Computers & Education 57 (2011) 2451–2461

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

Hands-on experiences of undergraduate students in Automatics and Robotics using a virtual and remote laboratory

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ARTICLE INFO

Article history:
Received 2 February 2011
Received in revised form
21 June 2011
Accepted 11 July 2011

Keywords:
Blended learning
E-learning
Interactive environments
Robotics
Virtual and remote laboratories

ABSTRACT

Automatics and Robotics subjects are always greatly improved when classroom teaching is supported by adequate laboratory courses and experiments following the "learning by doing" paradigm, which provides students a deep understanding of theoretical lessons. However, expensive equipment and limited time prevent teachers having sufficient educational platforms, and several low cost and flexible solutions have been developed to permit an effective teaching in Automatics and Robotics at a reasonable cost. Virtual and remote laboratories are inside this group of solutions as Web-based experimentation tools which have demonstrated the importance and effectiveness of hand-on experiences. This paper presents an experience teaching based on a blended-learning method using as experimentation tool a virtual and remote robotic laboratory called *RobUALab*, which is also described in the paper, in Automatics and Robotics subjects of the Computer Science degree at the University of Alicante. Students experiment with a set of hand-on exercises about Automatics and Robotics using *RobUALab*, firstly in face-to-face classes where they experiment in-situ with the real plant and, afterwards, they access to the experimentation environment in order to finish remotely their practical exercises outside the laboratory. The results obtained in the evaluation of the educational methodology proposed attest its efficiency in terms of learning degree and performance of the students.

1. Introduction

Experimentation in an engineering laboratory is nowadays one of the most important issues for undergraduate students because it allows them to observe and explore real-world applications of fundamental theories and to develop a deep understanding of theoretical lessons. Thus, the role of experimentation is a key concept in the education world, mainly in science and engineering disciplines such as Automatics and Robotics, where practical training and experience can only be provided to students by real equipment as for example an industrial robot or automatic devices. Nevertheless, some problems prevent teachers having sufficient educational platforms for student experimentation. These include, on the one hand, a high cost of the equipment what reduces laboratory resources. On the other hand, a fixed and regular class schedule which only permits students experiment with these real devices in a limited time during the attending classes. Therefore, a critical problem in engineering education is the provision of relevant and meaningful practical experiences for students because some drawbacks exist in giving sufficient laboratory experimentation for all students (Tiernan, 2010).

With the development of Internet technology, educational institutions have been expanding the available resources for practical learning thanks to Web-based experimentation, which represents an essential issue in the development of e-learning solutions in the current education paradigm (Macedo-Rouet, Ney, Charles, & Lallich-Boidin, 2009). These modern technologies offer a new way of producing, distributing and receiving university education, and complement traditional teaching and learning methods for undergraduate students (Orton-Johnson, 2009). Virtual and remote laboratories (VRLs) are inside of these group of resources because allow students access to Web-experimentation environments at any time, at any place and are quite well established in several scientific and technical disciplines. These computer based tools provide students realistic hands-on experiences (Dormido, Dormido, Sanchez, & Duro, 2005) and allow them to learn and to train through the Internet in a practical way.

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doi:10.1016/j.compedu.2011.07.003

In higher education, simulation tools serve as important resources for student's learning. However, real laboratories cannot be substituted just with this tool, especially in some fields such as Automatics and Robotics, in which the actual behavior and response of the real elements in the experiments is crucial (Alhalabi, Marcovitz, Hamza, & Petrie, 2000). Remote laboratories, which also deliver laboratory facilities to the door of the student such as the simulation software is intended to do (Gorrel, 1992), may constitute a better substitute or complement to real hands-on experiments. Moreover, virtual laboratories should be used to serve as an initial experimentation and a first contact with the studied phenomena for the student. In this way, VRLs are essential educational tools which provide students real-simulated experiments that can be conducted at any time, without instructor surveillance or guidance. Thus, each student learns with hands-on experiences in a way that can practically fit into their education schedule. In addition, expensive equipment can be shared among students enrolled in different programs and with different schedules and knowledge levels.

Automatics and Robotics are essential topics in the current technological world which have accomplished an explosive growth in the last few years. Consequently, educators have to provide students suitable practical environments to give them appropriate learning practices. For this reason and the statements mentioned above, the authors of this paper have developed a VRL for training and learning in Automatics and Robotics called *RobUALab* (http://robualab.eps.ua.es). This system allows users to simulate and test positioning commands for a robot by means of a virtual environment with augmented reality support, as well as execute high level commands in a real remote automated cell through the Internet. The application has been developed using *Java*, which has allowed a full portability and an interactive graphical user interface. One of the most important aspects of the system presented is that it collects a lot of interesting and suitable features for Automatics and Robotics education. Among them, it is worth mention a complete robot and world simulation, a very realistic 3D graphical environment, robot dynamics, programming, remote power, lightning and robot control, and augmented reality. Some of these features are not found together in any free software platform.

