Design of a low cost LIDAR scanning system for didactical applications

L. Olcomendy, F. Santos-Cessac, Ph. Dondon

Abstract— with the permanent arrival of new technologies, electronic teaching consists nowadays of numerous updated fields and topics. However, connections and footpaths between them must be done by students. In that way, transdisciplinary projects were started in our electronic institute while respecting severe budget constraints. As example, we present here the complete design of a low cost scanning system for didactical applications. The design includes a LIDAR sensor, motor control system, a processing board with embedded open source software for processing data and generating a formatted VRML file able to be displayed with a 3D viewer, for a 3 dimensions visualization of the scanned environment. General context is highlighted. Global design and results are detailed. Lastly, pro and con's as well didactical and financial aspects are discussed within the context of global economic difficulties and budget reduction for education.

Keywords— LIDAR sensor, Arduino, VRML description language, didactical tool, student's project.

I. INTRODUCTION

A. General context

ENSEIRB MATMECA is a high engineering school with several departments of which the electronic ones. In second year of study, we propose to the students a "learning by project approach". This represents around 40 projects per year with 80 students by pair, covering a wide range of electronic topics. Unfortunately, most of these transdisciplinary projects consist in the design of electronic systems which require buying expensive electronic components, printed boards and other extra components. Various CAD tools are used for the design and heavy test equipment are also needed. Thus, the global budget for projects is one of the most important supported by the electronic department. Within a context of global reduction of educational budget, one of the most important and difficult challenges in our didactical strategy is to reduce the design's cost while ensuring a high technical level and skills.

This paper presents an original study and project to illustrate this design challenge, applied to 3D environment detection with a low cost Lidar sensor.

B. State of art

L.Olcomendy, F Santos Cessac, Ph. Dondon are with Bordeaux INP Aquitaine, ENSEIRB-MATMECA, Av Dr A. Schweitzer 33405 Talence, France. (e-mail: Philippe.Dondon@enseirb-matmeca.fr).

LIDAR (laser detection and ranging) is widely used in many applications:
pollution analysis[1], [2], archelogy [3], [4], robot motion control and obstacle detection [5], [6], [7], forest observation and monitoring [8] architecture for 3D modelling and renovation of old monuments, visual effects for movies[9], by Google for street cartography, and so on.

Such commercial and professional equipment are very expensive (several 10.000 $) and not easily usable for didactical purposes. Some companies (Osram Opto Semiconductors, Velodyne…) are currently working for vehicle applications and LIDAR mass production to reduce the manufacturing costs. But these equipment's still remain not compatible with student training needs.
So, we chose for our design and educational experimentation, a low cost module [10] with open source hardware and software [11], [12].

Thus, after the technical design detailed description, we discuss various aspects of our work in § .IV.

II. SCANNING SYSTEM DESIGN

A. General electronic design
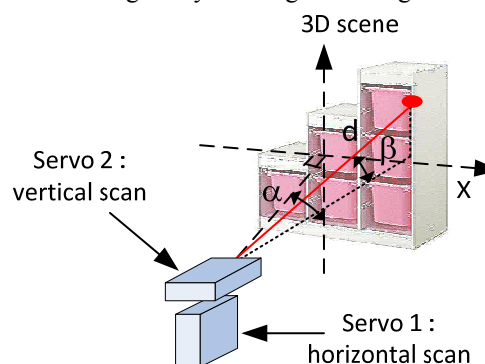Principle of the designed system is given in Figure 1.

Fig. 1: Scanning principle

Environment is scanned point by point, while α azimuth and β elevation angles are given by servo motor's position. LIDAR returns the distance d between the sensor and the scanned target. The maximum number of points is set up in the program as well as angle's range and angle's step.

