MANCHESTER 1824
Manchester University Press

Automation and control remote laboratory: a pedagogical tool

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Abstract This paper presents a study to evaluate students' perception of the development and use of remote Control and Automation training kits developed and tested in two Portuguese universities. Three projects were implemented based on real-world environments. The students, supervised by teachers, designed and implemented the kits using the theoretical and practical knowledge taught in traditional classes. The end-user students tested the kits in the course curricular units, operating them either locally or remotely. Successful results were achieved not only in automation and control skills (hard skills) but also in the development of soft skills, leading to encouraging and rewarding goals, inspiring future decisions and promoting synergies in teamwork.

Keywords automation; control; engineering education; learning by doing; problem based learning

Apart from the process of course harmonization[1] and the translating of students' workload into the European Credit Transfer and Accumulation System (ECTS), the Bologna Declaration was also the beginning of a new paradigm: the student is responsible for his/her own learning process (student-centered model), acquiring not only technical competencies but also skills needed for his/her personal development.

Among the challenges brought by new teaching/learning methodologies, web-based learning environments help students and teachers' engagement in the knowledge acquisition process. These web environments must allow other functionalities rather than traditional lectures, and exercises support uploading. Several concerns must be taken into account when designing web environments for learning as it will be the main factor in engaging students with this learning methodology. So, more innovative and illustrative interactive learning environments must be developed. The teacher must be aware and be prepared for using virtual environments as a complement to the traditional face-to-face lectures.

Another key feature in the teaching/learning process remains experimental work in the laboratory. Here, the student puts into practice the theoretical concepts. The student constructs, manipulates, modifies and controls the experiments. This 'learn by doing' is essential to develop good professionals, especially in engineering areas. Hansen[2] states that students retain only 25% of what they hear, 45% of what they hear and see and about 70% when they apply the methodology 'to learn by doing'.

To achieve successful laboratory classes, a well-organized scheme must be prepared. Especially in engineering courses, it is difficult to install and maintain several working positions in a laboratory. Due to the cost of some equipment, the replication of working positions (as well as space to accommodate them and qualified personnel) is not viable. This problem becomes highly important if physical and human resources are replicated at each school.

To overcome this problem the remote laboratory concept is used.[3] The idea is to carry out laboratory experiments via Internet, anytime and anywhere. The students can also have immediate feedback, allowing them to work in their own space, providing them with the opportunity to practise when and where they please.[4,5]

From an educational point of view, replacing traditional classes with remote laboratories is not only a matter of developing appropriate technical tools but also it requires an innovative educational approach and a close interaction between technical and pedagogical aspects. A good understanding of the pedagogical aspects is essential for efficient use of remote labs.[6] Even so, a remote laboratory is not the bare exchange of data between a web browser and the instrumentation; rather it is characterized by a large set of issues related to pedagogical, technical, and organizational aspects, which are not so trivial to solve.

A comparison of the different technologies used to conduct electronic measurement experiments via remote access is available in Ref. 7. The comparison takes into account some parameters, in particular the development time of the systems; type of operating system and Internet browser; and the need for the installation of drivers in the client's computer, among others.

In Ref. 8 the authors describe some relevant features of the platform *flock.uc.pt* under development at the University of Coimbra in Portugal, including some application examples. The authors believe that combining design techniques with virtual and augmented reality, contents and interfaces can improve users' analytical capabilities of perception and cognition.

NetLab[9] is a remote laboratory used by undergraduate students to perform experiments on electrical circuits. It is designed as an interactive collaborative environment where a number of students can remotely access the devices from different places in the world. Students can collaboratively wire circuits, connect and set up instruments and perform measurements.

In Ref. 10 the authors present and discuss the electronics remote laboratory VISIR shared among three institutions, two universities and one high school. VISIR is present in seven universities: six in Europe and one in India. The idea is that remote laboratories enable students to use real equipment located in one university via the Internet. This way, students can extend their personal learning even if the traditional laboratories are physically closed.

Ref. 11 describes a virtual laboratory environment for running real-time robot control experiments over the Internet through a standard web browser. Ref. 12 presents a tool that combines the use of Matlab and LabVIEW to allow students to gain remote access to a data acquisition system to setup several experiments such as a tank-level control process and temperature-air flow process.

In Ref. 13 a remote lab experiment RC oscillator, based on MATLAB, LabVIEW and DSP2 learning module, is presented. Step and sinusoidal responses analysis, proportional controller design as well as controller performance are available to students in this Web platform.

