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LABORATORY COURSE OF ELECTRONIC INSTRUMENTATION BASED ON THE TELEMETRY OF SEVERAL PARAMETERS OF A REMOTE CONTROLLED CAR

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Abstract – A new laboratory course in electronic instrumentation based on the telemetry of the temperature, revolutions per minute and acceleration of a remote controlled car is described in this paper. The main objective of the course is to cover the disciplines involved in Instrumentation, that is, sensor use, analog and digital design, microcontrollers, data acquisition and software, within a framework that provides highly motivating work.

Keywords: Education, instrumentation, sensors

1. INTRODUCTION

Electronic Instrumentation course has contents largely dependent on the University and country where the course is run. Instrumentation and Measurement was not usually a major subject at universities [1], most of which include instrumentation, measurement and control as part of the Electrical and Electronics Engineering curriculum. Instrumentation and Measurement [2], [3], [4] and [5] involves many disciplines, which turns creating a course and deciding on contents into a daunting task.

Engineering technology programs that include instrumentation, measurement, control, and similar topics really should include courses in automatic control systems, fundamentals of electricity and electronics, microprocessor systems, programmable logic controllers, thermodynamics, fluid dynamics, chemistry, algebra and calculus, and other areas of study [5]. In Spain, BSc and MSc degree courses in Electrical and Electronics Engineering cover not only these disciplines but also Networks, Programming Languages, Power Electronics, and so on. Most Spanish universities include a 45-hour final year undergraduate course called "Electronic Instrumentation", or some such name.

Electronic Instrumentation course includes both, theory and practice parts to cover its main objectives.

1.1 The theory part of the Electronic Instrumentation course at the University of Oviedo.

The basic elements of a measurement system are the sensor, the signal conditioning circuit and a display to show results [6]. However, most systems are more complex and include analog-to-digital conversion, signal processing and signal transmission before or after digitalization (Fig. 1). Furthermore, several signals must often be either time or frequency multiplexed over the same transmission channel, thereby adding to the complexity to the system. Students who undertake the theory-based course at Oviedo have already taken courses in fundamentals of electronics, A/D and D/A conversion and displays.

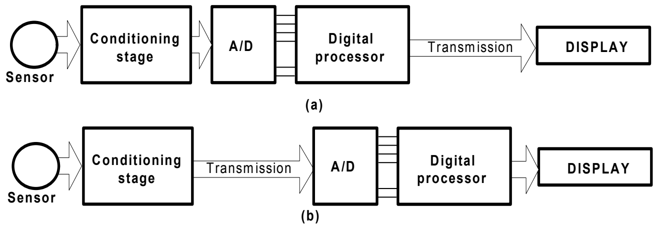

Fig. 1. Two typical topologies of instrumentation systems for single-variable measurement: (a) digital transmission option; (b) analog transmitter sends data to processor.

Thus, the theory-based course essentially deals with those subjects that have not yet been studied, i.e., sensors, the design of signal conditioning circuits, an elementary introduction to signal transmission and several lectures on noise and interference (table I). This theory-based course runs in conjunction with a 15-hour laboratory course.

TABLE I Contents of the Electronic Instrumentation course in the Oviedo University

Introduction to Electronic Instrumentation.
Amplification.
Parameters of the real operational amplifier, other types of amplifiers and noise.
Filtering.
Sensors and their signal conditioning circuits.
Resistive sensors.
Inductive and capacitive sensors.
Signal generating sensors.
Criteria for sensors selection.
Signal conversion and transmission.
Electromagnetic interference.

1.2 The laboratory course at the University of Oviedo

Traditional education is based on the belief that students with solid theoretic knowledge can effectively develop into professional engineers by training in industry [1]. However, significant pressure is now being brought to bear in an attempt to change this situation, and as a result laboratory courses have become ever more important in recent years. Most laboratory courses are based on a number of one-off experiments, in no way inter-linked to each other. But, as other engineering subjects, Electronic Instrumentation involves applying a large number of different disciplines to deal with issues related to such fields (analog circuit design, digital circuit design and software development).

The most important goal of the laboratory course will be the integration of each discipline, instead of them being dealt with in separate experiments. This would be extremely practical, as experience shows that such integration is not obvious to all students.