The authors of this paper have been using VRLs for teaching of Automatics and Robotics courses since 2003 at the University of Alicante. More specifically, the platform *RobUALab* is being used since the academic year 2008 in the courses "Robot and Sensorial Systems" and "Automation" in the Computer Science degree. In order to give students sufficient laboratory experimentation, *RobUALab* includes a booking system which permits students make a reservation of the real laboratory for exclusive use by specifying the experiment timetable (day and time). In this way, student can use the robotic plant more time that the provided in the attending classes (see subsection 4.2). Thus, students can enhance their constructive learning and training from home by using real equipment of Automatics and Robotics. In addition, this system belongs to a network composed of different VRLs from Spanish universities called AutomatL@bs (http://lab.dia.uned.es/automatlab) (Dormido et al., 2008). The main goal of this network is to provide a collaborative environment based in *eMersion* (Gillet, Anh, & Rekik, 2005) where students and teachers from different universities of Spain can experiment with real equipment and share experimental results. In this way, several universities are being benefited from this initiative by sharing experimental resources and increasing the number of laboratories available for their students.

However, powerful tools based on VRLs such as *RobUALab* must be used with a correct educational methodology because they are usually designed to be used individually, and this can cause feelings of isolation in the student and hence reduces his/her motivation (Kamel, Taylor, & Breton, 2005). Students do not receive instant feedback from their questions and cannot talk in a face-to-face way about the results obtained in the learning activities. Furthermore, previous research about the use of VRLs in the educational process using only an e-learning method stated that students consider VRLs as effective web-learning resources to the traditional teaching, but many of them prefer to perform their practical exercises in the real laboratory since they can work in coordination with their classmates and with the teacher support (Candelas et al. 2004; Candelas, Puente, Torres, Segarra, & Navarrete, 2005; Torres et al, 2006). Thus, from the academic year 2009, authors have integrated the practical experimentation of this VRL in a blended-learning methodology, a current trend to complement face-to face classes with web-based resources (Garrison & Kanuka, 2004). With this educational method proposed by the authors, students carried out firstly face-to-face classes where they interact and experiment with a real engineering laboratory and afterwards, they were able to access to the experimentation environment in order to finish remotely their practical exercises outside the laboratory. In order to evaluate this new educational methodology proposed, two types of outcome measure were obtained from the blended learning experience. On the one hand, based on the student's perception of the blended learning experience based on the aspects utility, motivation and satisfaction of using *RobUALab* by means of the educational methodology proposed (Section 6). On the other hand, a comparison between the final exam mark awarded of students who employed the blended-learning method and who not (Section 7).

The remainder of this paper is organized as follows: Section 2 discusses both the related work about virtual and remote laboratories used for Robotics education and the use of blended-learning in engineering courses. Next, the hardware and software architecture of the VRL *RobUALab* will be explained in detail. The following section describes the virtual and remote educational capabilities of the application developed. Afterwards, the educational methodology proposed will be described in Section 5. Next, Section 6 explains the results of an educational evaluation carried out with the students. Two empirical studies to assess the approach's efficiency will be presented in Section 7. Finally, some important conclusions are shown in Section 8.

2. Background research

2.1. Virtual and remote laboratories for Robotics education

The great evolution of network technologies allowed the creation of a fast media for global communication and information sharing between computers: the Internet. This communication channel, together with advanced programming platforms for Internet such as Java was the precursors of the *Online Robots* (Goldberg & Siegwart, 2002): remote robotic devices which enabled the general public of anywhere to provide adequate robotic learning elements. Some of the first successful examples of remotely driven industrial robotic cells were the Mercury Project (Goldberg, Gentner, Sutter, & Wiegley, 2000), the Telegarden Project (Goldberg, Gentner, et al., 2000; Goldberg, Kusahara, et al., 2000) and the remote laboratory developed at the University of Western Australia (Taylor & Dalton, 2000). In these systems students could move the robot and manipulate objects in the workspace through the WWW. These Internet-based remote laboratories opened a new pathway for robotics e-learning in the last decade.