A remote internet-based laboratory for the characterization of MOS capacitors involving high-k gate dielectrics is shown in Ref. 14. The LabVIEW environment for online web-based communication between client and server through web services is explored.

In Ref. 15 the authors explored LabVIEW virtual instrumentation techniques for creating interactive simulations for Electromagnetic Compatibility (EMC) functionalities.

The Massachusetts Institute of Technology (MIT) has the interactive platform iLab Shared Architecture available, in which dedicated experiments can be developed based on this architecture. The sequential logic iLab[16] utilizes the National Instruments Educational Laboratory Virtual Instrumentation Suite (NI ELVIS II+) hardware through an interactive user interface developed in LabVIEW. The platform supports experiments with counters, shift registers, frequency dividers and digital clocks, with appropriate electronic component selection and configuration.

Several others such as Weblab[17] and RMCLab[18] are remote labs for practising on electronic instruments and measurement methods executing real experiments.

Following the concerns and the choice of the technologies to be used in the development of remote laboratories in the specific areas of Automation and Control education, it is necessary to be aware of some characteristics (technological and/or of pedagogical requirements).[3]

The possibility of a remote laboratory developed in LabVIEW® language allows students to access and publish data as well as performing experiments without any limitation of time and location.[19]

In this paper, regarding automation and control education, a multidisciplinary group of teachers from University of Minho and from Polytechnic Institute of Cávado and Ave (IPCA), North Portugal, designed and implemented a pedagogical tool.

The four academic teachers involved in the experiences came from different scientific backgrounds and had different teaching styles. This can be considered as a positive feature since they can emphasize different aspects of the experiential learning cycle in the methods they use. Different technologies and learning environments are described in order to develop illustrative and interactive situations, as, for example, virtual processes, local and remote laboratories and interactive animations. It is a dynamic learning task: some students actively participate in the development of the learning content and other students use and test them. The basis of this project is the development of three remote control laboratory kits implemented by the design students. The feedback of both the design and the end-user students were analyzed. It is the researchers' belief that the end-user students' experiences of this new teaching-learning approach is relevant to the continuity and improvement of this methodology.

Project development

The authors are involved in developing an automation & control remote laboratory that fulfills students' expectations and learning needs. To accomplish these requisites, students can contribute with interesting ideas, as they are also the final users of the laboratories.

During the semester, regular meetings with the students group were scheduled not only to give some theoretical/practical support, but also to enrich reflection and learning in the education process.

Three different kits were designed and developed in the remote laboratory by engineering students: the 'Small intelligent house', the 'Velocity control of a d.c. motor', and 'Temperature control of a classroom'.

The first kit, 'Small intelligent house', was designed and implemented by three students from the 4th year of the Industrial Electronics Integrated Master (five year course), under the curricular unit (UC) called Project that lasts for one semester. In this particular case, the students had no previous knowledge of automation and control subjects needed in the project development. The students, after a brief overview of the related theoretical background by the teacher, autonomously started their practical development. The experiment ran successfully despite the students' obligation to learn by reflecting on their observations of the real experiment, encouraging them in their future decisions and promoting synergies in team work.

The kit 'Velocity control of a d.c. motor' was designed and implemented by a final year student of the Industrial Electronics Integrated Master and was part of his Masters thesis.

The last kit, 'Temperature control of a classroom', was implemented by a final year student from the Industrial Informatics course (three year course) at IPCA.

It must be pointed out that for these last two kits the students attended theoretical classes before developing their project work.

When operational, these kits were used in Automation and Control units as non-compulsory extra class activities (in the Automation UC, on the 3rd year of the Industrial Electronics Integrated Master; and in the Process Control UC, on the 2nd year of the Industrial Informatics course of IPCA). The learning outcomes are focused on the experimental test of an on-off controller (changing hysteresis value); the use of PID controllers (choosing and testing different digital algorithms, changing controller gains); verifying the different control performances; and also, how to implement a 'small intelligent house' by using a programmable logic controller (PLC).

In order to evaluate the use and the capabilities of this methodology a questionnaire was developed. It allows an understanding of how students perceived the use of remote labs as well as their difficulties in this process towards further improvements.

Automation and control laboratory kits

The kits developed for the automation and control laboratory can be remotely accessed under an authorized registration by the web manager. The user monitoring interface was developed in LabVIEW® considering the performance of the platform in data acquisition purposes.