However, a practical, integrating course of this type would involve a greater student workload…

1.3 Laboratory course objectives

So, it should therefore be carefully designed so as to motivate students as much as possible despite this inevitable extra burden. However, despite its integrated nature, such a course would benefit also from being divided into several independent assignments, or blocks, so that a whole range of marks and assessments is available to grade students by.

The main objectives of this course, therefore, are:

a) To design a complete instrumentation system involving several disciplines
b) To clarify as many concepts of the lecture classes as possible
c) To motivate the students towards maximum progress.
d) To promote teamwork.

The main restrictions to achieve those goals are a limited budget, limited time to use the laboratories, and the limited number of credits assigned to laboratory courses.

2. LABORATORY COURSE CONTENTS

To fulfil the above-mentioned objectives, a project-based course was designed along the lines of other successful experiences [9] related to instrumentation systems. It consists of designing a system, shown in the block diagram in Fig. 2 to measure several parameters of a remote controlled car (engine temperature, engine r.p.m. and two-axis acceleration), to radio this information, and to display all data on a PC. Note the similarity to the block diagram from Fig. 1b except for the multivariable characteristic.

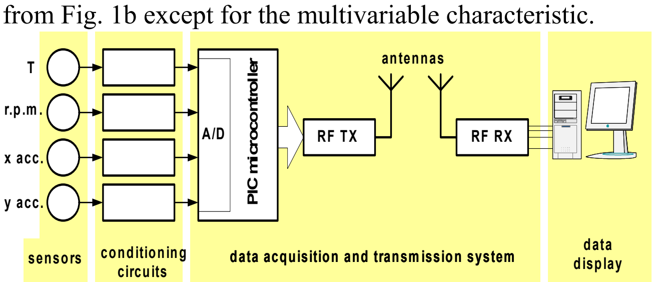

Fig. 2. System block diagram.

The laboratory course is divided into six main work packages (WP) as we can see in Table II; students are grouped into three-person teams and each team must complete as many work packages as possible.

TABLE II. Work packages of laboratory course.

WP	Description
1	Measurement of the engine temperature
2	Measurement of engine r.p.m.
3	Measurement of xy acceleration
4	Data acquisition and transmission
5	Computer data storing and visualization
6	Final mounting and testing

All the work packages are independent to such an extent that a team completing. All teams, including those who fail to complete all the work are allowed to move on to the final tests using the remote-controlled car.

A further advantage of the course is that the sequence of the work packages is quite similar to the syllabus of the lecture (Table I), allowing different concepts dealt with during these lecture classes to be reinforced.

The first three WP are related to sensors and signal conditioning. The diagram of each circuit (devoid of all values), a printed circuit board and another diagram showing the component location of each circuit is given to the team, who can optionally re-design the PCBs. These circuits must be powered by a 9.6V, Ni-Cd battery so they can be assembled on the car. The output of each circuit must be in the range of 0-5V, as this is the input range of the A/D converter used on the following WP.

WP4 basically consists of programming a PIC microcontroller to perform the data acquisition and signal transmission tasks. WP 5 consists of programming the computer. Finally, WP 6 consists of mounting the system and carrying out tests with the car. The team must also write a complete report that must include:

- Calculations.
- The results.
- The answers to several questions.

As far as laboratory facilities are concerned, there is a main laboratory in the Engineering School where the students can work several hours a week. The number of teams is about eight per course and previous experience has proved that there are no large logistic problems. There is also a basic electronic devices store at the school (resistors, capacitors, semiconductors, cables and the like) where students can acquire components once authorised to do so by a lecturer without incurring the expense in terms of both time and money of having to buy them.

2.1 Sensors and conditioning stages

A Pt100 sensor is used to measure engine temperature. As has already been pointed out, the diagram of the circuit, the PCB and the drawing showing component location as well as a brief explanation are given to the team. Most commonly-used circuit in electronic instrumentation is the unbalanced bridge and it is used for the signal conditioning circuit without hardware calibration.

The final circuit includes an INA118 instrumentation amplifier and an LM336-5V as the voltage reference to supply the bridge.

An optical encoder is used to measure rear axe revolutions per minute. It is constituted by a 25-gap disk attached to one of the car's rear wheels (Fig. 3) so an opto-switch provides a signal whose frequency is proportional to the axle r.p.m.

Fig. 3. Custom design for r.pm. sensor.