Nowadays, many different VRLs for Robotics education are available over the Internet world. Four outstanding educational systems are the ARITI project (ARITI, 2000), RLab (Safaric, Debevc, Parkin, & Uran, 2001), the UJI Robot (Marín, Sanz, & Del Pobil, 2003) and Robolab (Candelas et al., 2005). ARITI is a telerobotic system that allows students controlling a Cartesian robot with an interface based on Augmented Reality. UJI Robot consists of a multi-robot architecture system that gives access to both educational and industrial robots through the Internet. Moreover, this system uses augmented reality to manipulate the robot arm. With regard to RLab, it is a collection of Internet-based prototyping laboratories for Robotics subjects, which provides users with on-line access to real hardware for remote experimentation. Finally, Robolab is an open architecture for simulating and teleoperating different robot arms. The main lack of these mentioned systems is that they permit the practice of basic concepts, reaching only to the kinematics of robots. None of them covers advanced topics such as dynamics and programming, issues addressed in many of the subjects related to Robotics and Automatics.

Other successful VRL which combines Robotics and Computer Vision fields are RACT (Casini, Chinello, Dominico, & Antonio, 2008) and those presented in (Sebastian, Garcia, & Sanchez, 2003; Tzafestas, Palaiologou, & Alifragis, 2006). In these applications, several practices are proposed for student experimentation on Robotics and Computer Vision.

RobUALab contains interesting and advanced features which compose a complete software platform for simulation, programming and teleoperation of a robotic plant. Students can experiments with several basic and advanced concepts about Robotics and Automatics such as kinematics, path planning and dynamics of a robot manipulator, and programming of an automated cell. Moreover, *RobUALab* contains a high number of robotic experiments which permits students to easily acquire skills and hand-on experience related to Automatics and Robotics. They cover a complete evaluation for student performance in two training modalities: virtual and remote training on a robotic cell programming.

2.2. Blended learning in engineering courses

The current trend to complement face-to face classes with web-based resources is known as blended learning (Garrison & Kanuka, 2004; Graham, 2005). This style of learning is defined as the integration of traditional classroom methods with online activities (Voos, 2003) and nowadays, this educational methodology is becoming increasingly significant to complement, not replace, traditional forms of learning (Mitchell & Forer, 2010). This learning method represents an opportunity to integrate the innovative technological advances offered by online learning with the interaction and participation offered in the best of traditional learning (Clark & James, 2005). Moreover, this method is usually applied to adapt the new subjects to the process of convergence to ESHE (European Space of Higher Education) (Clausen, 2005), in which the use of e-learning resources occupy an important role.

However, the blended learning approach in the engineering education on undergraduate studies was not so common until recently (López-Pérez, Pérez-López, & Rodríguez-Ariza, 2011). Main reason is that there was no replacement for the laboratory exercises, which are important part of the engineering education. As commented before, e-learning tools such as VRLs can be used in order to add virtual and remote experiments in the whole learning process. Nevertheless, it still can't be expected that virtual and remote e-learning tools will totally replace local laboratory exercises. Therefore, a combination of in-the-classroom lessons and self-study of e-material with both local and virtual/remote exercises can bring the best educational results. This approach has been recently applied in several engineering courses such as mechanical engineering (Cortizo, Rodríguez, Vijande, Sierra, & Noriega, 2010; Rojko, Hercog, & Jezernik, 2010), programming (Alonso, Manrique, & Viñes, 2009; El-Zein, Langrish, & Balaam, 2009), control courses (Méndez & González, 2010) and computer networking (Gil, Candelas, & Jara, 2011).

The work presented here explains how the blended learning has been combined with the use of the VRL *RobUALab*, and describes different studies about how this methodology can improve the learning efficiency and the student's satisfaction with regard to the use of only VRLs.

3. Hardware and software architecture of the virtual and remote lab

The virtual and remote laboratory *RobUALab* provides, on the one hand, a virtual environment which allows student develop experiments with a simulated robot arm enabled to interact in its simulated workspace and, on the other hand, teleoperation functions for execute the programmed task in a real robot which is identical to the simulated one. The real robot (Scorbot ER-IX from Intellitek) is located in a laboratory in the Polytechnic School of the University of Alicante, together with other devices, as the Fig. 1 shows. The robot can grasp colored pieces from a warehouse or from a conveyor belt, and manipulate them to construct forms over a turntable.

In addition to robot and the other devices in its workspace, there is other equipment in the laboratory which is needed to provide the virtual and remote capabilities to students. Fig. 1 represents the most important hardware devices of the laboratory, which is briefly described following. The Main Server is a standard PC that works as a web server and provides the web pages and the Java applet that allows student access to the virtual laboratory through Internet. Moreover, the Main Server manages the user access, and also provides an interface to remotely control the power of the robot and the lighting by means of a PLC (Programmable Logic Controller). Through a local network, the Main Server is connected with the Teleoperation Server, which checks the commands sent to the robot, translates them to the robot language, and sends them to the robot controller. This check attempts to minimize the possible failure of the robot due to collisions with other objects or high speeds. In addition, the Teleoperation Server obtains information about the state of the robot to allow an on-line feedback to the student. Finally, an IP servo-camera also permits a video stream feedback for the remote operation.

