# iCERi 2009

International Conference of Education, Research and Innovation

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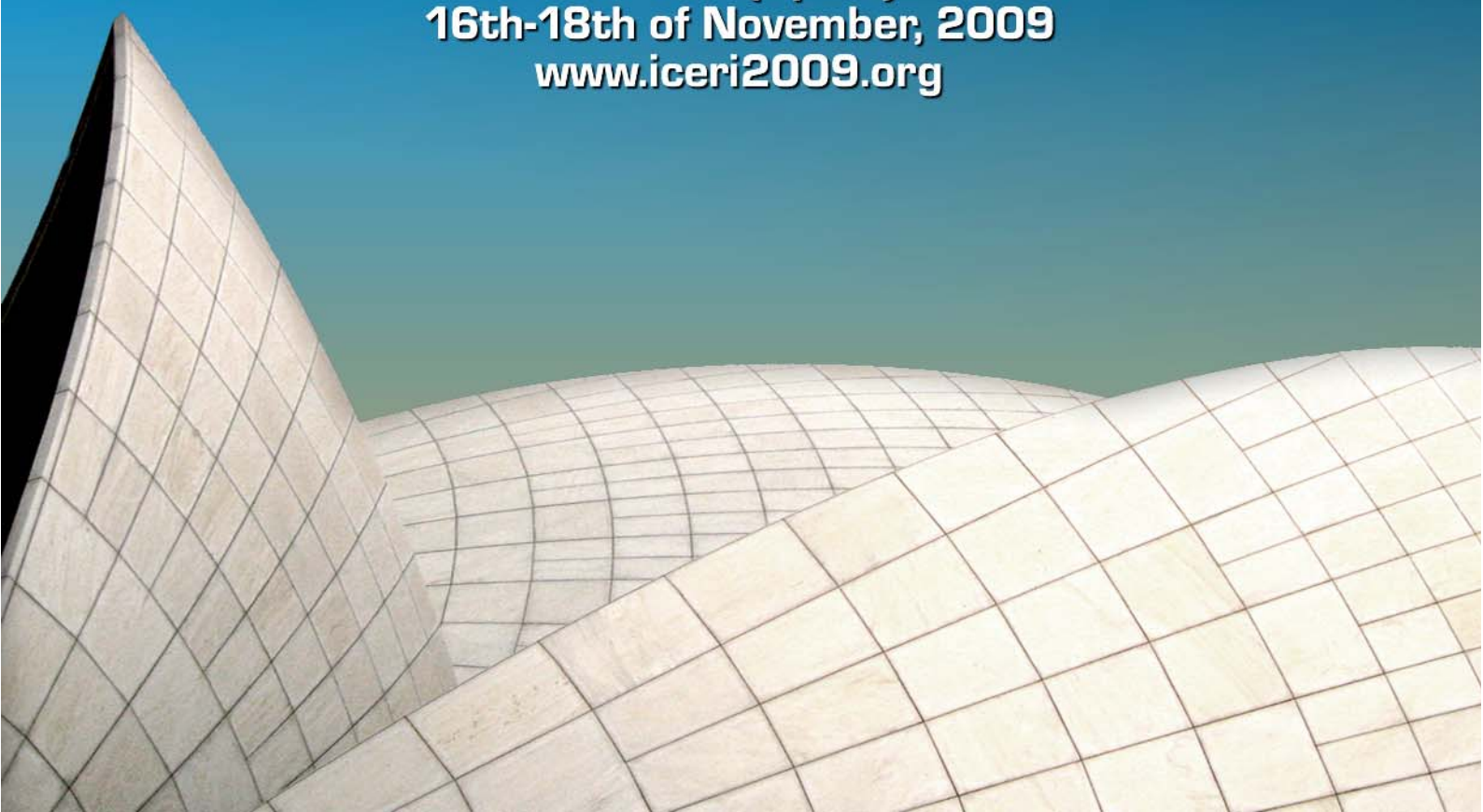16th-18th of November, 2009
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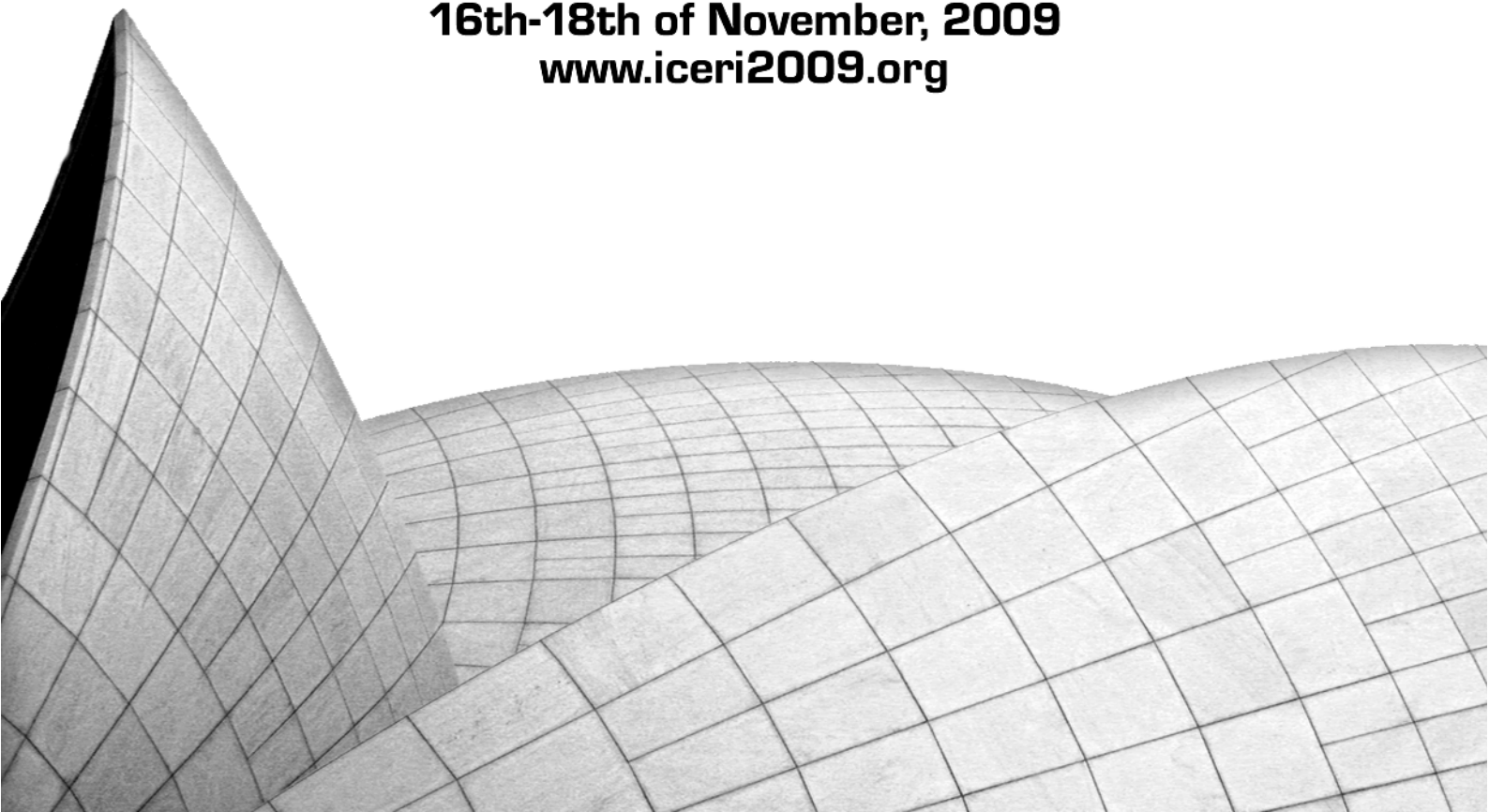Madrid (Spain)
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# USING A REMOTE LABORATORY FOR TEACHING LABORATORY PRACTICES IN ENGINEERING COURSES