From electronic point of view, the designed system consists of a LIDAR sensor (LIDAR-Lite v2) with its integrated processor chip [1], two servo motors assembled on a rotating turret for horizontal and vertical scanning, an Arduino mega 2560 processor board [13] for controlling servomotors, data acquisition and processing, two separate power supplies for servo motors and Lidar sensor, and lastly an Ethernet connexion with a host computer as indicated in figure 2.
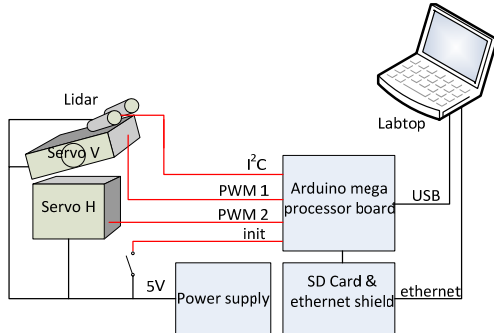

Fig. 2: Simplified block diagram
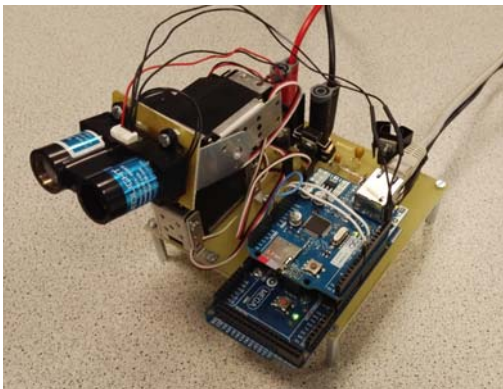
Figure 3 shows the practical design which was done.

Fig. 3: View of the scanning system.

Hobbyist servo motors are controlled by a PWM classical signal (frequency 50 Hz, pulse width 1 to 2ms). Angle of rotation between 0 to 180° is proportional to the pulse width value.
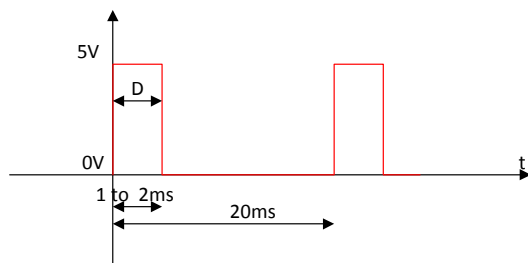

Fig. 4: Standard control signal for servo motors

B.   Software design and processing algorithm

Acquisition system is based on open source Arduino kit: Mega 2560 board with and Ethernet/SD card shield.

A "C language" program (around 1000 lines of codes) has been implemented in the Arduino controller. It works as follow:

A client/server relation is defined between host and Arduino shield.
User interface is shown in figure 5. From this user interface, the user can request a Lidar scan (left button). When acquisition is completed, the users send another request to transfer the resulting file on the PC computer from right button.
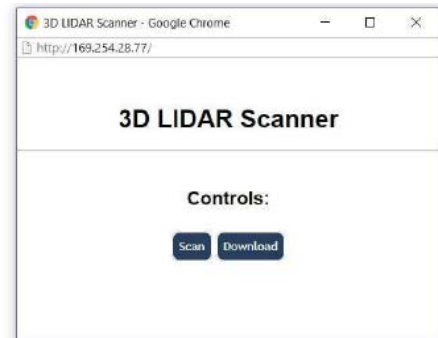

Fig 5: User interface.

When a scanning is initiated by users, the physical scanning process is started. To avoid time losses, the scan is done continuously from right to left on odd lines and left to right for even lines as shown in figure 6.
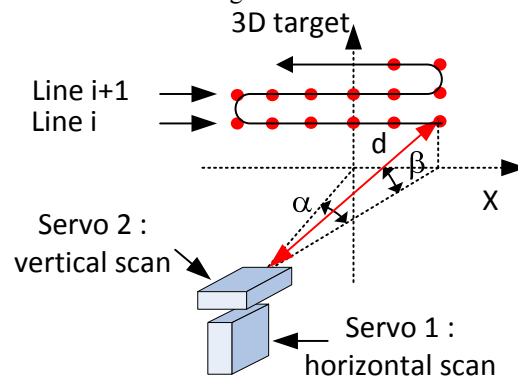

Fig 6: Scanning process.