The signal conditioning circuit includes a LM2917 as frequency-to-voltage converter, using the built-in operational amplifier of the LM2917 to design a Butterworth filter in order to apply the knowledge that students acquire during lecture classes.

The acceleration measurement system is based upon the sensor ADXL250 from Analog Devices. This sensor needs few additional devices which values can be obtained from datasheet or changed in order to obtain good calibration with low-cost single-turn potentiometers.

2.2 Data acquisition and transmission

This work package consists of data acquisition, serial transmission and reception by radio, and signal adaptation to the RS-232 serial port of the PC (see Fig. 2). Data acquisition is performed with a PIC microcontroller: 16F876. Its features include a built-in 5-channel 10-bit A/D converter and allow in-circuit-serial programming. Data are time multiplexed and transmitted by using a low-cost RF transmitter (the Tx-Saw 433/s-z from Aurel) able to use a transmission frequency of 433.92MHz (so far from the 40 MHz of control system working frequency of the remote car). The radio frequency receiver (an Aurel BC-NBK model) provides a TTL compatible output and it is translated to serial PC input RS-232 level specifications by means of a MAX232.

2.3 Visualization

The team must program the PC using Visual Basic to display the results. Programme objects and their basic structure are given and explained to the students in order to reduce the workload for this work package. One of the objects is for serial data acquisition and provides four numbers corresponding to each sensor signal. The number of bits in the object corresponding to the transmission may be changed according to the number of bits selected in the previous work package. The other objects show the temperature, the engine r.p.m., the x and y accelerations, and the sum of both accelerations graphically and numerically. The scale of representation may be changed; so, students can adapt it to their specifications. Moreover they must add elementary controls to achieve two points calibration to measure the engine's temperature. Fig. 4 shows a typical graphical interface made with the objects.

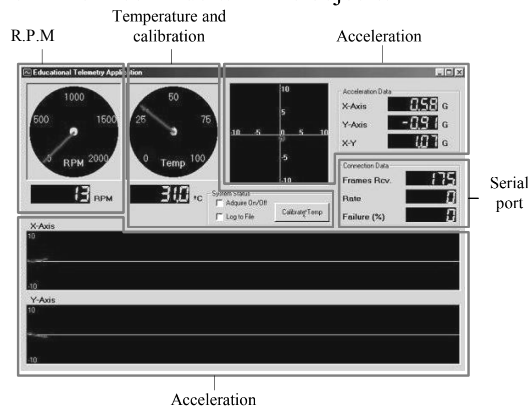

Fig. 4. Typical graphical interface to display car parameters.

Some students have considerable knowledge of computer programming and prefer to make their own objects. However, the use of designed objects is encouraged because the programming tasks uses a lot of spare time of students.

2.3 Mounting and testing

Each student team assembles the whole system and carries out several tests to verify the right operation of system. One of its tasks is to wire the system in such way as to cut out noise and interference. Important principles must therefore be applied such as proper grounding, using of twisted-pair cable where necessary, etc. Finally, each team is allotted a session to perform a demonstration for the teacher.

An example of final work of students during this laboratory course is shown in Fig. 5.

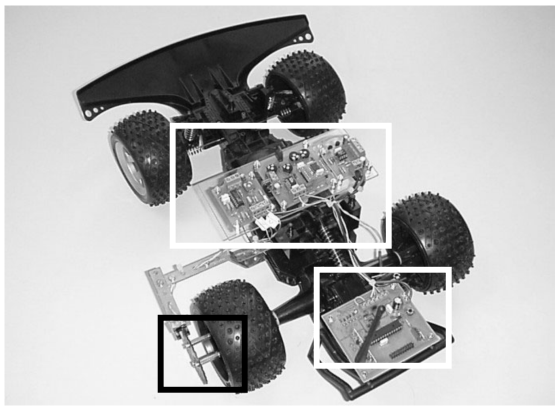

Fig. 5. An example of students work.

3. RESULTS

As in other hands-on courses, student motivation and expectation are great. In fact, a low percentage of students opt for a traditional laboratory course (it is also offered to students). Particular caution must be shown in order to avoid an excessive workload, the most typical complaint levelled by students on this kind of course. This is the main reason because both, the printed circuit boards and the objects necessary to program the computer are given to the students. Nevertheless, the course, however, still allows students to make their own decisions since they must propose specifications and design depends on them.

