Distance Practices in Subjects of Automatic Control

Iván Santana Ching, Luis Hernández Santana
Dpto. de Automática y Sistemas Computacionales,
Universidad Central Marta Abreu de Las Villas,
Santa Clara, Cuba,
ching@uclv.edu.cu

Manuel Ferre Pérez, Rafael Aracil Santonja, Enrique Pinto, Ángel García Beltrán
Dpto. de Automática, Ingeniería Electrónica e Informática Industrial, UPM, ETSI Industriales,
Madrid, España,
mferre@etsii.upm.es

***Abstract*—This work aims at suitably combining hands-on and remote practices in the teaching of automatic control subjects. Virtual and Remote Laboratories in Automatic education have increasingly become a method utilized by universities in their efforts to offer greater schedule flexibility and operation of available resources. This paper discusses the implementation of remote experiments for Automatic Control through both the Distance Laboratory System (SLD), developed at the Universidad Central Marta Abreu de Las Villas, and AulaWeb, developed at the ETSI Industriales of Universidad Politécnica de Madrid.**

The SLD allows users (i) to learn and adjust predefined controllers, (ii) to design new controllers, and (iii) to test and analyze the performance of the predefined/designed controllers over a set of physical devices. The SLD uses MATLAB-Simulink for the distance laboratory, i.e. testing the predefined/designed controllers for practice and the Real Time Workshop Toolbox (RTW) as a real time kernel.

AulaWeb is used as an aid for students and teachers of academic subjects. AulaWeb has been tested at several engineering schools and has been used by over 2000 students each year.

This work shows the results using SLD and AulaWeb in Regulación Automática I of the Universidad Politécnica de Madrid. The distance and virtual practices, made in SLD, are combined with the question in AulaWeb to form Web self-assessment tools.

Keywords- education of control, remote control, remote laboratories, virtual laboratories, innovative education

I. Introduction

Laboratory experiments are an essential part of engineering education. They complement theoretical lectures, as well as illustrate and validate analytical concepts which introduce students to professional practice, social development and teamwork skills in a technical environment [1]. These reasons explain the student's high expectations for laboratory activities.

Simulation tools for training have been popular mainly due to the high cost of maintaining and operating lab equipment. However, despite the advantages – low cost and relatively ease of use – simulators cannot efficiently replicate noise, frequency responses, D/A conversion and other physical phenomena that characterize real systems [2].

The advent of computer technology, particularly the arrival of the Internet, has presented new opportunities to the sharing of expensive software and hardware resources. Consequently, virtual [3] and remote control [4] applications have been developed. These new applications offer the capabilities and flexibilities of simulation tools; while keeping important characteristics of physical systems [5], and distance laboratory applications. Remote experimentation facilities, offered as part of a web-based learning approach, afford a number of critical benefits. For engineering distance education courses, remote facilities constitute the only realistic method of performing many experiments. They allow remotely located students, no longer constrained by time or geographical considerations, complete lab assignments. Thus, it is fair to conclude that remote experimentation facilities enhance the development of skills in the use of real systems and instrumentation [6].

In [7], the authors provide a literature review of modern remote laboratories. In addition, they identify possible evolutions for the next generation of remote laboratories which are under a strong current of evolution. Such labs would no longer be restricted to a single educational topic, where Automatics and Robotics constitute the most frequently used tools.

In the majority of cited remote control experiments, remote users can run an experiment and adjust the process or controller parameters from a set of predefined controllers. This limits the practice to some type of controllers (PI, PID, space of state, etc.).

The Automatic Control Telelab (ACT) enables students to choose a control law, change the control parameters online, and even design their own controller [8]. Our developed Distance Laboratory System (SLD) allows learning and adjusting predefined controllers, designing new controllers, and testing and analyzing the performance of the predefined/designed controllers over a set of physical devices [9].

SLD exhibits some features in common with most distance laboratories in operation at present, such as ease of use, availability and accessibility. Some additional characteristics such as user-friendly and fast user interface, management of multiple requests in parallel form, controller development using MATLAB and Simulink in a remote way and reference change are also added [9]. The SLD incurred in various technological updates aiming to improving its performance and security [10].