And the acquisition process is divided in several phases as indicated in figure 7.
After Lidar and SD card initialisation, the scan starts. Azimuth and elevation angles α, β are returned, as well as measured distance d through the I^{2}C Lidar interface for each scanned point. These spherical data values are converted in cartesian coordinates X, Y, Z. If a point localisation seems to be wrong (distance too much different with the value given at the next point, a spatial smoothing filter is applied on the 5 neighbour points. Then, coordinates are written in a text file on SD card.
When the scan is ended, a VRML header is added in the file, triangular faces are computed to mesh the points and an auto adaptive colour palette is built to assign colour to each faces in order to make the final visualization more realistic.
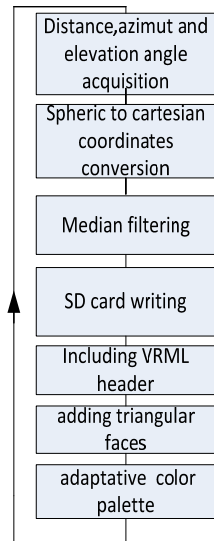
Fig.7: Main structure

Some more precisions on VRML are given in the next paragraph.

III. VRML SHORT DESCRIPTION

"Virtual Reality Modelling Language"(VRML) was coined in 1995. Initially, it was emerging as a need of people who wanted to make three dimensions drawings and virtual animation for didactical and/or scientific purposes [14], [15]. VRML can be considered like one of the "fathers" of the most popular and modern 3D design software's tools.
Virtual VRML images can be displayed with "cosmoplayer" plug-in or "orbisnap" viewer.

A. VRML basic's

For an efficient use of VRML, it is important to understand the basic when drawing an object. An object can be defined in several ways. We can use standard shapes such as boxes, cylinder, cone, or we can define the object point per point (i.e. vertex per vertex). In this second solution, connexion lines between vertexes must be added and faces must be created (mesh) and finally coloured. Thus, such 3D representation of the object makes it easily understandable for a human eye.
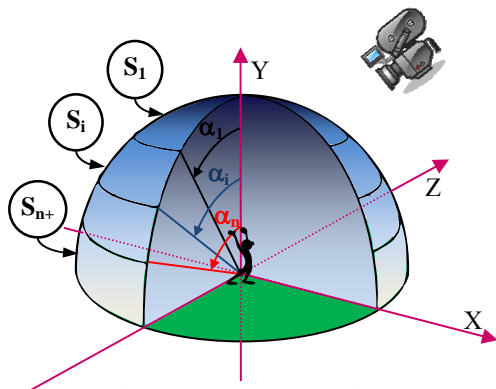

Fig. 8: Background and viewpoint definition

In order to complete the 3D representation, a background, which can be seen as a 3D sky dome above the object, must be often drawn as indicated in figure 8. An ambient light or directional light can be included to add light effects. At last, one or several viewpoints (like cameras) can be added to observe the scene.

B. VRML 3D file data processing details

Here, from the scan acquisition process, we get a list of several hundred points 3D coordinates X, Y, Z. All points are automatically included by our software, listed and indexed inside the "point" keyword (see figure 9)

```
#VRML V2.0 utf8
#Projet LIDAR : Fabien SANTOS-CESSAC Loïc OLÇOMENDY
NavigationInfo {type "EXAMINE"}
Viewpoint {
position   0 0 0
description "Position 1"
fieldOfView 0.55
orientation 0 0 1 0
}
Shape {
geometry IndexedFaceSet {
solid FALSE
coord Coordinate {
point [   -2.19 -1.06 6.01, -2.10 -1.07 6.10, -2.01 -1.09 6.18, -1.92 -1.11
     6.27, -1.80 -1.10 6.26, -1.62 -1.07 6.05, -1.53 -1.08 6.14, -1.42 -1.08
……………………..]
```

X Y Z,

Fig. 9: Extracted from VRML initial file

So, that each point is known by its index number.

In order to define a surface S_i in VRML, we need to create the list of point index, encompassing the given surface and to add -1 terminator at the end of the list, to indicate a closed surface with keyword " coordIndex". In the example of figure 10, the closed triangular surface S_i will be defined as follow:
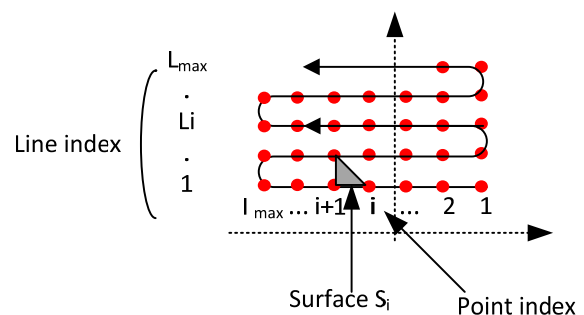coordIndex [i i+1 i_{max}+(i_{max}-i) -1]

