Automation and Control in Engineering

A Global Approach with Educational Kits

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Abstract— **The well-known paradigm learning by doing is particularly important in engineering courses. Still, in some situations, there is a lack of real-world didactic workbenches due to the absence of financial support, human resources or maintenances restrictions. Following this trend, the authors have been trying to overcome this difficulty designing and implementing virtual and remote laboratories in Process Monitoring, Control and Automation teaching applied to Mechanical, Electronics and Biomedical Engineering. The goal of this paper is to review and present the work developed regarding the real-world workbenches to be used in automation and control practical classes as an integrated virtual and remote laboratory. Some important points include the modelling and control of Discrete Event Systems, Continuous Systems and Real-Time Systems as well as Industrial Control Networks. The physical parts were developed and connected, in a closed-loop configuration, with the respective controllers. The developed kits and systems were geared towards the engineering students' needs. This integrated approach is very useful for providing students with a global set of skills in this domain. Quantitative and qualitative studies are continuously applied not only for obtaining students feedback but also to gather information to devise strategies for future virtual and remote laboratory applications development suitable for the target public. The positive results achieved so far are very encouraging.**

Keywords-automation; control design; control engineering; control equipment; engineering education.

I. INTRODUCTION

The design of new teaching/learning methodologies implies the definition of tools and environments that promote students and teachers' engagement in the knowledge acquisition process. These tools will serve as a complement to the traditional face-to-face lectures.

In engineering courses the laboratory work is very important since it is when students have the opportunity to apply the theoretical concepts learned earlier. So, to install and maintain several working positions in the laboratory is sometimes a challenge: the equipment is expensive, laboratorial space and qualified personnel are not enough. And this problem is replicated at each school.

The virtual and remote (V&R) laboratories may overcome this limitation [1-6]. The students may access the V&R laboratory at any time and place testing the real-world case-study through a graphical animation or a remote webcam.

Nevertheless, a good understanding of the pedagogical aspects is crucial for an efficient remote labs use [7]. Remote laboratories can also be used as a link between the University and the Industry, by providing remote monitoring for some industrial applications [8].

With this in mind and regarding Automation and Control education, a multidisciplinary group of teachers with different backgrounds, from the University of Minho (UM) and from the Polytechnic Institute of Cávado and Ave (IPCA), at North of Portugal, have been centering their attention in designing and developing workbenches in order to enable a practical learning environment. The goal was to provide to the engineering students different pedagogical tools/examples in order to have real-world interactive situations, for instance virtual processes and interactive animations, as well as local and remote experiences.

Considering the main domains, concerning Control and Automation, considered at UM and IPCA - namely: Discrete Event Systems modeling and control, Continuous Systems modeling and control, Real-Time Systems modeling and control and control industrial networks - several workbenches have been developed. For teaching these domains several software tools and controllers can be used. It was, in this spirit, that the workbenches were developed. Also, the physical part of the workbenches were developed and connected, in a closed-loop configuration, with the respective controllers.

Some (five) of the developed solutions include: the velocity control of a Direct Current (DC) motor (modeled as a Continuous System, controlled by a microcontroller in which was implemented a discrete Proportional, Integral, Derivative (PID) algorithm); two examples of systems controlled by Programmable Logic Controller (PLC): an automation workbench for testing and simulating PLC programs (modeled as a Discrete Event System), and the implementation of a small intelligent house (modeled as a Real-Time System); and, finally, two workbenches controlled by Industrial Computers modeled, both, as Real-Time Systems: one, of them - the level control of a two-tank

system - using LabVIEW, and the other one - the acquisition of physiological signals – using, first, LabVIEW and, finally, C# and Java. This paper presents the developed solutions as an integrated V&R laboratory. Among others, this approach allows students to support and consolidate the traditional classes' model allowing an efficient learning methodology in the specific areas of Control, Automation, Domotics, and Biomedical Data Acquisition fully integrated in one laboratory.

In this way, in order to describe the work developed and exchanged experience on best practice in the use of V&R laboratory for educational purpose over several years this paper is organized as follows: Section 2 presents the five developed real-world didactic kits used in the work, Section 3 describes the qualitative and quantitative students feedback obtained during the experiments and finally, Section 4 enunciates the final remarks.