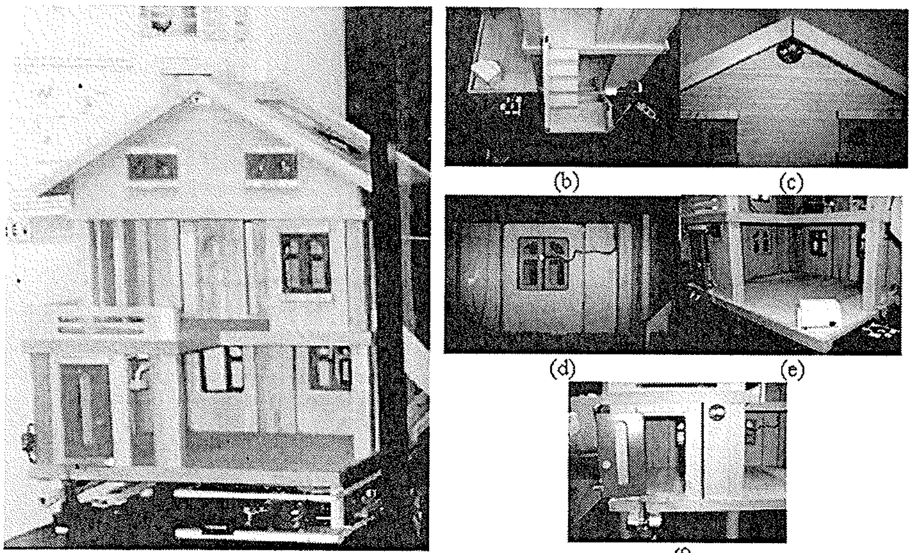
In the following sections, a detailed description of each kit is presented.

Small intelligent house

The main circuit of the 'small intelligent house' allows the user, using a push button, to activate and deactivate the maquette (Fig. 1). The sensors were positioned in order to allow control of alarm intrusion, main and internal illumination, main door opening/closing and attic temperature, using the PLC CQM1H-CPU61 from Omron. The staircase illumination is done by three push buttons placed as follows: the first at the top of the staircase, the second at the middle (half way) and the third at the bottom. For the internal illumination, a motion detector was used and whenever it detects movement, a signal is sent to the PLC to activate the light. If the alarm is switched on there is a light and sound signal whenever the alarm detects an intrusion. The control function activates and deactivates the alarm. The sound is performed by an independent circuit. The door has a d. c. motor placed underneath and a light bulb that is switched on when the door is opened or maintained open. The attic temperature control is performed by an Omron temperature controller E5CK.

Dedicated electronics hardware was developed to control the door, the alarm, the internal and the staircase illumination. Relays permit the d. c. motor to invert its rotating direction, LM555 based timer circuit from Texas Instruments, to control the alarm sound (buzzer) and the intermittent state of the light bulb, and a motion detector to control the light bulb of the internal illumination are included.

The simulation of the 'small intelligent house' was developed in LabVIEW®. The LabVIEW® interface enables both simulation and 'small intelligent house'



(a) (b) (c) (d) (e) (f)

Fig. 1 (a) *Setup of the experiment 'Small intelligent house'. Control points:* (b) *stairs light,* (c) *alarm light signal,* (d) *window intrusion alarm,* (e) *sensor movement,* (f) *entrance door.*

monitoring and actuation, but direct control is performed by the PLC. The interface allows also monitoring and testing different proportional, integral and derivative parameters of the attic temperature control algorithm.

In the simulation run the sensors and actuators are replaced by switches and colored signals, simulating alarm intrusion, main and internal illumination, main door opening/closing. For each control, the corresponding front panel and block diagram were developed separately (Fig. 2).

The software developed in LabVIEW® also permits the remote control of the 'small intelligent house' through the monitoring performed by a Webcam (Trust, 120 Spacecam). This feature was designed to provide students with real-time experiments via the Internet (Fig. 3).

Velocity control of a d.c. motor

A remote controlled d.c. motor was developed for undergraduate control studies, allowing discrete PID (proportional-integral-derivative) algorithm testing.[22] The control methodology was implemented in a microcontroller. Four different digital versions of the PID algorithm are available.