Fig. 10: Surface definition

According to this process, all the surfaces S_i are generated automatically and added to the VRML file in a coordIndex [S_1, …. S_i ….] block.
Here, we chose to create triangular surfaces instead of square surfaces for a better visualization.

surface

```
...........................
coordIndex [
1 81 80 -1, 0 1 81 -1, 2 80 79 -1, 1 2 80 -1, 3 79 78 -1, 2 3 79 -1, 4 78 77 -1, 3
4 78 -1, 5 77 76 -1, 4 5 77 -1, 6 76 75 -1, 5 6 76 -1, 7 75 74 -1, 6 7 75 -1, 8 74
73 -1, 7 8 74 -1, 9
.................]
```
Fig 10: triangular surface generation

An example of results after surface generation and meshing is given in Figure 11.
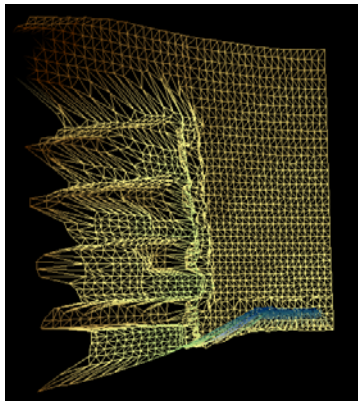
Fig.11: meshing

Then, the most distant surface and the closest surfaces of the scanned scene are identified.

As predefined color's palette (for example yellow brown scale, in figure 11), is automatically adapted in order to assign the darker color to the far-off surface and lighter color to the closer surface. So, the optimum range of color is used to colorize the image.

Fig 11: Yellow brown scale

Color palette is defined as a list of shaded color defined by a mix of the three primary colors: red, green, blue (R, G, B). The percentage of each primary color is given by a number comprised between 0 and 1. The palette is included in the VRML file using the VRML keyword, "color block" as written in figure 12.

R G B triplet, color number 3

```
color Color {
color[
0.00 0.20 0.40,0.08 0.29 0.40,0.17 0.39 0.41,0.25 0.39 0.41,0.34 0.58
0.42,0.42 0.67 0.42,0.51 0.61 0.81,0.61 0.81 0.45,0.71 0.84 0.47,0.8 0.88
0.5,0.9 0.92 0.53,1 0.96 0.55,0.91 0.85 0.47,0.81 0.73 0.39,0.72 0.62
0.31,0.63 0.5 0.24,0.53 0.39 0.16,0.44 0.28 0.08,0.35 0.16 0.00,0.00 0.00
0.00]
}
...............
```
Fig 12 : Example of color palette definition

At least, the color of each face is computed and defined in "colorIndex" block (see figure 13) by an index seeking on the

colour which must be chosen in the color palette. Here, in the example color number 3.

Index of used color for surface S_i

```
...............
color Color {

colorIndex [     i
0 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 3 3 0 0 0 1 0 0 3 3 0 0 0 1 0 0 1 1 0 0 0 1 0 0 1
1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 1 1 0 0 0 1 0 0 1 1 0
0 0 1 0 0 1 1 0 0 0....
...............
```
Fig 13: Color palette and color assignment to surfaces.

After this operation, we obtain from figure 11, the colorized image with filled surfaces given in figure 14.
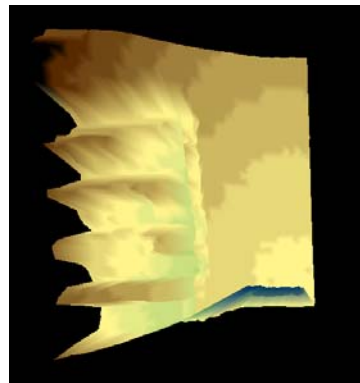
Fig 14: Colorization

Thus, color's gradient represents the depth of the scanned scene.

IV. PRACTICAL EXPERIMENTS

Lidar sensor was first tested alone to check calibration and detection ability. Table 1 shows an average offset of 7 cm on the measured distance d, which has been later compensated by software. Resolution has been evaluated at around 1 cm which coherent with specifications given in data sheet.

True Distance (cm)	Measured distance (cm)
30	37
60	67
168	174
300	306

Table 1: Lidar sensor preliminary calibration.