II. REAL-WORLD DIDACTIC KITS

The real-world engineering problems are from automation and control areas. The goal was to provide students with practical real-world examples previously learned at class. These examples were used in engineering courses of different areas Mechanical, Electronics and Biomedical, at two institutions, Minho University (Braga and Guimarães, Portugal) and IPCA (Barcelos, Portugal) with 3rd and 4th year's students. In the next subsections there are presented five developed kits: the velocity control of a DC motor, controlled by a Microcontroller; two examples of systems controlled by PLC: an automation workbench for testing and simulating PLC programs and the implementation of a small intelligent house; and, finally, two workbenches controlled by Industrial Computers: the level control of a two-tank system and the acquisition and treatment of physiological signals. The booking of students to access the developed kits is done by a queue defined by a set of conditions for proper priority (i.e., role of the participant – administrator or general user, user with/without previous scheduled access, etc).

A. Velocity Control of a DC Motor

A remote controlled DC motor velocity was developed for undergraduate control studies [9], allowing discrete PID algorithm testing and simulation [10]. A DC Motor "Maxon RE36" is inserted with an encoder "HEDS-5540 A11" for velocity measurement. The control methodology was implemented in a microcontroller. Four different digital versions of the PID algorithm are available. The microcontroller 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 user interface was developed in a LabVIEW (Figure 1). Twelve motor velocity values can be selected (from 7m/min to 335m/min). The user must select the PID algorithm to be tested as well as the proportional, integral and derivative controller parameters.

B. Automation Workbench

The main focus of the workbench is to allow faster testing and validation of PLC programs, modeled as discrete event systems. The global goal of the developed system is to simulate and test the control programs in order to be sure that, when tested on the real system, those programs will not damage the physical part of the platform. It must be highlighted that this platform can be accessed from outside by different users – using Internet access - from different origins.
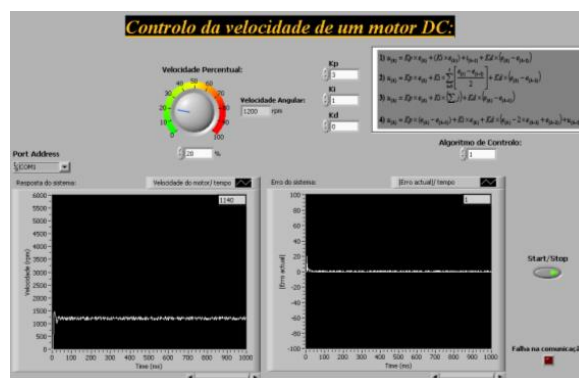

Figure 1. User interface [9].

Thus, it was decided to use a PLC as the controller device and another PLC that will interact with the first one, using a developed network for that, as the plant simulator. For this purpose, the PLC that will run the program that simulates the plant behavior generates all the input signals for the PLC that runs the program of the controller.

The best configuration to meet the needs of the proposed workbench is presented in Figure 2. OMRON equipment was used due to its availability in the laboratory. Both the controller and the plant models were implemented in the controllers OMRON CP1L M30 with CX-Programmer. The physical connection between components (the convertor MDW-45 and Personal Computer, PC and the converter and the PLC) was done using a serial port RS-422; in the connection PC-Converter an adaptor USB to serial port RS-232 was included.
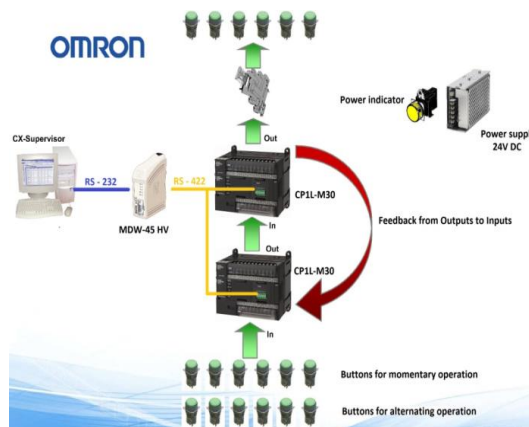

Figure 2. Hardware In the Loop Workbench circuit.

There were used the CX-One software and CX-Supervisor from OMRON. CX-One allows using CX-Programmer to edit and simulate programs and CX-Designer that allows creation of simulation scenarios (drawings, schemes, among others) and using these scenarios associated to the program developed in CX-Programmer the user can understand the simulation of the system. Together with these tools, CX-Supervisor is devoted to the design and operation of PC visualization and machine control. It allows interaction between the user and the PLC program that is running on the controller and also the interaction with the program that is in the PLC that simulates the plant.