Figure 4 presents a schematic view of the developed system. A 'Maxon RE36' d.c. motor is inserted with an encoder HEDS-5540 A11. The microcontroller

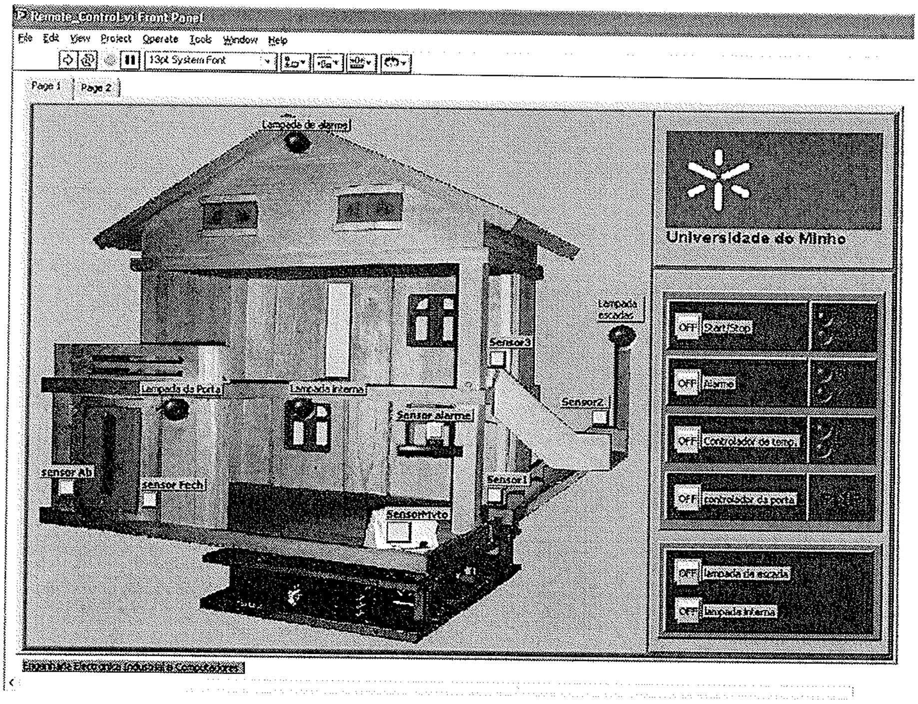


Fig. 2 *LabVIEW® front panel interface for the virtual simulation of the 'small intelligent house'.*