With regard to the software design, there are three main entities to be considered as follows: the Java Applet, the Main Server and the Tele-operation Server. The main functions of these entities are shown in Fig. 1, and they are described next. Firstly, the user interface is a Java applet that has been developed with Easy Java Simulations (Esquembre, 2004), and it has the models of the robot and its environment in order to generate a 3D simulation for the virtual laboratory. This applet is embedded in a web page that can be downloaded from a web server located in the Main Server (http://robualab.eps.ua.es). The access to the applet is free and, thus, everyone can use the virtual laboratory for simulation without any previous registration. Moreover, the applet can be executed in different platforms because it is entirely programmed in Java language, which is platform independent.

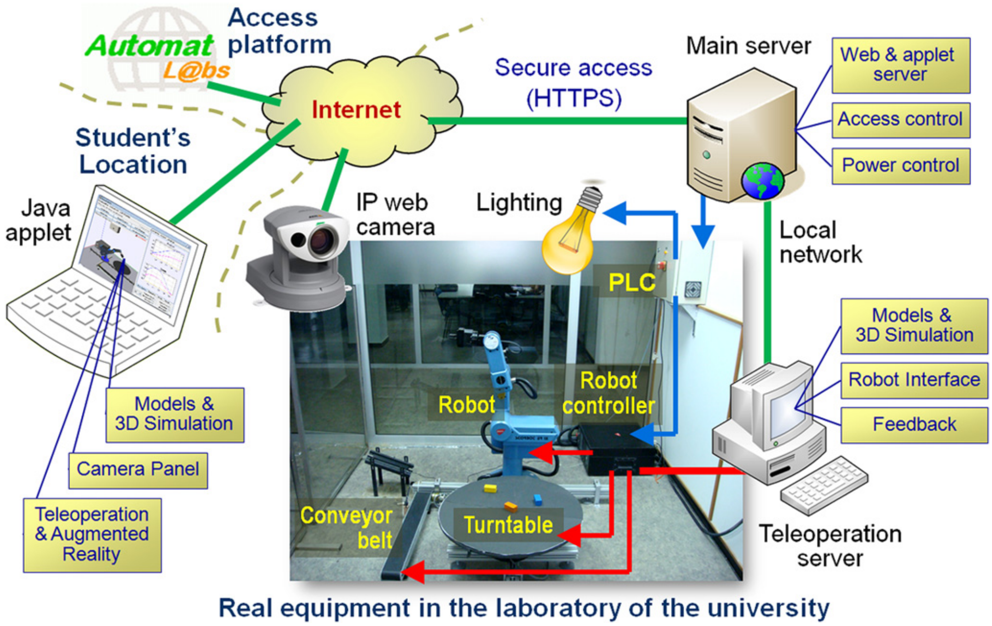

Fig. 1. Hardware and software architecture of the virtual and remote laboratory *RobUALab*.

Secondly, the applet has a teleoperation module, which communicates with the Main Server for the remote operation mode. In this way, a user can connect to the main server to request an operation the real robot, after doing a previous local simulation in the virtual laboratory. For remote operation, it is necessary an access control in order to manage an ordered use of the real robot based in bookings. Thus, the Main Server checks if the user has a reservation for the date and time of the access by communicating with the booking system of the AutomatL@abs network (Dormido et al., 2008), where the teacher must firstly register their students in the database in order to enable them to access to real equipment. If the user is allowed access to the system, the Main Server establishes a connection between the applet and the Teleoperation Server. Then, the user can send a list of commands to this last server, which first executes a simulation of the commands in order to verify that they are correct and there is not any collision of the robot with other objects or itself. If the command list is correct, the Teleoperation Server translates and sends them to the robot controller.

Finally, while the robot is moving during a remote operation, the Teleoperation Server gets the real positions of the robot, and sends them to the 3D simulation in the applet, in order to update the graphical representation and the and graphics of the user interface according the real movements. In addition, the IP camera transmits an online video stream to a window in the user interface. Therefore, user has a complete feedback which allows him analyze the real execution of the robot. During a remote operation, other functions are also available, as will be detailed below, in Section 4.

4. Virtual and remote capabilities

This section briefly describes the virtual and remote capabilities of *RobUALab*. Moreover, the functionality of the booking system is also explained.