AulaWeb [11] is a Web self-assessment tool (WSAT) which serves as an aid for students and teachers of academic subjects. AulaWeb was built by the UPM and has been tested at several engineering schools and used by over 2000 students each year.

The paper shows a suitable combination of hands-on, remote practices, virtual practices and variable questions in the subject of Regulación Automática I at the Universidad Politécnica de Madrid, using SLD and AulaWeb.

This paper is organized as follows: section II describes the subject of "Regulación Automática I". Section III shows the works that are performed by the students by using SLD, taking into account their possibilities of use in Automatic Education. Section IV focuses on the methodology used in the subject. Section V shows the results obtained in the last course. Statistics about the time devoted by the students is summarized according to the survey completed at the end of the course. Finally, section VI summarizes important conclusions.

II. SUBJECT ANALYSIS OF REGULACIÓN AUTOMÁTICA I

The Regulación Automática I contents have been adjusted to cover the important aspects of the subject assuming a realistic balance between workload and dedication of the student [12].

The subject is made up by 144 hours, 78 of which are study hours (Figure 1). They are equivalent to 4.8 credits ECTS.

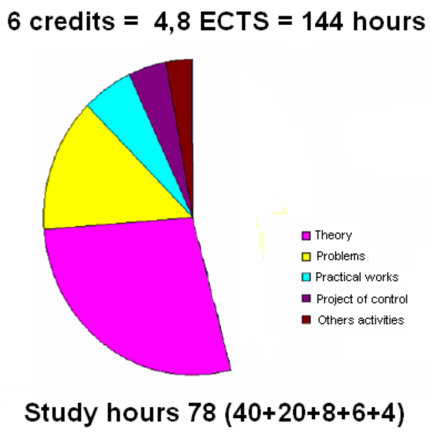

Figure 1. Study hours of students.

The program of the subject is made up by fourteen lessons and eight practical works [12]. This equates to an approximate average of a lesson per week and a practical every fortnight. The studied matters are dedicated to model and analyze discreet systems, as well as to study the feedback systems, with emphasis in the calculation of regulators. One of the chapters is concerned with the methods of system identification using algorithms based on square minimums.

A. *Hands-on practices in Regulación Automática I*

The subject has three real experiments in the laboratory of automatic.

The first practical work developed by the student consists of the implementation in real time of a system of control with continuous regulator. By means of this practice, the student will be able to analyze the advantages of operation of classic regulators P, PI and PID on a real system. The interface used is Simulink executed in real time with Real Time Target Windows.

In a second practical work, the student makes a model of Simulink in real time testing on a physical system.

The implementation of discreet regulators R (z) is made in a third practical work. In this activity, the student tries to design a discreet regulator by means of some of the techniques studied in class.

The laboratory of practices, where these activities are carried out, is formed by eight positions, each equipped with a computer, a data acquisition card (AD622 of Humusoft), two scale models, a thermal system and DC motors.

B. *Practical activities in AulaWeb*

The subject has five activities in AulaWeb. In each of them, the student only needs Matlab.

Before making a practical work, the student must complete a self-assessment exercise through AulaWeb.

C. *Project of control*

The control project is an activity that is made so that the student applies the knowledge acquired in the accomplishment of a control system. The student must choose what technique of modeling and what control tools has to use at every moment.

III. USE OF THE SLD IN THE SUBJECT REGULACIÓN AUTOMÁTICA I

The SLD has the capacity to support any type of practice where measurement and control are electrical signals; at present, the experiences developed, use DC motor and a robot manipulator [13] at UCLV and a thermal system at UPM.

A DC motor and the thermal system are single input and single output process (SISO) that lets to carry out identification, position control, velocity control and temperature control, experiments without loading disturbances.

The robot manipulator is a system with multiple inputs and multiple outputs (MIMO) that exhibits very coupled and stronger non-linear dynamics. It permits to carry out more complex positioning and trajectory tracking control.

The Table I summarize some topics, in Automatic Control Systems Education [14], where the SLD could be effectively used.