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## Abstract

In this paper the results reached in the use of a remote control laboratory are presented and analyzed. During both last academic years (courses 2007/08 and 2008/09) a set of remote laboratories has been operational so that the students of diverse subjects of engineering and Universities can perform the laboratory practices through Internet. In engineering studies the accomplishment of practices with physical or virtual systems that complement the knowledge acquired by the students is essential. By means of these laboratory practices and experiments the students can understand and assimilate the theoretical knowledge provided in classical lessons. In this type of technical degrees, is of great importance the use of real physical systems. One of the main problems that must be take into account by education centres is the possibility of having a high number of laboratories and physical systems on which the students can make these teaching practices. Frequently, these laboratories need equipment that is expensive and must be replicated in enough amounts so that the students can realise experiments individually or in groups composed by few students. The use of the remote laboratories, which have arisen during the past few years, allows that the students can accede to these physical systems at any moment and from any location, whenever they have access to Internet. In this way, the use of laboratory equipment is made flexible allowing a more suitable use of it, since it is not necessary to go to the laboratory to realise the experiments.

During both last academic courses, an action of educational innovation has started up at the Elche's Miguel Hernandez University that has allowed a group of students to arrange the traditional laboratory practices with this remote laboratory. This experience has been carried out in subjects related to the discipline of automatic control. Specifically it has carried out in several courses: PLC's and Control Systems within the degrees of Industrial Engineering and Telecommunications Engineering. Some of the most significant aspects reached in this experience are analyzed in this paper: types of practices carried out during these two academic courses; number of students who have accomplished them; index of satisfaction in the execution of the practices; evaluation and learning success in relation to the traditional practices, etc. Of the experience obtained during these two academic courses it is possible conclude that the results are highly satisfactory from both: the student point of view with a more flexible participation to their needs, and from the teacher point of view that could interact with the student, in specific questions and observe at any moment the degree of learning of the student.