C. Small Intelligent House

A test kit for a "small intelligent house" [2] with the following functionalities was developed: alarm control, temperature control, entrance door open/close, and illumination control (Figure 3). 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 simulation of the "small intelligent" house was developed in LabVIEW (Figure 4). The LabVIEW interface enables both simulation and "small intelligent" house 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, as well as real time monitoring using a Webcam.

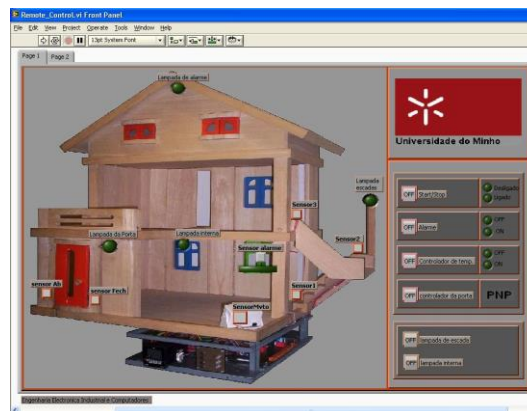Figure 3.   Small Intelligent House Kit.

Figure 4.   User interface.

D. Level Control of a Two-Tanks System

This work considers the objective of the design and implementation of a remote experiment for controlling the water level in a two-tank system (Figure 5) [7].
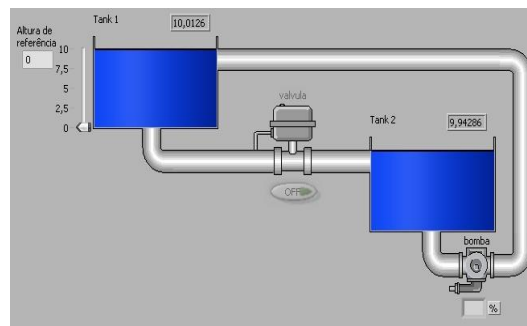

Figure 5.   Two tanks system Layout [7].

The system includes two tanks made in acrylic, a pump to circulate the water from the lower to the upper tank, two ultrasonic sensors for measuring both tank levels, an electrovalve to stop the flow between the upper and the lower level tank and a manual valve for security purposes. The upper tank is being controlled and the lower tank serves as a buffer.

An 8-bit Atmega16 microcontroller from Atmel is used for data acquisition, control and pump actuation. A custom made LabVIEW tool, the Watch Tank, was developed for monitoring purposes. The control algorithms, on-off and PID are implemented in the microcontroller that is connected to a PC by a RS232 protocol.

The user interface, Watch Tank, developed in LabVIEW allows the monitoring of the system (Figure 6). In the Watch Tank program, the user must select the PID type algorithm to be tested, as well as the controller parameters, Kp, Ki and Kd, the proportional, integral and derivatives constants, respectively.
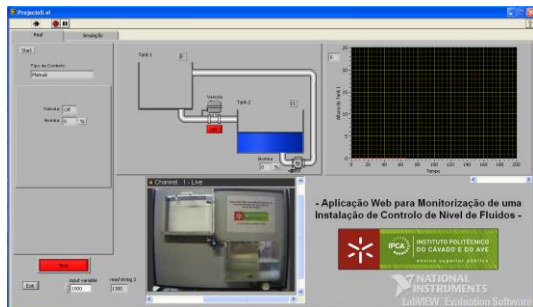
Figure 6.   User interface [7].

The user can test the digital algorithms and parameters, change level reference values and register the output data. The system can be set available with either local or remote control configurations for teaching/learning purposes. A Webcam is used for real-time monitoring.

E.   Remote Physiological Signals

The study of human physiology allows understanding the human body's structure and the processes that are carried out within it, which involves mechanical, electrical and chemical forces. So, and in order to support the biomedical engineering undergraduate students' learning process on physiological data acquisition studies, an innovative remote laboratory has been developed: RePhyS (Remote Physiological Systems) laboratory. RePhyS is capable of engaging biomedical engineering students, providing the real-time remote acquisition of physiological signals from the human body through a web platform. The educational goals should be achieved, namely the knowledge of acquisition methods, the recognition of the signals and the identification of important components of each one [11].