The cost of the course can be considered reasonable. The more expensive components, such as the accelerometers, the RTDs, the f/v converters or the microcontrollers, as they are plugged into sockets, and they can be re-used in later courses. The only components that need be replaced are resistors, capacitors, interlocking and printed boards for the signal conditioning circuits. For the first year the course material cost is about 240€/team including the car. In subsequent years the cost is less than 75€/team.

3.1 Outcomes of teacher observation and experience

The effort required on the part of the instructors is considerable when compared to traditional courses, as they increase the interaction with students. A meeting with each team, which is scheduled for each WP in order to:

- Check progress.
- Solve major stumbling blocks
- Help students to work to a deadline

So, the instructor has and additional work in relation to traditional courses. However, the benefits are well worth the effort.

The course allows students to acquire and consolidate most important theoretical concepts from lecture classes, reinforced through experimentation; it provides students with a global view of Electronic Instrumentation and contributes to improving teacher-student relations. Fig. 6 shows the progress of the students during both the Electronic Instrumentation theory-based course and the laboratory course in several topics covered in the syllabus.

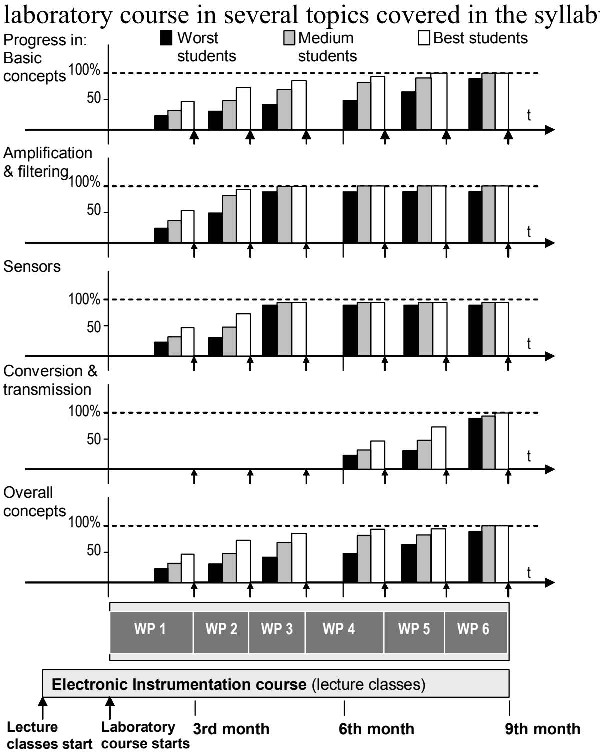

Fig. 6. Student progress during the course.

To estimate the results of this laboratory course it is necessary to refer to the Fig. 6 and its consequences: it is easy to obtain a good knowledge growth in good students and very difficult to reach similar results in worst students but, what is about the ‘medium student’? Usually, the medium student obtains medium results. In the laboratory course of Electronic Instrumentation in Oviedo University, medium students can obtain a knowledge level very close of best students (Fig. 7). There are several causes for this improvement:

a) A high self-motivation state caused by the participation in a complete project (from the design to the test of prototype).
b) Group work: best student in each team can help other team members, introducing a positive feedback in the knowledge growth.
c) After finishing each work package, the motivation of students increases to face the next WP.

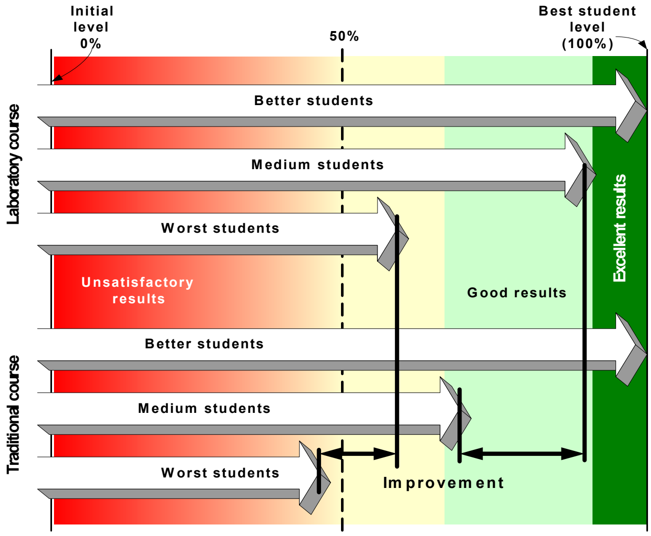

Fig.7. Comparison between the presented laboratory course and a traditional course in Electronic Instrumentation. Knowledge level improvement is quite important for medium students.