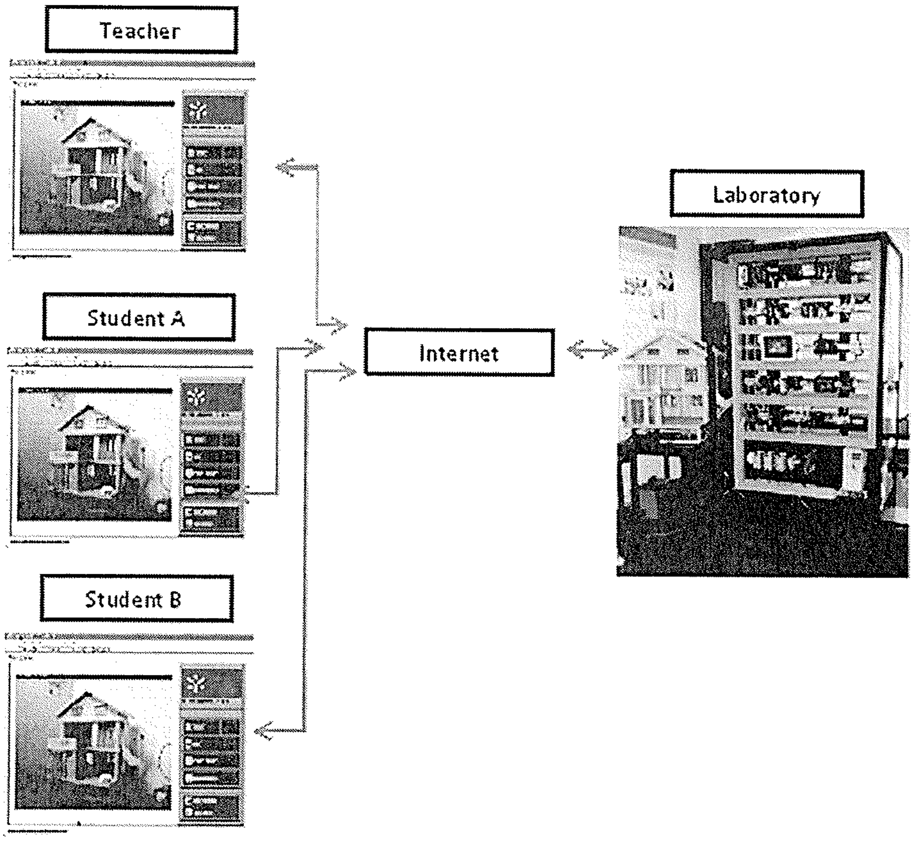


Fig. 3 *Basic scheme of the remote lab for the 'small intelligent house'.*

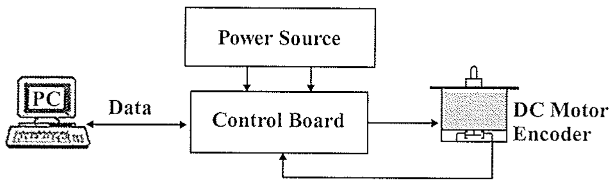


Fig. 4 *Schematic view of the developed system.*

PIC16F876 from Microchip is used to directly control the motor; the control board is linked to the local personal computer by a serial RS-232 communication link for monitoring.

The PID algorithms were programmed in Assembly language. The user interface was developed in a LabVIEW® environment. Twelve motor velocity values can be selected (from 7 m/min to 335 m/min – cylinder diameter coupled to the motor main shaft of 3.09 cm). The user must select the PID algorithm to be tested as well as the

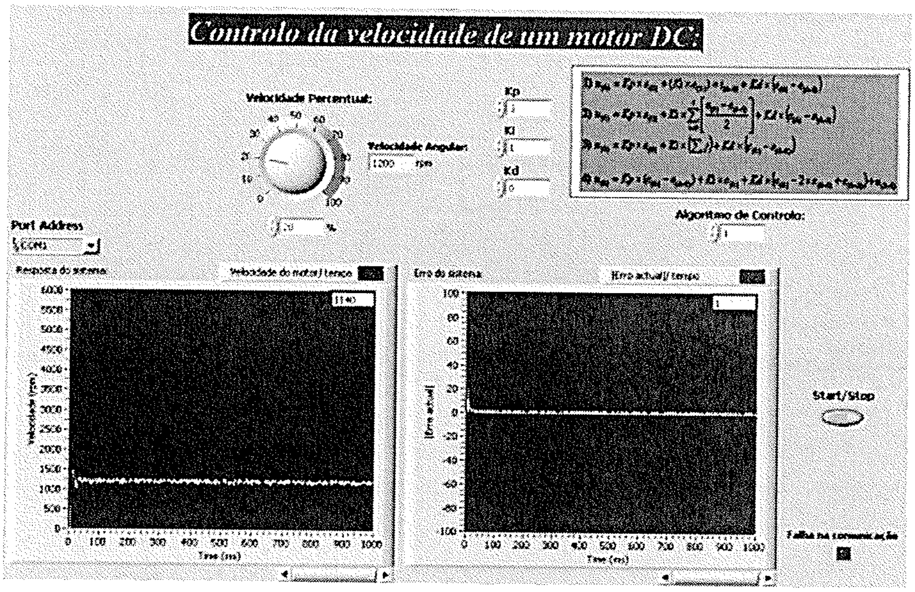


Fig. 5 *LabVIEW® user interface (in Portuguese).*

proportional, integral and derivative controller parameters (limited to prevent controller saturation).

Using the Web Publishing Tool, a webpage was developed in LabVIEW® (Fig. 5), enabling the remote access and control of the developed system, generating a web server with an HTML page, which any device that supports LabVIEW® can access using the Internet. An automatic waiting queue is managed by LabVIEW®, allowing a single control user.

Temperature control of a classroom

The goal of the work is to remotely monitor and control the temperature of a scale model classroom. It is designed for a resistive temperature sensor with a positive temperature coefficient (PTC), controlled by a PC with custom software developed in LabVIEW® using actuators for cooling and warming. It integrates a webcam to observe the activity inside the classroom, as well as the possibility to simulate a temperature disturbance. This scale model can be used to assist educational purposes stimulating students to real world problems.

The designed prototype is based on the block diagram presented in Fig. 6.

Figure 7 presents the developed prototype. The system software was developed in LabVIEW®. The On-Off control methodology[20] is established according to the setpoint value defined by the user. The monitoring can be performed locally through a 7-inch touch screen display from Lilliput.