TABLE I. TOPICS WHERE THE SLD COULD BE EFFECTIVELY USED

Subjects	Topics
Modeling and simulation	Experimental Identification of SISO Systems. Transient Response Analysis.
Classic Control	Control System Design by Transient-Response. Control System Design by Frequency-Response. Tuning of PID Controller.
Modern Control	Design of Control System in State Space. Design of Regulator-Type by Pole Placement. Design of

	State Observer. Optimal Control Adaptive Control.
Digital Control	Sample Time Selection. Selection and Tuning of digital Controller. Digital Leg Compensation. Digital Lag Compensation.
Robotic	Dynamic Modeling of Manipulators. Trajectory Planning. Independent Joint Control. Computer Torque Feed forward Control. Control with Compensation. Adaptive Control

The SLD is used to make virtual practices and real practices remotely. It is also utilized in the development of the integrated project.

As exposed in [9], the SLD allows the performing of simulated and real practices in two variants: with predefined controller and with controller user defined. In this subject, all the variants for the design of the practices are used.

A. Real and virtual practices in a remote way

Real and simulated practices were designed in the SLD for the thermal scale model present in the laboratory (Figure 2). The theoretical transfer function of the thermal system shows in (1).

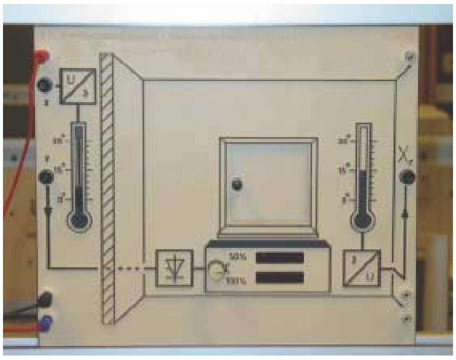

Figure 2. Thermal model

$$G(s) = \frac{0.9}{(1+7s)^3} \qquad (1)$$

Firstly, a practice was made which allowed the adjustment of a regulator PID to obtain the desired results (Figure 3).

This practice agrees with the first practice developed by the student. The reason behind making it remote is that it allows the student to perform new tests and see the effects in the answer of the system.

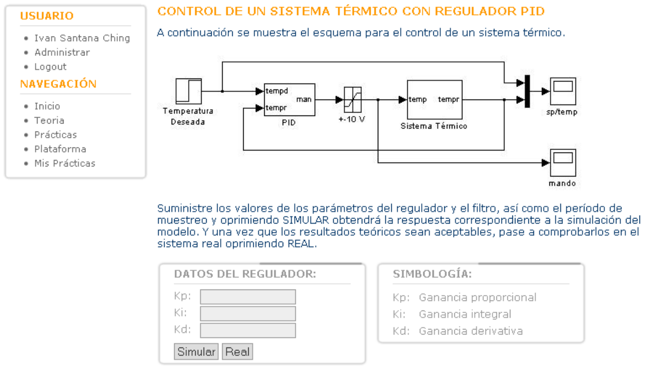

Figure 3. Web Page of thermal system practices with regulator PID.

The students have numerous possibilities to test the effects of proportional, integral and derivative control actions on the system step transient-response, first by simulation and then in real way.

The simulated and real answer of the thermal system with regulator PID, for Kp = 1, Ki = 0,067 and Kd = 7 as in (Figure 4).

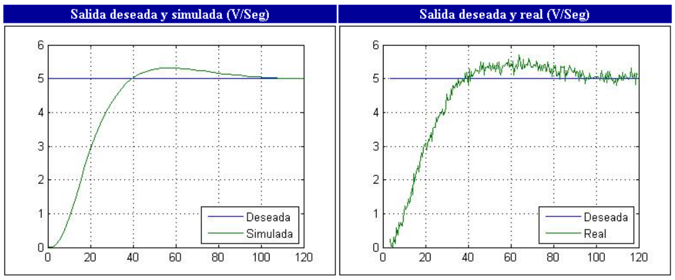

Figure 4. Simulated and real answer of the thermal system with regulator PID

In addition, a practice with controller user defined was designed. With this practice the students prove other algorithms of control and design their own regulators using MATLAB/Simulink.