4.1. The virtual laboratory

The virtual lab's interface is shown in Fig. 2. It implements a large amount of options suitable for Automatics and Robotics e-learning. Students will be able to learn complex concepts by means of a virtual reality environment in an easy way. Among the possibilities of user experimentation, it is worth pointing out:

- Kinematics: users can move the robot specifying both the exact joint values and the Cartesian coordinates of the end effector, both limited by the real mechanical constrains. Denavit-Hartenberg systems (Denavit & Hartenberg, 1955) and transformation matrices can be visualized in the user interface.
- Path Planning: users can practice and carry out movements of both joint trajectories and Cartesian trajectories. The simulated trajectories can be stored in a command list and simulated sequentially.
- Environment modeling: users can introduce specific virtual objects (cubes and parallelepipeds) in the workspace to do pick-and-place operations.
- Dynamics: users can evaluate the torques in the actuators when the virtual robot is simulating a task. They can modify dynamic parameters such as link masses, inertias and friction from the virtual robot and realize how the dynamics change. Moreover, users can visualize in real-time all the values about the dynamic model of the virtual robot.
- Programming: users can program routines in the simulation in order to manage the robotic cell elements. They can create variables, mathematical operations and command movements.

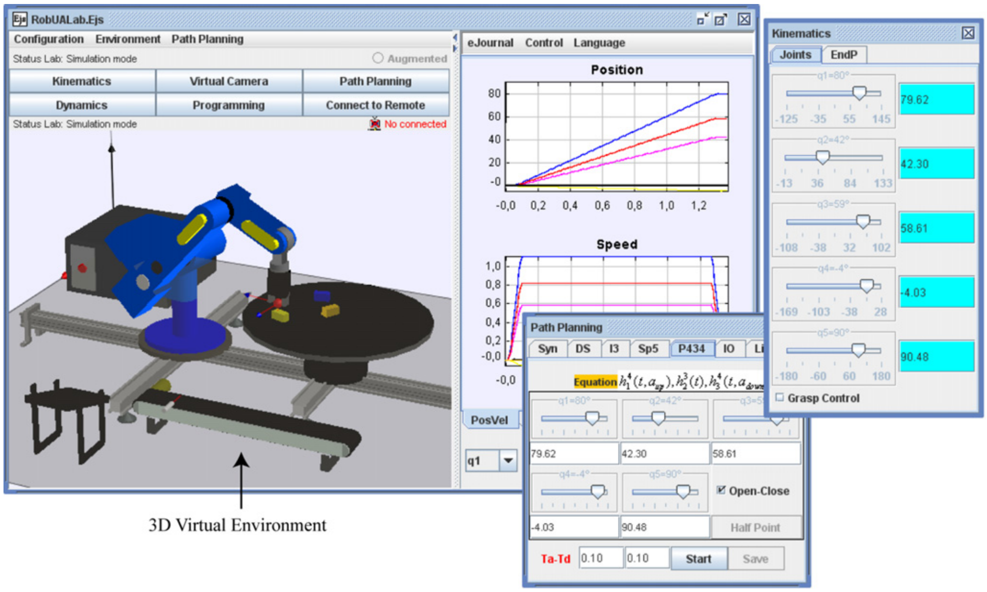

Fig. 2. Appearance of the virtual lab's interface.

4.2. Remote options

The teleoperation options implemented in the system allow the remote control not only of the robot, but also of some electronic devices of the real automated cell. They are the following:

- Remote PLC/Camera control: users can control from the applet both some PLC control parameters (switch on/off both the light and the robot controller) and the real camera projection (pan, tilt and zoom). These elements are shown in Fig. 1.
- Remote robot control: users are able to execute remotely in the real robot the command list stored in the virtual simulation. As mentioned before in Section 3, the path planning sent to the real robot is previously checked in the Teleoperation Server which detects the possible collisions of the robot-arm.
- Feedback options: the application gives the user two options for performing the feedback of a teleoperation: an online video stream and graphical updating of the 3D simulation with the current position of the real robot.
- Augmented reality: the real information from the robot scenario is complemented with some virtually generated data from the virtual environment (Fig. 3).
- Object recognition: the Java applet contains a module to recognize basic objects of different colors from the IP camera images. In this way, simple objects from the real laboratory can be imported to the virtual lab.
- Booking system: remote access to real equipment is controlled by a booking system. Thus, authorized users can make a reservation of the real lab for exclusive use specifying the experiment timetable (day and time). In this way, only one user can control the robotic plant at the same time and it avoids multiple user connections. The booking system is a part of the whole project AutomatL@bs.

