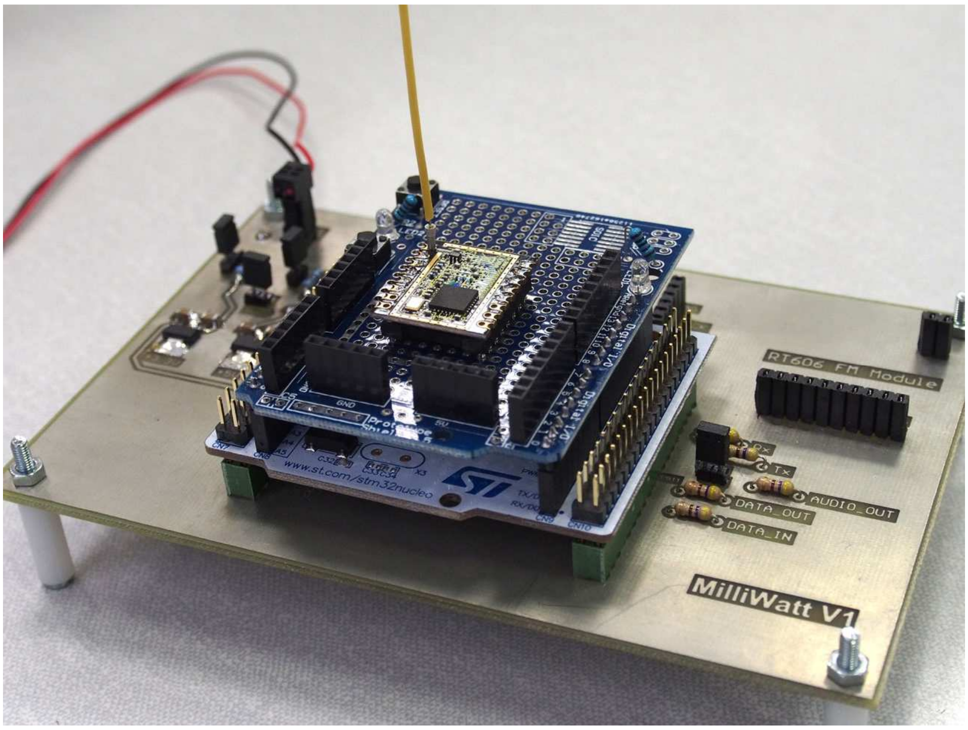
In 2016 were introduced two new radio means:

- Bluetooth BLE (Low Energy) transceiver based on TI chip CC2541 (photo 4)
- LoRa transceiver based on the Semtech SX1272 chip (picture 5)

The SX1272 chip is compatible with the LoRaWAN library distributed by ST.



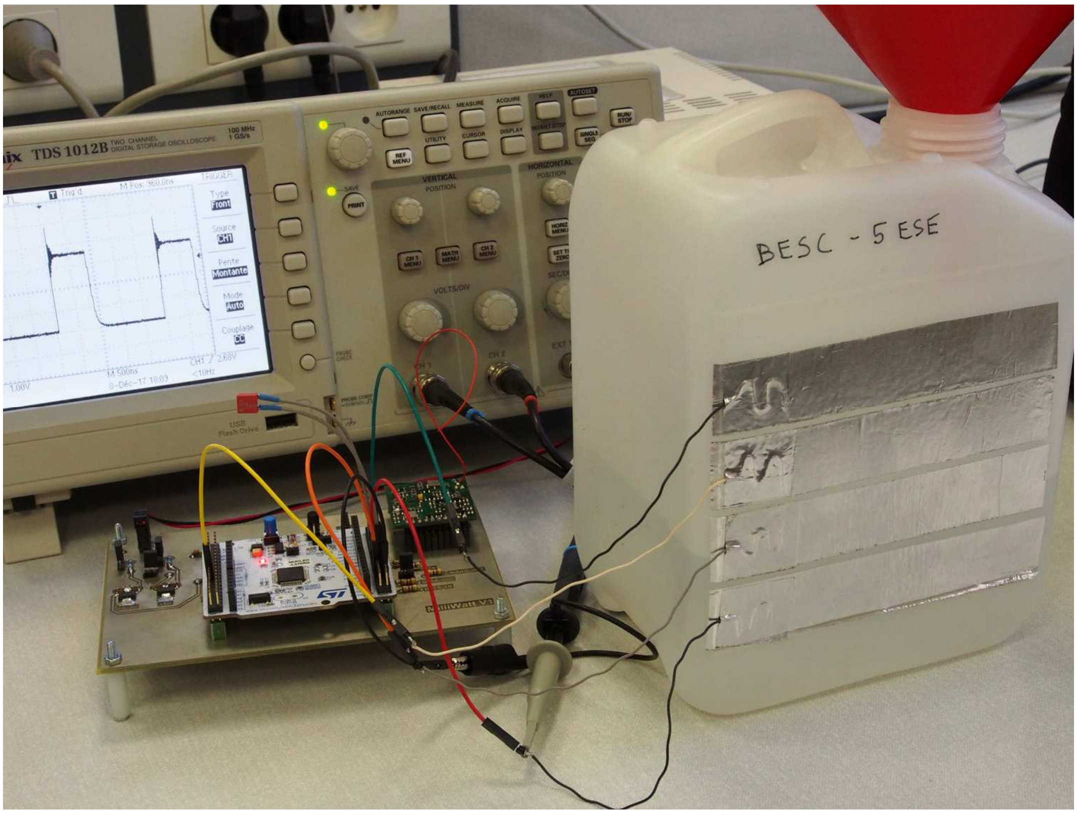

**Picture 4:** Bluetooth module




**Picture 5:** LoRa module

In 2017 was introduced STM32L476 Touch Sensor (TSC) device in an industrial sensor context (other than touch-panel).

This application is illustrated using a scale model of an aqueous liquid storage tank whose level is measured without contact by externally bonded electrodes (Picture 6).




**Picture 6:** TSC module and the “tank”

In 2018 will be put into operation a specific measuring equipment, the coulombmeter, under development. This instrument will be used for fine measurements of consumption over a range of 0.1uA to 100mA. It will include a logarithmic amplifier and a STM32 which will integrate and transmit the results via USB.

**Title**: Project "Smart Classroom Door"
**Year**: N/A
**Teacher(s)**: Jean-Louis Noullet (noullet@insa-toulouse.fr)
**Development:** Jean-Louis Noullet

**Description:**
The goal is to display the occupancy schedule of each room next the door.
This is currently done by means of printed sheets, renewed once a week by the secretariat staff.

Many institutions use a more modern "airport" style process, based on a large LCD screen for each corridor, driven by a PC communicating with the database.

The solution proposed here is more distributed and more interactive: a small LCD screen next to each door, by default displaying the schedule of the room on the current half-day, but giving users the ability to navigate in planning of the room over several days, and to have access to many other information updated in real time.

This navigation is done using a touch screen, responding in the manner of a smartphone screen.

Realization :

- microcontroller-based solution
- low voltage power supply by telephone type cable
- transmission of data on the supply leads, from a single computer connected to the INSA schedule database.
- platform STM32F746G-DISCO

Additional motivations:
This realization would be a showcase showing to a large population the interest of the control of microcontrollers as taught in the Department.

In addition the entire system would be powered by solar panels already installed on the roof of the building, and the modules would give access to statistics of production and energy consumption of the facility.

**Photo 1:** L'agenda électronique des salles sur une carte Discovery-F7