*Keywords -* Remote laboratory, Control practice, engineering courses.

## 1  INTRODUCTION

In recent years, the use of new technologies in education has experienced a remarkable growth. In this sense, it is remarkable the increasing in the number of students using an applying new technologies in their learning process. Thus, nowadays it is easy to find Internet sites that offer remote training courses that enable certain tasks to support throughout the network. Remote tools through Internet such as tutorials, images, videos or simulations, offer excellent opportunities for teachers and students. The teachers can find so many possibilities in the way they can show the contents related to a particular subject. A wide range of possibilities can replace the limitation of traditional lectures to a high number of students. The quantity of examples that can be found by means of internet about a concrete subject grows exponentially in time.

On the other hand, the use of new technologies allows students to modify substantially the classic learning process. Attendance at lectures where a professor imparts knowledge from a platform can be modified by new teaching methods [10] [11]. Some years aho the student planned schedules to attend such contact sessions (sometimes mandatory). However with the use of new technologies the students have the potential to acquire new knowledge as this is being assimilated [9]. The use of Internet as a channel from which to develop the teaching-learning processes, enables students from wherever you are to have all materials needed for the assimilation of knowledge in a specific subject. The student no longer need the assistance and permanent presence in the lecture, but from any location with internet connexion can use the documents, examples, graphics, etc. necessary to acquire such knowledge. But not only improves the possibility of not attending lectures in person. The student decides when is prepared to acquire such knowledge. This time is also elected by the student according to their particular needs [3].

As a consequence, during recent years the number and type of resources that students can access via the Internet have increased [4] [6]. Such resources undoubtedly allow to the student to acquire a better and more flexible acquisition of knowledge in a particular subject. However, there are subjects in which in addition to theoretical knowledge about them, it is necessary to undertake and acquire a range of skills so that learning is complete. Traditionally these skills are acquired by students in laboratories where they can experiment with equipments and plants physically available in them.

This paper is focussed on it. The results achieved in the use of a system that enables to the students the implementation of practices through the Internet with remote physical systems is discussed in this paper. The use of remote physical systems by the students allows them to experiment with these physical system and to acquire the skills necessary in the subject. The problems associated with the use of such physical systems via Internet are more important and numerous than those addressed in other systems. Some problems must to be take into account in the design and implementation of this remote laboratory. We present in this paper the experience with the use of one of remote laboratory using during the last two years at the University Miguel Hernández de Elche.

The remainder of the paper is structured as follows. In the following section the importance of practical content in engineering-related degrees is discussed. Similarly we classify the different laboratories we can use in the learning process. In Section 3 we present the subject in which this remote control laboratory has used during the last two years. In the next section some details of the implemented system, both from the standpoint of hardware, communications and software and user interface are discussed. In Section 5 the results using this remote control laboratory over the past two academic years is analused, to then address the reviews received by students compared with other available resources. Finally conclusions are presented.


## 2   PRACTICES IN TEACHING


As it was mentioned earlier, experimental work is essential in subjects of technical content to establish the theoretical knowledge previously received. In subjects related to engineering it is necessary to undertake such kind of practices to consolidate the previously acquired knowledge. In recent years a significant number of simulations can be found on the Internet on a variety of physical systems. These simulations can be downloaded by the users on their computer, or remotely executed, varying operating conditions so that they can experience different situations in a simulated way [8].

In any case, these systems can not replace the experience in the manipulation of physical systems by the student, that is an important part of the learning process. This is especially important in the subjects in the field of engineering. The use of physical systems like servo pendulums, coupled deposits or temperature control systems is an essential tool in many courses and subjects related to engineering and more specifically in courses or subjects related with the control theory. Moreover, the use of programmable logic controllers that control production lines, classification systems or manipulators is typical in automation courses.

Traditional and classical teaching in this area is affected by three factors that degrade the educational results:

1. The limited time availability of laboratories. Students can carry out experiments in laboratories in inflexible schedules and most cases too tight. Thus the student can not experiment freely and discuss the issues they consider most necessary with more emphasis.

2. Limitation on the number of laboratory equipments. The high cost of the models and control systems makes the number of equipments available is low for the number of students in practice. This causes that students should share the equipment with three or more partners in many cases reducing the learning ability in the experiments. It also limits the variety of physical elements available in a laboratory due to their high costs.

3. The evaluation system. The traditional methods of reporting results in many cases is not an effective mechanism for real learning. Self-evaluation by the student encourages self-learning. Also self-evaluation requires a more active presence of the student during laboratory practice.

The use of remote labs via the Internet can improve these aspects getting include:

- Improving the availability of new equipments in the laboratory due to it is not necesary to acquire several unities.
- Increasing the number of practices.
- Timetable and scheduling of wider access and flexible.
- Increasing student commitment to the completion of the practices.
- Improving the learning process.