RePhyS was developed using the commercial BioStarter® kit, with sensors' modules: Electrocardiogram (ECG), Electromyography (EMG), Galvanic Skin Response (GSR), Strain Gauge and an accelerometer. The system includes different remote experiments for the acquisition and study of different physiological signals [12]. The data processing, storage and transmission are made by a computer Bluetooth connection. The general architecture of the RePhyS lab is presented in Figure 7. The ShimmerTM device captures the data through the electrodes placed on the human body. The Bluetooth (IEEE 802.15.1) connection established between the computer, in the real laboratory, and the experiment allows the control and the configuration of the device, and the transfer of measured physiological data. The students, located in a distance place, access the experience through an interface, on an Internet browser, facilitating the interaction with the device through various control buttons. A webcam allows monitoring of the experience.

Figure 7.   General architecture of RePhyS.

Figure 8 shows the user interface for the acquisition of ECG remote data acquisition. The experiments developed were initially implemented with LabVIEW being others user-side solutions (C and Java) under development [12].

Thus, the student/user can acquire, visualize and analyze, in real-time, the results of practical experiences being able to interact and to control the measurement parameters. The stored data is always available for further processing.

Currently, the architecture defined for the first version of the remote laboratory is being improved. Thus, RePhyS will allow simultaneous access up to three users, each having a control experiment, and will also allow the simultaneous use of several modules that is, in the same experiment, able to study various physiological conditions of the system.

Figure 8.   RePhyS user interface during an ECG remote acquisition.

III.   QUALITATIVE AND QUANTITATIVE STUDENTS FEEDBACK

For all kits and systems described herein, and in order to obtain the feedback of students, questionnaires were always presented and results analyzed by the teachers involved in the process. The studies also allow the identification of students learning style in order to develop a platform suitable for the engineering learners. The detailed results can be found elsewhere [9, 13].

The use of these questionnaires (n=200, number of students) enabled the improvement of the educational kits in order to accomplish their objective. The questionnaires had open questions in order to obtain students feedback towards specific points as well as quantitative questions defined in

the Likert scale (1, strongly disagree, to 5, completely agree). The analysis was performed using SPSS software.

The questionnaires were divided in sections: after the student characterization, close, open and multiple choices responses, and the evaluation of several statements for the experiment evaluation, the simulator assessment, and to analyze students' perspectives, fillings and knowledge before and after carried out the experiment were used.

The students that participated in this study were from Mechanical, Electronics and Biomedical engineering courses, having an average of 21 years old, of which 20% were female (Biomedical presents the highest percentage of female students with 40%). Concerning the experiment evaluation, on average, students evaluate it with a positive score (values higher than 3 for Q1, Q2, Q4, Q5, Q6 and lower than 3 for Q3), as described in Table I.

TABLE I.   KITS AVERAGE STUDENTS' EVALUATION BY ITEM

Item	Average
Q1: In general, I was motivated for the use of these kits in the course context.	4.4
Q2: In general, I can say that the performance of the kits…	
1: … helped me assimilate the concepts presented during the course	3.6
2: … made my learning more objective	3.7
3: … increased my chances of getting a high final evaluation	3.5
4: … motivated me towards the course	3.8
5: … raised my expectations relative to the assessment	3.5
Q3: Running the kits had nothing to do with my motivation and my interest in this course.	2.2
Q4: The kits are suitable for my Control/Automation learning process.	4.2
Q5: I recommend the implementation of these kits and activities, in the next school year, as a teaching/learning tool.	4.3
Q6: The implementation of the remote experiment …	
1: … has increased understanding of the operation of an on-off controller.	3.5
2: … has increased understanding of the operation of the PID controller.	3.1
3: … allow the visualization of the effect of the off-set reduced when going from a controller P to PI.	3.0
4: motivated to learn the subjects under study.	3.5

Based on a protocol, Biomedical engineering students performed several remote experiments in physiological signals acquisition (RePhyS: ECG, body acceleration and body temperature acquisition). All students understood the ECG signal acquisition and they were able to identify all the waves' constituents during the data real-time visualization (as demonstrated in Figure 8). For the other two experiments, 89% identified to have understood and visualized the experiments.

Recently students' perception in relation to their own learning style and the learning style employed during the experiment performance, in accordance with the students' perspective, has been considered. The analysis of this factor becomes an important indicator on how these kits or the V&R laboratories procedure is appropriate for the students' learning process.