When a practice with controller user defined is selected, a Web page is shown. This web page permits the downloading of a Simulink file (Figure 5). This file contains the block diagram of the practice. In addition, the user can modify the subsystems Reference and Regulator using software Matlab/Simulink, altering neither the name nor the amount of entrances and exits of the subsystems (Figure 6).

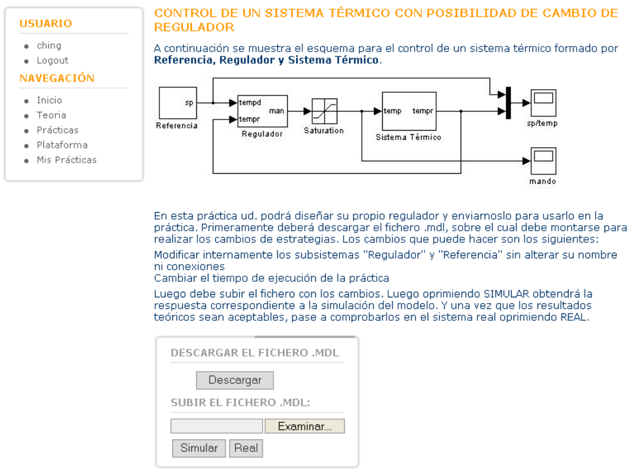

Figure 5. Web Page of thermal system practices with regulator user defined.

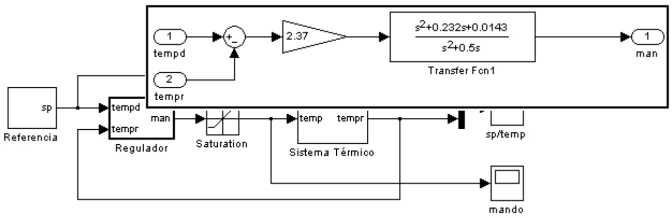

Figure 6. Simulink diagram of thermal system practices with regulator user defined.

B. *Practices developed for the integrated project.*

The integrated project was formed by three parts. In the first the student identified a system that varied depending of its registration number. A practice was designed that showed the answer of the system with white noise in the reference and step in the disturbance (Figure 7). The student identified the different blocks that formed the system, using the methods learned in class.

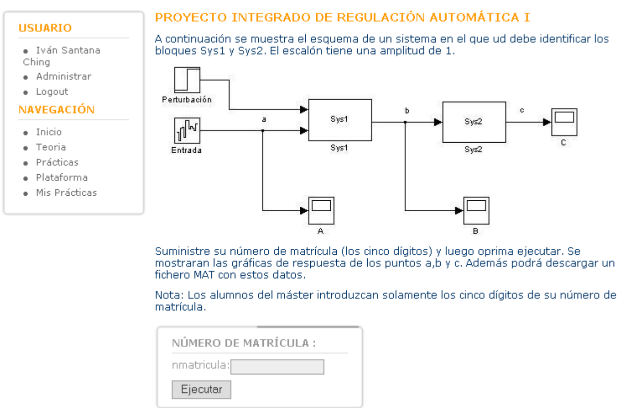

Figure 7. Web Page of integrated project part one.

In the second part, the student designs regulators for the identified system fulfilling some requirements in the answer. The designed practice is of controller user defined. This is the reason why the student designs his regulator and test with the real system comparing the answers.

In the third part, students make designs of compensation such as feedback and cascade compensation. The designed practice is of controller user defined like in the second part.

IV. METHODOLOGY USED IN REGULACIÓN AUTOMÁTICA I SUBJECT

As mentioned previously, this work shows the suitable combination of hands-on experiments, remote practices and activities of self-assessment.

The practical activities with AulaWeb were made several courses ago and allow a continuous assessment of the subject.

The combination of hands-on practices in the laboratory and remote practices was used as methodology, taking advantage of both variants. Hands-on practices have a great formative value for the students. They allow them to know and manipulate the physical equipment with which they work.