## 2.1 Laboratorios virtuales y remotos

The use of the new technologies in education in the field of work experience has led to the emergence of different kinds of experimental environments. From the standpoint of the user who interacts with these systems a dual classification can be derived: depending on the form of access to the resources, and based on the type of system on which the student operates. Following the first criterion, one can differentiate between remote access through to Internet and local access in which it is not necessary a network to operate with the components of the laboratory. In relation to the second criterion we can distinguish between simulated models of real physical systems or work directly with real physical systems. From the combination of these criteria four different types of laboratories can be established [1],[2].

1. **Local access – Real resource.** It is the traditional laboratory used for educational practices. Classical laboratory.
2. **Local access – Simulated resource.** The environment of the student in the laboratory is simulated. The student must to assist to the laboratory to use this simulated resource of a equipment. Simulated laboratory
3. **Remote access – Real resource.** This method provides work experience with real laboratories through the Internet. This laboratory is denoted as remote laboratory [5].
4. **Remote access – Simulated resource**. The difference with the previous item is that the user uses remotely a resource that is not real but is a simulation of a real system. This laboratory constitutes what is known as a virtual laboratory.

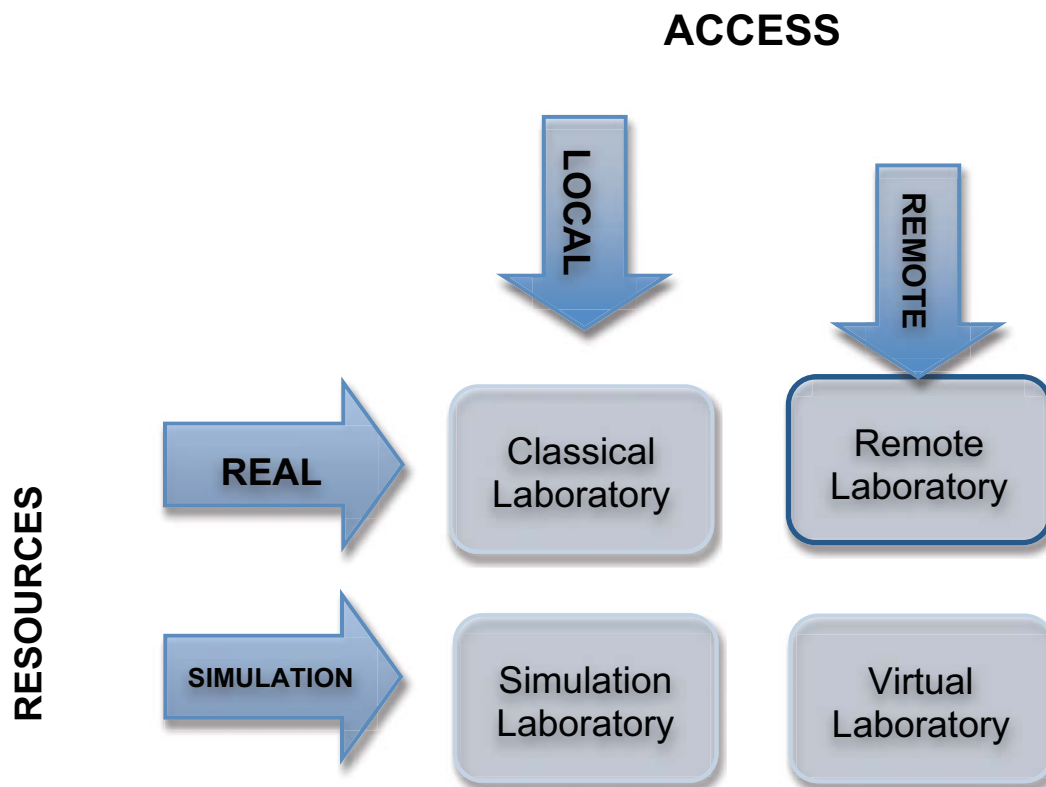In Figure 1 we show this classification.

**ACCESS**



Figure 1: Different modes of access to laboratories.

The system presented in this paper falls under the third paragraph (remote laboratory) and the student or user operating remotely with the remote physical device that is in the laboratory.

## 3   TEACHING FRAMEWORK

Automatl@s project spans over six Universities involved in teaching controls courses using remote laboratories. Improving the accessibility of students to physical systems distributed over distant laboratories, has been a key goal of the proposed system. "Miguel Hernández" University of Elche (Spain) contributes with a remote lab focused in teaching control theory as part of Automatl@s team.

"Miguel Hernández" University of Elche (Alicante–Spain) is structured in nine faculties. The Polytechnic school of Elche imparts engineering degrees in: Industrial, Mechanics, and Telecommunications specialities. Teaching control courses is spread over all engineering degrees, but is emphasized in the Industrial Engineering student with five courses that range form basic theory to advance control methods.

- o **Electric and Systems Theory:** this is an introductory course to open-loop modelling and analysis for analogue and digital systems.
- o **PLCs and Control Systems:** this course covers PLC programming, feedback analysis of analogue and digital systems, PID and digital controllers design.
- o **Automation and Electronics Systems:** electronic components for control systems together with space state system modelling and control approach is covered in this course.
- o **Advanced Control Systems:** fuzzy, stochastic and optimal control theory is addressed in this course

- **System Identification and Modelling:** advanced modelling and identification methods for adaptative control are covered in this course.