Figure 8 shows the developed application interface. The inputs of the developed software are the disturbance activation button and the setpoint adjustment; the

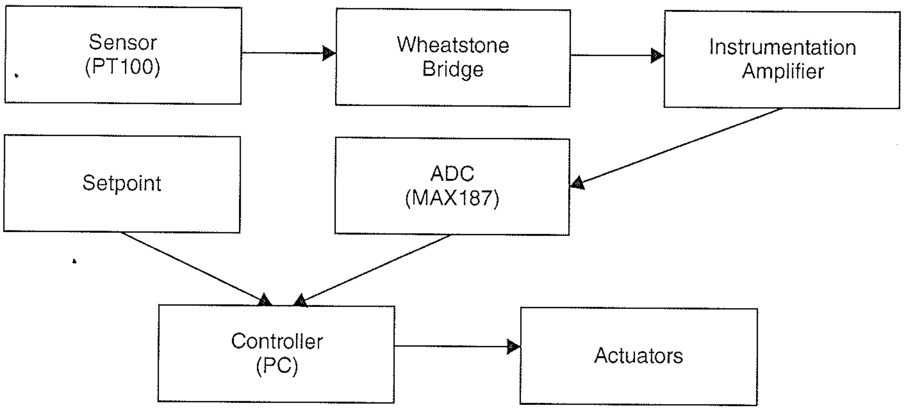


Fig. 6 *Block diagram of the project.*

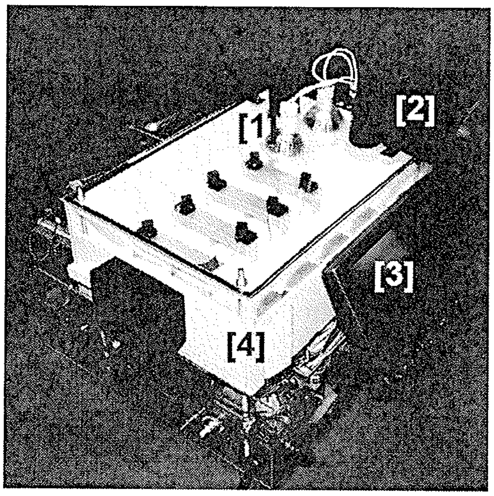


Fig. 7 *Final appearance of the scale model. 1, Heating actuators; 2, cooling actuators; 3, touch screen display; 4, disturbance (door).*

outputs are the Webcam display, the actual and over time temperature values and the input voltage value over time.

Evaluation of students' attitude

An added value of this work is what students can learn by using the Automation & Control remote laboratory as their study tool. In order to analyze the motivation of both the group of students engaged in this laboratory (design students) and the end-user students, two questionnaires were developed and applied. In this section the obtained results will be presented and analyzed.

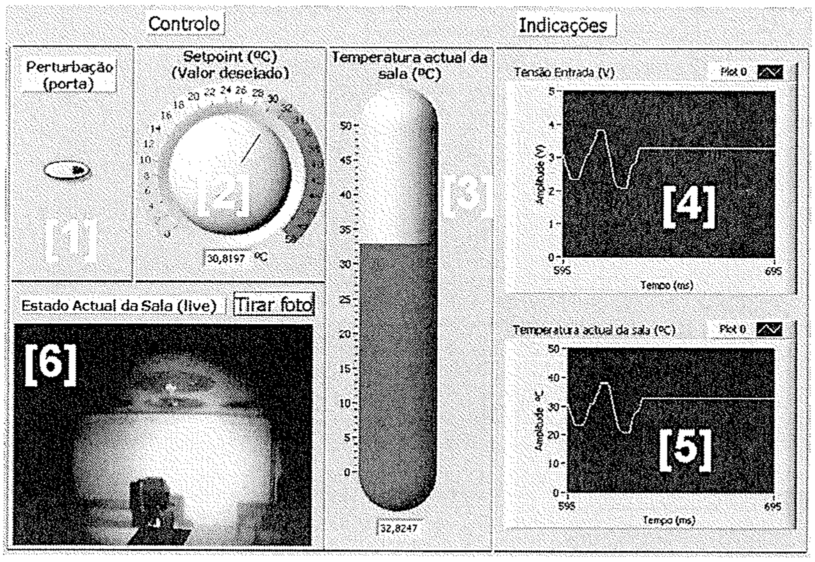


Fig. 8 *Application interface. 1, Disturbance (door) activation button; 2, setpoint adjustment; 3, classroom temperature (°C); 4, input voltage over time (V); 5, temperature over time (°C); 6, webcam display (in Portuguese).*