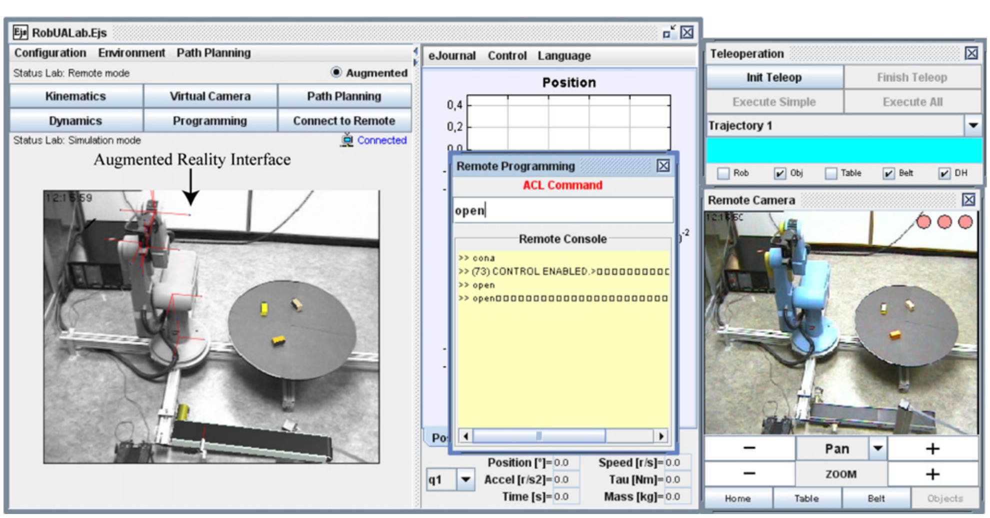

Fig. 3. Remote experimentation of *RobUALab* using the augmented reality interface.

5. Educational methodology

The authors of this paper have been using VRLs for teaching Automatics and Robotics courses since 2003 in the Computer Science Engineering degree at the University of Alicante. During the first academic years (2003–2008), as mentioned in the Section 1, VRLs were used by means of an e-learning method. Students experimented only with the real plant utilizing a VRL in a remote way from home. In order to evaluate virtual and remote laboratories' acceptability and its effect on learning and training in this period, several statistical studies were carried. The main results obtained in these research studies were that, although there are a great number of students who happily accept VRLs for learning and training in Automatics and Robotics, many of them also preferred to have a real laboratory at the University where they could work in coordination their class-mates and have the support of a teacher (Candelas et al. 2004; Candelas et al., 2005; Torres et al., 2006). Therefore, considering not only that VRLs can improve practical training with regard to offer only classroom experiments, but also that student requires a support, authors decided to integrate the VRL *RobUALab* within a blended-learning method.

This section is focused on describing with detail the blended-learning method proposed for the Automatics and Robotics subjects in academic years 2009 and 2010, whereas the next sections will show both a study of the student perception for this method (Section 6) and a comparison with results obtained in previous academic years when no blended methodology was used (Section 7). The learning schedule of the blended method proposed use the following resources for the face-to-face interaction: theoretical lectures and problems, textbooks, seminars, common tutorial classes, and practical exercises where students experiment in-situ with the real plant based on both supervised remote and simulation hands-on experiments using *RobUALab* and real laboratory setups. Table 1 show the scheduling and distribution of the diverse activities, since these subjects are defined with six European Credit Transfer System (ECTS) credits and about 150 h each one. Regarding e-learning activities, students access to the experimentation environment in order to finish remotely their practical exercises outside the laboratory. For that end, the booking system provides a reservation organization of the real plant for exclusive use.

The same blended methodology has been applied to all the students during years 2009 and 2010, and no control groups were used, because it was not possible to maintain two learning methodologies. However, the results of this study can be compared with similar studies carried out by authors in some previous academic years (from 2003 to 2008) when blended methodology was not used yet (Candelas et al., 2004; Candelas et al., 2005; Torres et al., 2006). This comparison is valuable because students had the same profile, and also the curriculum, teachers, real laboratory equipment are the same. Furthermore, in previous courses, also VRLs, including *RobUALAb*, were used, but not within a blended methodology.

The practical exercises of the subjects are organized in four hands-on experiences. In the first three exercises, students use the virtual and remote laboratory *RobUALab* where students experiment with several theoretical concepts related with Automatics and Robotics (kinematics, path planning, dynamics and programming). The practical experiments are proposed to reinforce these concepts and for a deep understanding. A collection of HTML pages provides the documentation to carry out the exercises by the students in an autonomous way. This teaching material provides students on-line information in web format for all the theoretical and practical contents required to complete the experimentation sessions both in the virtual platform and the remote plant. This documentation can be seen at the following web page: http://robualab.eps.ua.es/practices/index.html. The last exercise (exercise 4) is the most important one and it consists of programming the real automatic robotic cell. This experiment is like the tasks that the undergraduate students will have to face in their professional life.

All the practical experiences using *RobUALab* proposed for the students are composed of two training modalities: 1) virtual mode, where students interact and program the simulation environment; 2) remote experimentation, where students send to the real laboratory the high-level commands previously obtained and checked in the virtual lab. This practical methodology helps students to visualize the correlation between the virtual model and the real system since they can see the actual behavior and response of the experiments in the real plant. In the following points, the three practical exercises supported by *RobUALab* are briefly described.