The use of a remote laboratories improves the accesibily of students to practice control theory in different courses without the limitations imposed by lab scheduling and more important, allowing the student to access to a more diverse set of physical systems by the ability to share equipments between Universities.

# 4   HARDWARE ARCHITECTURE

Recolab system is based in the integration of three main software components:

- Easy Java Simulations (EJS) software [3]. This platform allows the implementation of advanced graphical simulations of physical systems that can be connected to real physical systems.

- The main goal on developing the system was to achieve accurate real-time executions over physical systems through internet. In order to do this, the real-time control executions is performed in server side by means of Matlab/Simulink [7] real-time schemes that are connected to EJS by means a software interface.

- The third software component is emersion [12] developed by EPFL of Lausanne, implements the collaborative environment for the student could access the material, schedule its practice and publish and share the results with teachers and other students.

The general scheme of the application architecture is shown in figure 1. In this diagram, the hardware and software elements are split into two main blocks: local area where the user works, and remote area where the whole physical system and control elements are located. The detailed elements of local and remote areas are the following:
1. Local area:

   - Computer with Internet connection and an HTTP 4.0 client application (Firefox 3) and Java 1.6 virtual machine. The student application runs as a Java applet.

2. Remote area:

   - High speed Internet Connection.

   - Computer Server: the current implemented system consists of a PC Pentium IV running Microsoft Windows XP operating system.

   - Data acquisition system: NI 6024E acquisition board with analogue and digital I/O

   - Physical system to control: DC motor model 33-002 from Feedback

   - Image capture system and web video server: an Axis network camera with MPEG-4 video compression streams video and static images to the user.

   - HTTP Server Apache v.2.0.54 with PHP 5.0 module. This server allows the communication of the computers using the http protocol.

   - Mysql server for accounting and collaborative content management.

   - MATLAB R12 with SIMULINK V. 4.1: executes the program that makes possible the real-time control of the system and the generation of the results in a file.

   - Real-Time Windows Target Toolbox V.2.1: this toolbox allows executing Simulink schemes in real time. For this purpose, it provides the necessary blocks for the interaction with the data acquisition system.

## 4.1   EJS-Matlab Connection

EJS application allows the access to both: virtual simulation and real physical execution of control algorithms. Remote access to physical systems uses Matlab Simulink together with Real-Time Workshop in order to achieve the real-time execution. The connection between EJS and Matlab is important module called JimServer.  Figure 2 shows the basic communication scheme used in

Recolab. JimServer/Matlab can reside in separate computers allowing several physical systems using different interfaces (Matlab/Labview/C), it also permits direct communication to Matlab (workspace variables and command console) and Simulink.

The physical system (DC motor) is controlled from a Simulink scheme that operates the DC motor through the I/O acquisition board. Since there are two types of experiments performed on the DC motor (speed control and control position) two different Simulink control schemes have been developed.

Figure 2 shows an example of control scheme implementing position control of the DC motor through acquisition board. The regulator parameters can tuned through Matlab cammands. This way, user can modify controller parameters and EJS sends that information to Matlab using JimServer.
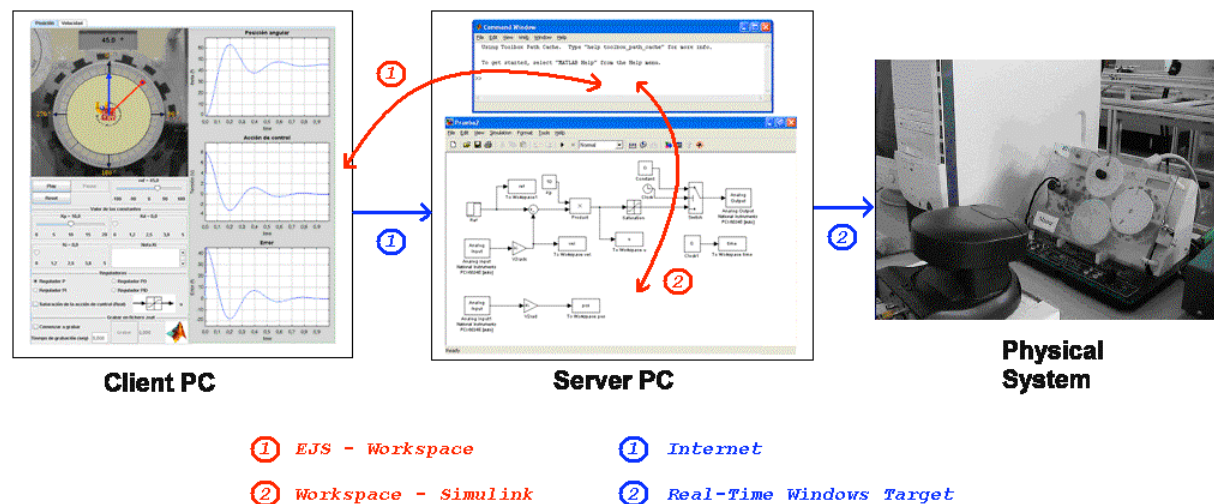


Figure 2: EJS-Matlab Connection.