Design students questionnaire

The questionnaire 'Learn by Doing' was divided into two parts: (1) student characterization and (2) student attitude characterization during the project. Closed questions and a Likert scale were used in order to make a consistent analysis. In the first part, the student identified his/her personal data: sex, age and year of access to the university. In the second part, comprising a set of twelve questions, the student answered the procedural questions describing his/her attitude during the project development. In particular, the goal was to understand the students' perception of the methodology applied in the kits' development, in comparison to traditional educational methodology.

Through analysis of the questionnaire answers, it was possible to trace the average profile of the students: male, 23 years old. All were unanimous in considering that the Internet must be used in university education and in believing that 'virtual' can be used as complementary classes in addition to face-to-face-teaching. Moreover, 67% of the students stated that the methodology 'learn by doing' significantly encourages the development of group work whereas 33% have a medium position. It is confirmed that the involved students had improved, in group work, their creativity and responsibility. Students participated in this project on a voluntary basis and, when asked to identify possible reasons for choosing this project, 60% indicated the acquisition of new knowledge in the Automation and Control area and improving skill qualification for their future professional careers as the most important ones. Other reasons – working in a group; the possibility of working in the Automation and Control area; and colleagues' influence – were only indicated by 30% of the students. All the students were unanimous in stating that the projects corresponded to their expectations.

The methodology used and described allows students to acquire an easier understanding of Automation and Control. In general, all the students identified the relationship teacher/student as a highly important issue and that the teachers were available to resolve students' doubts, to present new points of view and to encourage them to state their ideas. It was interesting to realize that most of the students had identified that they had applied the knowledge acquired during the project in other curricular units.

End-user students questionnaire

This questionnaire aimed to understand and analyze the students' reaction to the use of didactics kits in the teaching and learning of Automation and Control. A group of 34 students responded, with an average of 22 years old; 4% were female and 91% were 3rd year students.

The questionnaire was divided into five main parts: (1) student characterization, (2) work environment identification (operating system and browser identification), (3) didactics kits (technical skills), (4) didactics kits (motivation) and (5) students' habits and attitude characterization during the project. Analysis of the answers is focused here on the average value obtained from a set of nine items evaluated from 1 (strongly disagree) to 5 (completely agree):

Q1: *In general, I was motivated for the use of these kits in the course context.*
Q2: *In general, I can say that the performance of the kits ...*
  1: *... helped me assimilate the concepts presented during the course semester*
  2: *... made my learning more objective*
  3: *... increased my chances of getting a high final evaluation*
  4: *... motivated me towards the course*
  5: *... raised my expectations relative to the assessment*
Q3: *Running the kits had nothing to do with my motivation and my interest in this course.*
Q4: *These kits are suitable for my Control/Automation learning process.*
Q5: *I recommend the implementation of these kits and activities, in the next school year, as a teaching/learning tool.*

Figure 9 illustrates the average values obtained for each analyzed item regarding students' motivation in using kits. The horizontal dashed line indicates no opinion (level 3) where values above this line indicate a positive agrement and below a negative one. The average evaluation was positive (higher than 3) in all the considered items, except for the Q3 item. However, since this sentence was placed in a negative style, so being less than 3 corresponds to a positive perspective. On average, students fully agree that these kits and activities should be used in the coming years (Q5, average = 4.3), being suitable for the Automation and Control learning process (Q1, average = 4.2). The majority of students (90%) felt encouraged to use these kits.