Then, sensor was tested in front of different flat raw materials target. There were placed in front of the sensor at 55cm to check detection ability vs. angle of incidence of laser beam. (cf. table 2)

In order to limit the effect of a bad reflection due to the angle of incidence, the horizontal angle is limited to 30° in the following experiments. And angle step size is 1°.

Some objects are obviously not reflecting laser beam, but for the others, no significant variations in measured distance were found.

Material	Paper Sheet	Transparent Plastic sheet	glass	Metal sheet	Rough Wall
Normal distance (cm)	55	55	55	55	55
Measured value (cm) (angle 0°)	57	invisible	58	57	57
Measured value (cm) (angle 30°)	55	invisible	57	57	57
Measured value (cm) (angle 60°)	54	invisible	57	57	57

Table 2: Lidar sensor detection test

Finally, we performed some tests with some real targets.
Figure 14 shows, using a grey scale, the results of a human body scan and the comparison with the digital camera picture.

Fig. 14: Orbisnap viewer (left), photo (right), front view

Fig. 15: Orbisnap 3D viewer, medium side view

Figure 15 is a medium side view (obtained by rotating the image in orbisnap viewer to better highlight the 3D effect of

the scanned scene: the body seems to go out of the wall and the floor coming forward.

As all the materials (clothes and wall) are reflecting the laser beam, the previous image has no default.
The second test, using the same grey scale, in figure 16 and 17 shows the image of a practical classroom with table and its shelf, and some electronic equipment.
A default appears on the right side, because the presence of a non-reflective plastic material.
Table, chairs, wall and ceiling are correctly detected.
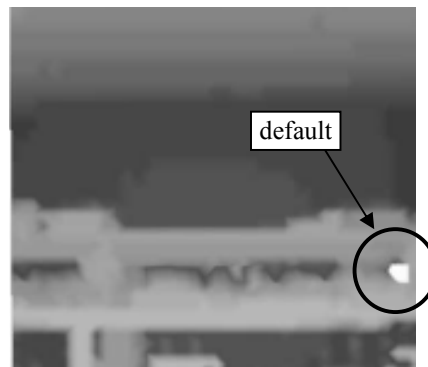

Fig. 16: Digital camera image

Fig 17: Result of the 3D scan

The last example is done using a coloured palette. A shelf with four levels and electronic apparatus is shown on figure 18 and 19. Visual interpretation requires some explanations.
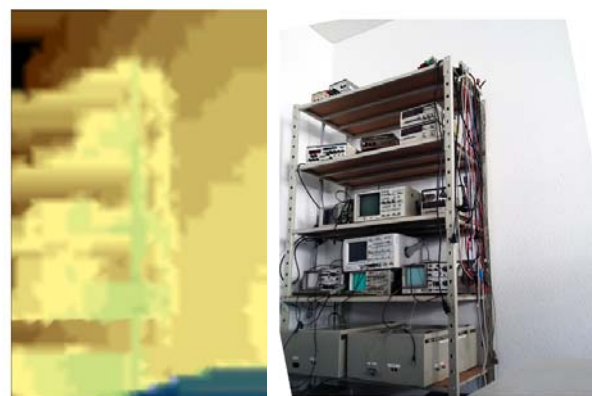

Fig.18: Shelf for electronic apparatus

On the side view figure 19, 3D effect appears more obvious especially for the floor (in blue) and for the depth of the shelf itself (looking at left "broken edge" of the picture). The four levels of the shelf are clearly detected as well as well the main boxes at the bottom level and apparatus (oscilloscope) on each upper level.
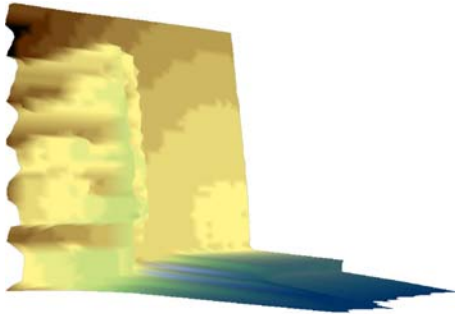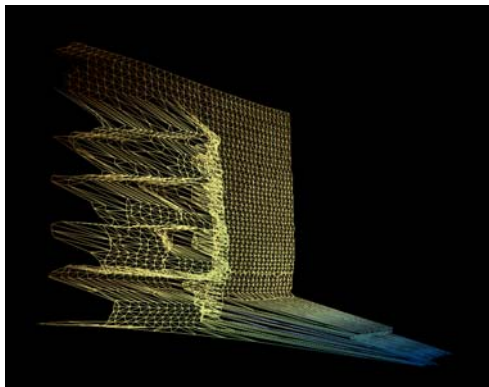