## 4.2    Real-Time Control Application

This application runs the real-time feedback control using the specified control scheme over the physical system. This application has been developed using the following tools: Matlab, Simulink and Real-Time Windows Target. This last tool allows generating the real-time code to execute the Simulink schemes using an acquisition board (and therefore, over the physical system, connected to it). The fact of executing a Simulink scheme directly is an added advantage, as far as the complexity and spent time working with Simulink are drastically decreased, allowing an easy and fast design and modification of control schemes.

Real-time control using Simulink is performed through Real-Windows Target. This  toolbox generates source code that translates feedback control of Simulink scheme. This source code is compiled with Watcom C compiler in order to generate the real time execution code. Each Simulink scheme depends on the type of regulator, control method and the physical system to be controlled, but there are some common elements:

o  A Regulator (specific in each case, P, Pi, PD, PID, state feedback, etc.)

o  Acquisition board interaction block that provides Analogue and digital input/output interface with the physical system. In our case this hardware is a National Instruments 6024E board that is managed through an specific  library block.

o  Auxiliary blocks for setting an initialization of actuators, and sensors.

## 4.3    Using Interface

The user interface is divided in three main windows:

o  Simulation window: it holds the simulation view, controls, display graphs for main variables and connection to the real system.

- o eMersion window: gives access to the collaborative teaching resources such as manuals, protocols,…

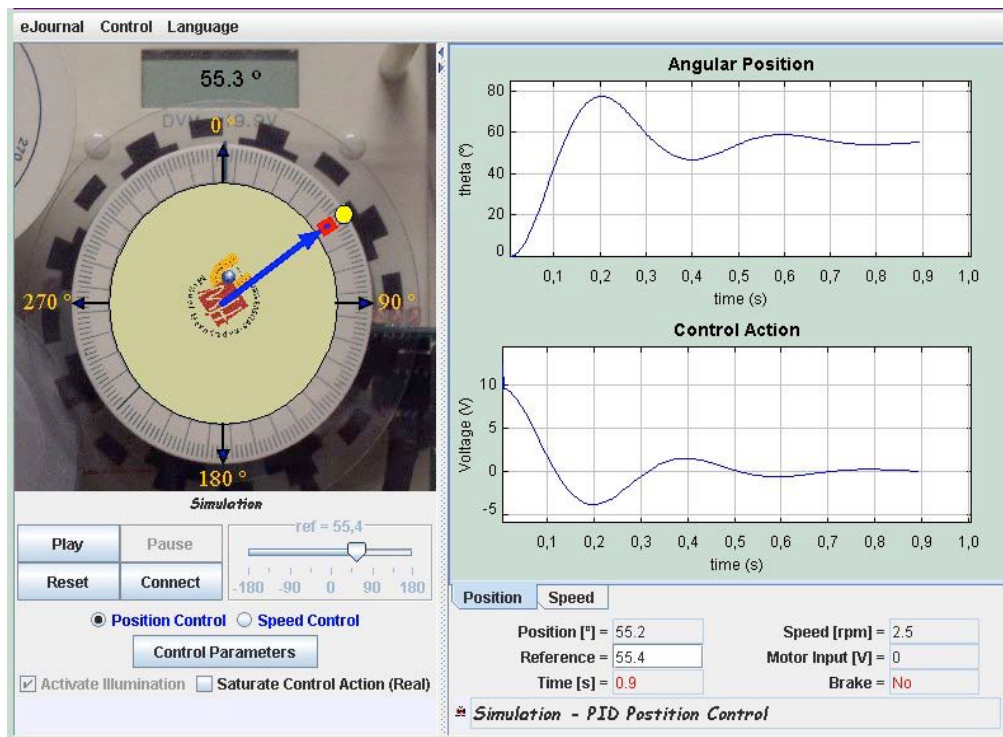- o e-Journal window: gives access to storage for reports and simulation data.



Figure 3: User Interface.

DC motor can be viewed as:

- o *Simulation mode*. The motor is displayed as shown in Figure 3. When the system is working in this way, the system works locally and evolves based on a mathematical model of the process, that is simulated by means of a set of differential equations.

- o *Remote mode (using video connection)*. The real motor located in the remote laboratory is shown. In this mode the image of the DC motor located in the remote laboratory is acquired by the video camera and transferred to the local host.

- o *Remote mode (using Augmented Reality)*. In this mode, the real DC motor located in the remote laboratory is shown and a simulation of the position of the motor is overlaid. These two last of viewed forms only can be selected if the user is working in remote access.