Once the student is familiarized with the systems they use, they can work at a distance with them, with the advantages of completion and optimization of the resources. Since the programming and capturing of data require between 10 and 20 minutes, the effective time using the devices is usually reduced. The accomplishments of remote works include time savings for the student and the sharing of resources. This is particularly important when the number of students is large and the equipment is expensive.

Another interesting aspect, that arises when combining hands-on and remote practices, is that the time of use of the equipment is not limited. The students can use them until they consider that they have reached the desired objectives.

In the integrated project, the statement of the different parts took place at AulaWeb, whereas the taking of data, graphs and the test of the regulators at SLD. The practices considered the registration number, thus they guaranteed a different game of data for each student which ensured the project's personalization. The delivery of the information took place through AulaWeb. This allowed the students to continue using the normal method of work and adapt to the SLD without difficulty.

V. RESULTS OBTAINED IN THE SUBJECT

The results obtained in the subject were good. The students were motivated with the use of the SLD for the integrated project. Nevertheless the access to the remote practices was modest, perhaps caused by the lack of information and ignorance of the possibilities that this method presents.

A survey on the subject was carried out. It took into account the following aspects:

- Dedication to the subject.
- Practical works.

Practical activities represent the most important aspect of this work. Items treated from this point of view include:

1. All practical works foster understanding of the subject.
2. The practical works and theoretical classes are balanced.
3. The integrated project contributes to the better understanding of the subject.
4. The time for the accomplishment of the integrated project was sufficient.
5. It was easy to use the Distance Laboratory System (SLD) in the integrated project.

Survey results, in a scale from 1 to 5, behaved as follows (Table II).

TABLE II. RESULTS OF THE SURVEY

Items (1 to 5)	Average	Median	Standard deviation
All practical works foster understanding of the subject.	3.94	4	0.85
The practical works and theoretical classes are balanced.	3.29	4	1.32
The integrated project contributes to the better understanding of the subject.	3.46	4	1.26
The time for the accomplishment of the integrated project was sufficient.	2.23	2	1.17
It was easy to use the Distance Laboratory System (SLD) in the integrated project.	3.19	3	1.22

The results obtained are positive. The students value the practical works which they consider to have a good balance with the theoretical activities. The students positively evaluated the integrated project; however, they considered that the time assigned to carry it out was not sufficient. Conversely, the professors agree that it lacked dedication on the students' part. Finally, the valuation of the SLD in the integrated project may be considered as acceptable, taking into account that it is used for the first time.

It was approved as an educative innovation project aimed at developing and evaluating the impact of new educative tools for learning subjects of Systems Engineering and Automatic.

VI. CONCLUSIONS

The accomplishment of practical works in the subjects of Automatic is a fundamental to achieve quality of teaching. The concepts explained in these subjects have an immediate impact in the implementation of control systems. The type of experiments to make is another important aspect. That is whether the student directly performs them on the physical equipment of the laboratory – as in the traditional way – or experiments accessing equipment remotely or using virtual models that simulate the physical behaviour of the systems.

The adopted option is that the students of the specialty will combine the execution of hands-on and distance practices. This allows them to know the operation of real equipments during the hands-on sessions, as well analyze different schemes from control at distance sessions. This methodology assumes no more than 100 students per classroom.

On the other hand, the students who are not of the specialty will work with virtual laboratories that simulate the behaviour of physical systems. This allows that large groups (classrooms with more than100 students) make several experimental works. In the case of hands-on practices, it would only be possible to make one or two during the course due to the limitation in the number of equipment.

In summary, the use of the SLD brings about a more flexible use of hands-on laboratories and a more rational use of the resources available. In addition, SLD offers the students great possibilities of development and investigation while trying studied algorithms of control in physical plants. The main benefit obtained to date is the reinforcing of the students' learning process when using the combination of hands-on and remote practices. This is derived from the fact that the real hours allow them to familiarize and manipulate the physical equipment directly, whereas remote working hours permit them to test different algorithms and techniques from control without the schedule restrictions.

This methodology increases the practical activities. In addition, students devote more time to the subject during the semester and this effort is rewarded in the final mark.

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