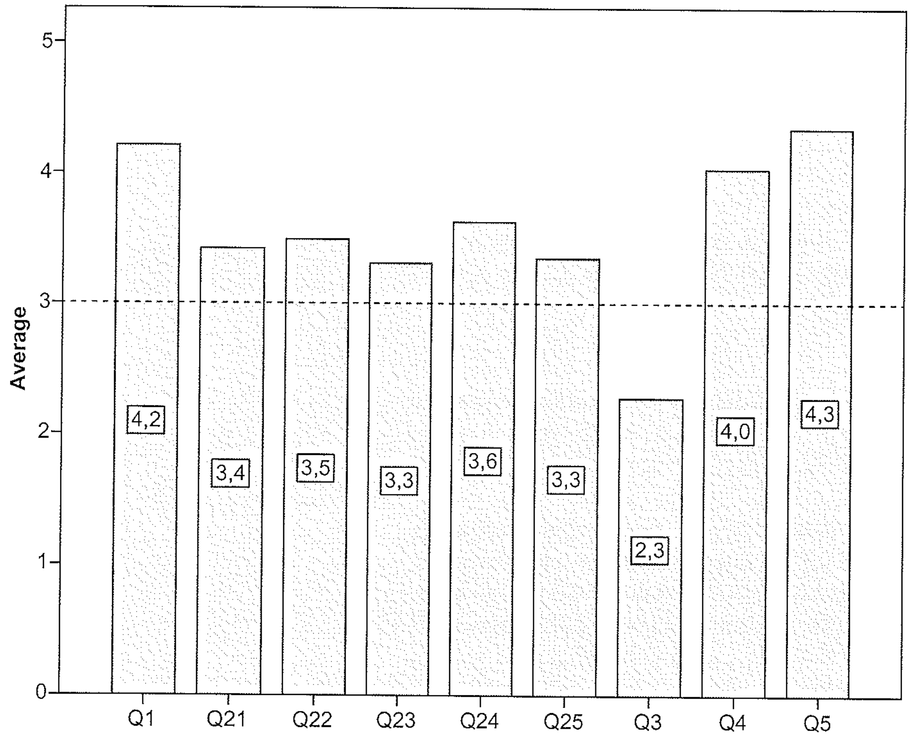


Fig. 9 *Average evaluation for didactics kits students' motivation, for each item.*

When examining what students say regarding kits' performance (Q21 to Q25), on average, the results were identical ranging from 3.3 to 3.6 ($\chi^2(4) = 3.04$, $p > 0.05$). However, not all the students agree on saying that kits increase the chance of getting a high final evaluation (Q23), as 15% preferred to disagree.

Conclusion

In this paper, educational experiences in Automation and Control subjects were described. A group of students voluntarily designed and implemented a set of didactic kits based on real environments, being involved and committed in their learning process. They implemented three different kits: 'Small intelligent house', 'Velocity control of a d.c. motor' and 'Temperature control of a classroom'.

From evaluation of the projects, the students fulfilled all the initial requests. The students' relationship established between the theoretical and practical concerns of the Automation and Control subjects were highly improved. All the developed kits can be used by other students as a demonstration tool in Automation and Control classes.

We believe that the paradigm 'learn by doing' fortifies the theoretical subjects presented in class. In this way, students enlarge their knowledge on the particular subject as well as in promoting their creativity, in their organizing capability and in the communication between working groups. Nevertheless, in the methodology based on experiential learning, the responsibility of learning must not be discarded. The experiential learning cycle imposes a powerful structure of its own, such as: timetables, deadlines, meetings, running and final reports.

The three developed didactic kits were introduced as a learning tool in the Digital Control course in the 3rd year of the Industrial Electronics Engineering undergraduate course and in the Process Control course on the 2nd Industrial Informatics undergraduate course. The students' agreement concerning their motivation in using the didactics kits as a pedagogical tool in their Control and Automation learning process was very positive and must be continued. To follow the students' opinion, the authors will continue with this methodology, implementing new kits developed by students for students.

It is worth mentioning that two institutions cooperated in developing remote laboratories in this work, enabling the optimization of human and physical resources and providing a high level education of excellence.

Acknowledgements

The authors are grateful to the Research Centers Algoritmi (FCOMP-01-0124-FEDER-022674) and 2C2T (PEst-C/CTM/UI0264/2011) as well as WALC research project (PTDC/ESC/68069/2006) for funding. The authors are also grateful to the students who participated in this project as designers and as end users.

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International Journal of Electrical Engineering Education

51/1

January 2014

International Journal of Electrical Engineering Education

Editorial Offices School of Electrical & Electronic Engineering, Sackville Street Building, The University of Manchester, Manchester M13 9PL, UK, Tel: +44(0)161 306 4799
E-mail: ijeee@manchester.ac.uk
Web site: http://www.eee.manchester.ac.uk/about-us/ijeee

Publisher Manchester University Press, Oxford Road, Manchester M13 9NR, UK
Web site: http://www.manchesteruniversitypress.co.uk
Advertising enquiries should be addressed to the Publicity Department, Manchester University Press

ISSN 0020-7209

Contents Vol. 51, No. 1 January 2014