At the right of the representation window is located the evolution window. The evolution window shows the evolution of the main variables of the process (see Figure 3). When the Position tab displays, in the graph above, the evolution of the controlled variable associated with the angular position of the disc. Also the evolution of the variable associated with the voltage applied to the DC motor (control action U) is displayed. In the same way, the Speed tab displays the evolution of the rotational speed of the disc, and the voltage applied to the motor (control action U) to reach that speed.

## 5   RESULTS IN THE LAST TWO ACADEMIC YEARS

The system previously presented has been used as test environment for the past two academic years 2007/98 and 2008/09. Below are the results with students who have used this system over the last two academic years at the University Miguel Hernandez de Elche. All students who have made remote practices with this laboratory have participated in previous courses and subjects with the same content of control theory. During the academic year in which the students made remote practices they were studying the subject 'Automatas y Sistemas de Control' located within the 3rd year of Industrial

Engineering degree. The basic content of this course correspond to those of a basic course in classical control theory.

It is noted that the implementation of these practices by students during the last two academic years has been entirely voluntary. During the academic year 2007/08 from a total of 97 students enrolled in the subject, 17 made practices with the remote control laboratory. Also, in the 2008/09 academic year from 115 students enrolled in such subject 19 made voluntarily practices in the remote control laboratory (see figure 4). The students that completed and exceeded these practices received an increase of one extra point in the final valoration of the subject. The time spent by the students in carrying out these practices by means of the remote control laboratory has been greater than that required in the case of a traditional practice. However, the degree of satisfaction of the students is higher than in the traditional presencial practices.
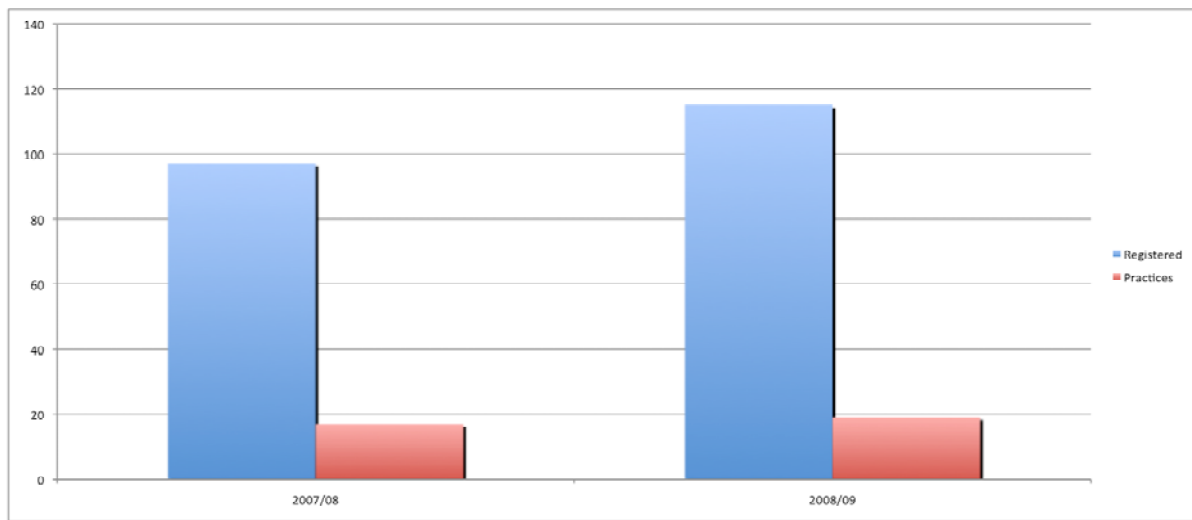


Figure 4: Number of enrolled students and number of students in the remote laboratory during 2007/08 and 2008/09 academic years.