5.1. Kinematics and path planning: a virtual-remote experience

The first experiment for the students deals with a path planning algorithm of a cubic spline (1). This is the kind of trajectory that real robot uses. Firstly, students have to compute the parameters of the trajectory proposed (a, b, c, d) using theoretical concepts on Robotics.

$$q(t) = a\cdot t^3 + b\cdot t^2 + c\cdot t + d \tag{1}$$

To that end, students are required to impose some specific position, velocity and acceleration constrains in the parametric trajectory. After that, they must represent the trajectory computed using any software program such as Matlab (www.mathworks.com). The aim of this first basic exercise is to compare the theoretical results obtained with the practical experiments which they have to carry out. Virtual training consists of simulating the parametric trajectory in the virtual environment. They have to configure the virtual robot with the same constrains chosen for the theoretical assessment. The virtual laboratory's interface will represent the position, velocity and acceleration of the path planning algorithm simulated (see Fig. 2). Thus, students will be able to validate their theoretical concepts on Robotics since they can compare both results. Finally, in the remote experimentation training, students have to send to the real robot the trajectories previously simulated in the virtual environment. Therefore, they can perform a comparison analysis between the simulated and real data of the trajectory proposed (Fig. 4).

Table 1
Scheduling and distribution of the activities in the Automatics and Robotics subjects.

Activities	Face-to-face interaction (hours)	Autonomous work (hours) -Included e-learning activities-
Lectures and supervised problems	30	55
Seminars	4	2.5
Tutorial time	11	2.5
Practical exercises (laboratory work)	15	30
Total	*60*	*90*

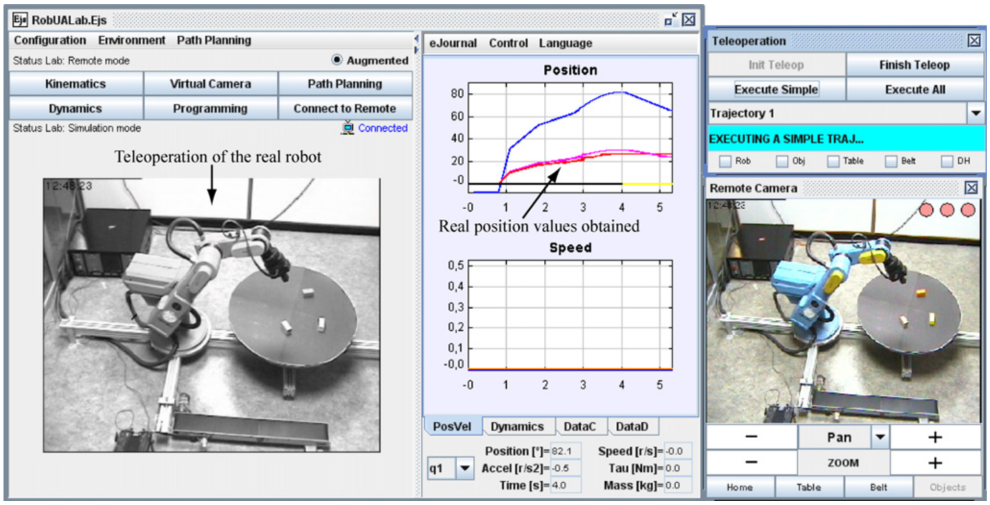

Fig. 4. Teleoperation of a cubic spline in the real robot and position values obtained.

5.2. *Programming the automatic virtual cell and viewing the real robot's behavior*

The second practical exercise proposed regards to a pick-and place experiment of a virtual object which models a real one of the remote plant. In this way, firstly students must recognize the real objects on the turntable in the real laboratory using the recognition module of the application (see Fig. 5). This feature allows the application to do grasping tasks by means of the teleoperation of the remote robot using the virtual laboratory.

Afterwards, students must develop an off-line-programming exercise within the virtual environment for a pick-and place operation of a specific recognized object (virtual training). As stated in Section 4, users are able to program routines in the simulation with a similar language that the real robot uses. This language provides classes and methods to move the virtual robot in the 3D environment (Fig. 5). Finally, in the remote experimentation training, students have to send to the real robot the trajectories previously programmed in the virtual environment. Therefore, they can perform a comparison analysis between the simulated and real programmed task.