Fig.19: Left side view of shelf

V. TECHNICAL RESULTS AND COMMENTS

The design of the scanner was performed over one academic semester and took around 60 hours. That is a little bit longer than the official scheduled duration of the student's project. It was because of its complexity slightly over estimated and its transdisciplinary aspect.

Considering the relative small working time, the first technical assessment is very positive:

On example given in figure 15, the scanning distance was around 4m. And average thickness of the body was approximately 20cm.

- The measured scanning time was around 10 minutes for the body with an angle step size of 1°. Shape of the body is easily detected and rebuilt in 3D. Shoes and hand are clearly visible. Spatial resolution is better than 7 cm.

Some other remarks can be done:
- Adding colours on the built image helps to better visualize the depth. (figure 18)
- The system allows detection of objects on the shelf (figure 18). Global shape is visible but the nature of object can obviously not be identified or recognized.
- Image distortion caused by orbisnaps 3D viewer makes the resulting image not always easily understandable; Adaptation time and some human interpretation are required (like for a medical echography image for example)
- The designed system is suitable for indoor applications but not enough powerful for outdoor uses.
- Since it is a student's design, mechanical robustness, global performances and reliability cannot be obviously compared to an industrial apparatus.

VI. DIDACTICAL ASPECTS

Our students highlighted some positive point in this project. They appreciated freedom into the design that gives the impression to the students to be actor and creator [16].

They also pointed out their daily difficulties to make connection between the lectures and courses in the traditional didactical approach. Here, this transdisciplinary project helped the students to better understand that all taught fields in electronic department are cross connected. Thus, it improved the global interest for each discipline such as analogue, digital, sensors, motor control, "C" language programming, and data processing.

Finally, it fit the main didactical goals of our learning by project approach while respecting the low cost design criteria (see details in paragraph VII).

VII. FINANCIAL ASPECTS

Thanks to open source hardware and software, the design of this Lidar detection system was quite cheap, excluding labours cost (as it was student's project), compared to build-in commercial solutions [17]. We give in table 3 the cost of raw materials.

materials	price
Lidar sensor	110€
Arduino mega	40€
Arduino SD card shield	25€
2 Servo motors Futaba	30€
Other	5€
Total	210€

Table 3: Cost of the project

VIII. FUTURE WORK

Since a few months, our electronic institute offers to students an easy access to an "on site" "fab lab". Thus, mechanical parts can be manufactured with 3D printers and automatic milling and sawing machines. This new and cheap possibility could be included in our student's project management to obtain better finished products at the end of a project.

IX. CONCLUSION

The design of a low cost LIDAR scanning system was presented within the frame work of transdisciplinary didactical project. It was an interesting pedagogical innovation in our electronic department since it was the first project including a LIDAR sensor.

Technical design has been presented and financial strong constraint has been explained. Looking at the low cost of the system, we obtained incredible enthusiastic and positive results. And, the most important is that we showed it is possible to raise the student's skills and to maintain a high technical level, while remaining within a reasonable design cost compatible with the financial capacities of the electronic department.

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 Ph. Dondon was born in Paris in 1960. He is a graduate from the High School of Electronic Engineers ENSEIRB Bordeaux, France.
After his electronic engineer diploma in 1983, he worked 5 years as product manager and computer aided manufacturing (C.A.M) in the French radio-communication systems company T.R.T. Back to the IMS microelectronic laboratory of Bordeaux, he received his Ph D in microelectronic analogue design in 1992. Member of the power electronic assembly design team, he worked on power circuits test and characterisation for a few years. He has more than 95 scientific papers in journal and conferences, several books, and took three patents. He is now teaching analogue electronic at ENSEIRB- MATMECA.
Dr Ph. Dondon became active reviewer in World Scientific and Engineering Academy and Society (WSEAS) in 2006, then, editor within "WSEAS transaction journal in 2010. He is organizer and chair of many international conferences.