In short, it is possible to observe that, and based on the Biomedical engineering students, 67% prefer to process information more actively (2nd and 3th quadrants, Figure 9),

and 67% also prefer to understand the concepts through concrete experiences (1st and 2nd quadrant, Figure 9). This behavior (expected in some way) is coherent to an engineering behavior: motivated to investigate how situations are processed and to put into practice ideas. This information is important as it suggests that the development efforts of these didactics kits meet engineering students' learning styles.
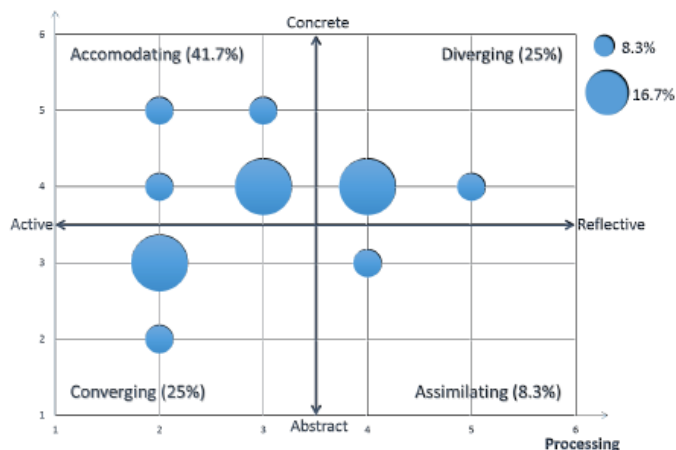

Figure 9.   Learning Styles diagram obtained: 1st quadrant – diverging style, 2nd quadrant – accomodating style, 3rd quadrant – covengent style, 4th quadrant – assimilating style.

The qualitative analysis of the data helped to recognize the necessity of devising and implementing new learning strategies to fulfill students' needs. The students replied to the questionnaire on a voluntary basis and according to the experiment conducted. A majority if not all students who performed the experience have accepted this challenge.

The strategy designed V&R laboratory development is appropriated for the target public's learning style (converging learning style) where students do the things in an active way and they have a more abstract perception of the situations.

In general, the students' feedback about the use of the kits and system in Automation and Control Engineering studies is very positive stating that these kits and activities should be used in the coming years, and being suitable for the Automation and Control learning process. The majority of students felt encouraged in using these kits and sentences like: "*an innovative and useful tool*"; "*easy to understand*", and "*rewarding experience*" were found.

The less positive issues pointed out by students were concerned to more technical aspects, like specific problems with the Internet connection, real-time monitoring of an experiment. For a continuous improvement, new alternatives are under studied to overcome the identified problems. The feedback from students to these real-world engineering problems was very positive allowing the researchers to continue and improve this methodology.

IV. FINAL REMARKS

This work describes the work undertaken at two Higher Education Institutions, from north of Portugal, on the development of V&R laboratories as facilitators in the students' study. The students can be from different engineering branches, aiming towards a final objective of optimizing their learning about different important subjects that must be highlighted in the context of teaching of Control and Automation for different future Engineers in many areas, including mechanical engineering, biomedical engineering, and electronics engineering that will need Control and Automation knowledge during their professional life.

Although some of the didactics kits developed and presented in this paper could be considered comparable to some described in the literature (while it has been authors' choice to include as they are part of the automation and control laboratory described), the acquisition and treatment of physiological signals correspond to an innovative remote laboratory. So, this paper describes the development of the virtual and remote laboratory since its creation until today, highlighting the strengths of the didactics kits selected.

A real added value of this project is the use of dedicated workbenches – covering, in a complementary way, the domains related with teaching of control and automation fields - for dedicated needs of real learning, as commercial tools available are very specific mismatching important concepts, together, in the Control and Automation domains.

Based on the different views expressed by students, the final users of the kits and system in Automation and Control Engineering studies, alongside positive points, there are also a few negative points to be identified. The positive points state that these kits and activities are suitable for the Automation and Control learning process and should be used in the coming years. The less positive point identified is concerned to technical aspects, namely specific problems with the Internet connection and real-time monitoring of an experiment.

Finally, it is important to highlight that strong physical and human resources have been optimized because students from both institutions can use this remote access laboratory and experiences have been developed taking into account their specific Curricular Unit's needs.

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