Students state that the course provided them with an understanding of the concept of a complex instrumentation system, and also testify to the course providing invaluable experience and know-how. The course encourages students to get involved in other courses run by the School of Engineering that involve solving real world-type problems. Most of the teams complete all the tasks satisfactorily. Typical failures are related to the design of the signal conditioning circuits and to inadequate wiring. Even so, the students state that they learn much from their mistakes.

Comparative analysis through student’s performance in subsequent courses is difficult since this laboratory course is included in the final year of the six-year undergraduate course and less than 5% of graduate students go on to post-graduate level. However, some feedback is feasible trough the lectures who supervise graduation projects in electronic-related areas: the time required by the students to do this final project (necessary to reach their MSc.) has decreased but also that the quality of projects has increased significantly since this laboratory course was introduced.

Lectures in projects in other fields profess to not having observed any such differences.

3.2 Outcomes of student assessment

In June 2002 (the month when the laboratory course finishes) the 25 students following the laboratory course described in this paper were asked to fill a questionnaire to evaluate the results:

a) Most of the students think that the course has been useful for a better understanding of lecture classes.
b) The majority of students think that the course was useful for other subjects, insofar as it contributed to overall academic growth.
c) It is also interesting that students do not consider the workload excessive; indeed, most of them think that the course was less difficult than they had imagined before it started.

However, these conclusions from students could be too subjective and they must be taking into account carefully due to the distorted point of view caused by the small time gap between the laboratory course and the questionnaire. But, feedback from students after their graduation, o later, becomes too difficult in most of cases.

4. CONCLUSIONS

This course provides student involvement in tasks that lead to usually successful, complete instrumentation design, similar to a real case, including signal conditioning, acquisition, signal transmission and visualization. However the course is not so different from a traditional one in several ways. It is made up of several tasks, it is relatively closely linked to the contents of lectures classes, and although the workload is greater than in a traditional lab course, it cannot be –nor was– considered as excessive. The main difference is the inter-connection between the tasks, which makes the course much more useful than a traditional one for a better understanding of lecture classes and for overall academic growth. Such conclusions have, in fact, been ratified by the students themselves.

REFERENCES

[1] K. Watanabe, "Instrumentation education in Japan: Despair and expectation," IEEE Instrum. & Meas. Mag., vol 2, pp. 14-19, Mar. 1999.

[2] R. A. Witte, "Engineering education for test and measurement designers," *IEEE Instrum. & Meas. Mag*., vol 2, pp. 11-13, Mar. 1999.

[3] A. Barwicz and R. Morwski, "Teaching measuring systems beyond the year 2000," *IEEE Instrum. & Meas. Mag*., vol 2, pp. 20-27, Mar. 1999.

[4] T. Laopoulos, "Teaching instrumentation and measurement in the complex-systems era" *IEEE Instrum. & Meas. Mag*., vol 2, pp. 28-30, Mar. 1999.

[5] J. L. Schmalzel, "I&M education for the new millennium. A U.S. perspective". *IEEE Instrum. & Meas. Mag*., vol 2, pp. 31-36, Mar. 1999.

[6] R. Morawski, R. Pallas-Areny, E. Petriu, M. Siegel, and Th. Laopoulos, "Current trends on teaching Instrumentation and measurement," in *Proc. 16th IEEE Inst. Meas. Tech. Conf., 2000*, pp. 1715-1726.

[7] S. Ghosh, "Integrating design into undergraduate honors theses in a computer engineering program: An experiment," *IEEE Trans. Educ*., vol. 43, pp. 200-210, May 2000.

[8] R.B. Hilbor, "Team learning for engineering students," *IEEE Trans. Educ*., vol. 37, pp. 207-211, May 1994.

[9] S. Horan, "Using measurements and sensors in a pre-college enrichment program," in *Proc. 18th IEEE Inst. Meas. Conf., 2001*, pp. 1968-1971.

[10] T.W. Matthews and R.R. Spencer, "An autonomous race car design competition," *IEEE Trans. Educ*., vol. 44, p. 215, May 2001.

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