During 2007/08 academic year the average number of accesses per student was 5.37; meaning that students preferred to split the work in different sessions, while during 2008/09 academic year the average number of accesses per student was 6.21. So we can conclude that during this last academic year the students made more accesses to the system. The number of accesses per student during 2007/08 academic year is shown in figure 5. The number of accesses per student during 2008/09 academic year is shown in figure 6.
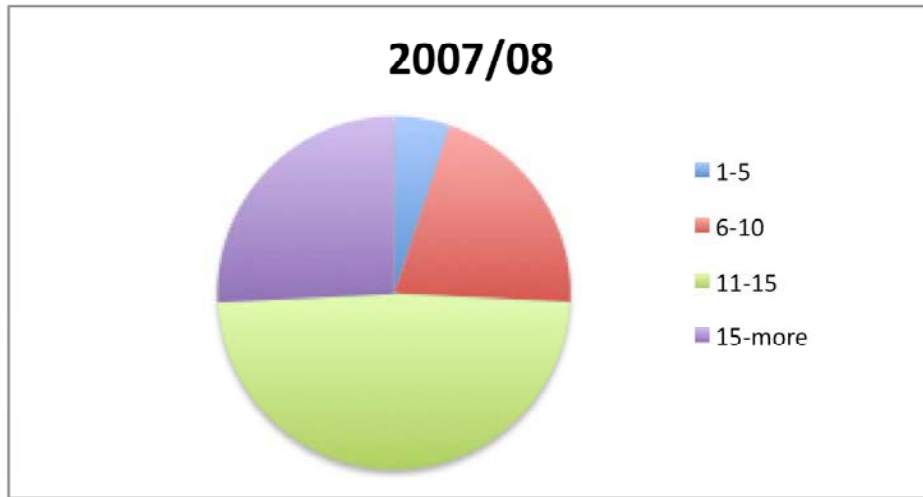
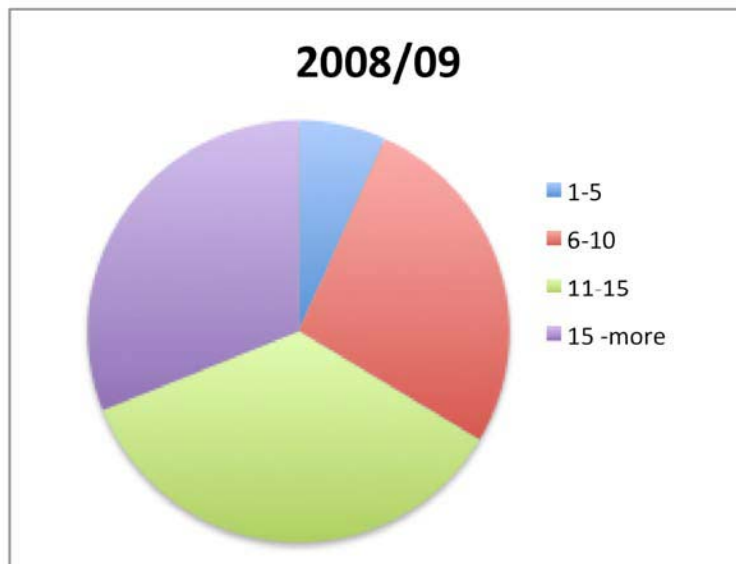Figure 5. Number of accesses per student during 2007/08 academic year



Figure 6. Number of accesses per student during 2008/09 academic year

The average connection time per session during 2007/08 academic year was 35 minutes, while during the following year was 46 minutes. The connection time per session during 2007/08 and 2008/09 academic years is shown in figure 7.
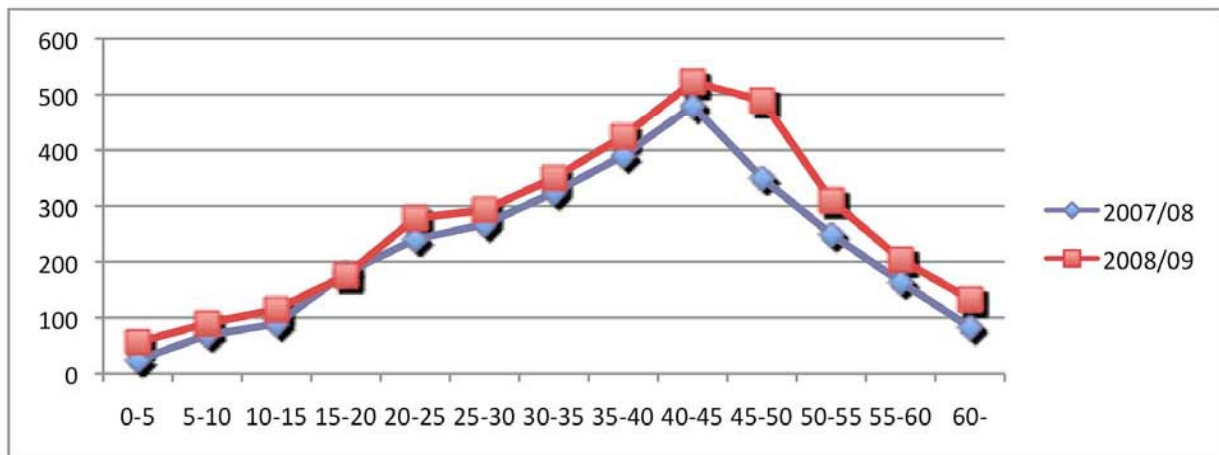
Figure 7. Connection time per session during 2007/08 and 2008/09 academic years.

## 6 CONCLUSIONS

In this paper some experiences in the development of a remote control laboratory have been presented. The results in terms of student participation for the last two academic years have also been detailed in the paper. We can conclude the viability of such laboratories that allow work experience to students from a remote computer with Internet access. Making experiments with physical systems is crucial for students to properly assimilate the knowledge and skills related to that subject. This kind of laboratory where students can engage in practices with real equipment is indispensable in technical studys such us engineering degrees.

The results about the number of students who have made the remote practices during the past two academic years have also been presented and detailed. We have analyzed the number of sessions that students use for each one of the practices as well as the average time that they are using the remote laboratory in each of the connections.

In future, these remote laboratories will be expanded both in its facilities, adding new hardware and physical equipments to make new practices and with the introduction of new practices to be performed on the same equipments.

## 7 ACKNOWLEDGEMENTS

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