5.3. *Working with virtual objects in the real plant: the augmented reality experiment*

The third experience consists of a practical exercise where students use the augmented reality interface which combines virtual objects with the current state from the remote laboratory (Fig. 3). This interface helps to improve user performance and provides more information

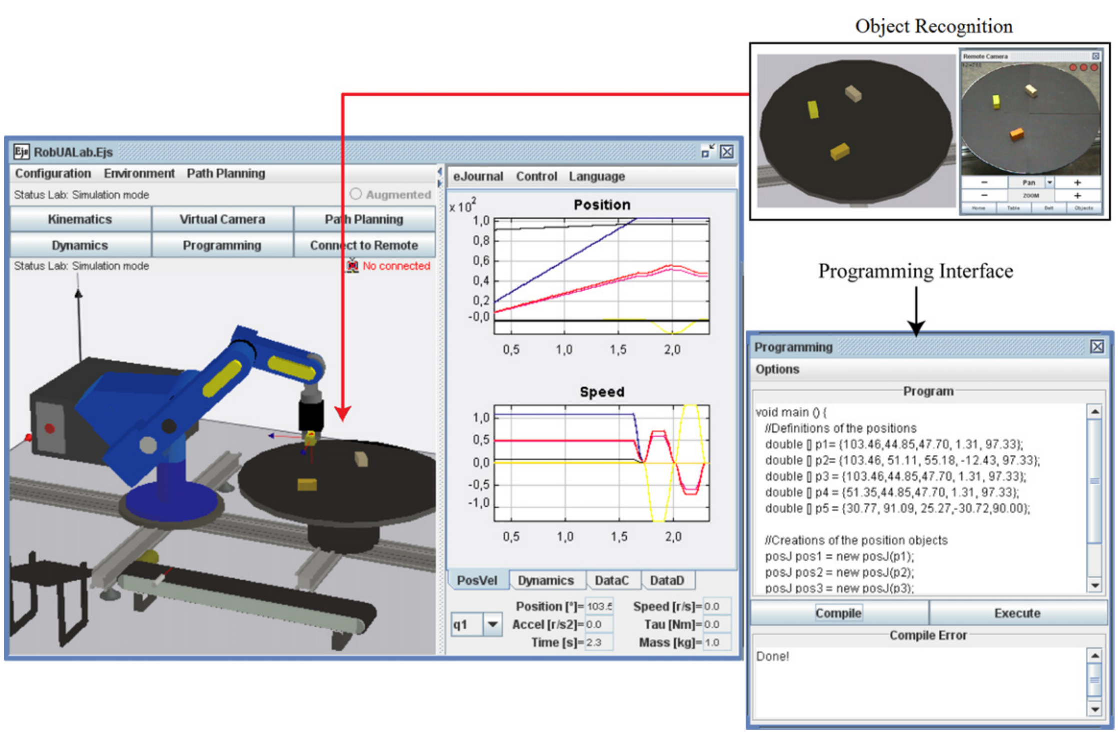

Fig. 5. Programming the virtual environment of a pick-and place operation using the recognized objects.

to the real plant and more flexibility for the practical experiments. The virtual training of this exercise deals firstly with the creation of a virtual object in the 3D virtual environment (see subsection 4.1) over the conveyor belt. Secondly, students must perform a program which executes a pick-and-place operation of the object located in the conveyor belt. Finally, in the remote experimentation training, students have to teleoperate the program simulated using the augmented reality interface where the virtual object in projected in the real robotic cell.

6. Student's perception study

Capturing students' perception of their learning experiences is an important issue to assess the quality of the educational method proposed. In order to evaluate the integration of the VRL *RobUALab* with a blended methodology, the system was tested with a total of 50 students coming from the courses "Robot and Sensorial Systems" and "Automation" of the academic years 2009 and 2010. The main aim of this study is to increase the quality and efficiency of the educational method employed using the student perception. To that end, students were required to fill out an evaluation questionnaire (see Table 2) based on the following issues:

- Satisfaction degree of students in relation with the practical experiences using the Internet.
- Learning with regard to the traditional methods, i.e. use of the virtual and remote laboratory *RobUALab* instead of classical use of the laboratory resources for the practical learning.
- Facility of using *RobUALab*.
- Quality of the virtual and remote laboratory.
- Most important learning resources.
- The suitability of *RobUALab* in the learning of relevant concepts about Automatics and Robotics.

A collection of charts summarizing the results obtained in the evaluation process are discussed hereafter. Fig. 6(a) shows a first general view concerning whether students felt satisfied during the practical experiences. The 36% of them answered that they strongly agree and a 46% agree with the use of the system. The results showed that the use of new technologies, specially the Internet, encourages students to conduct the most of their practical exercises with this resource. Fig. 6(b) gives comparative information about the learning improvement by means of these new technological tools such as VRLs. In relation to the facility of using *RobUALab*, Fig. 6(c) shows that none of the students had problems in the use of the application. It should be emphasized that our students study Computer Science and they do not use to have problems regarding to new technologies issues. They adapted quickly to the user interface of *RobUALab*. With regard to the quality of the virtual and remote laboratories (see Fig. 6(d)), most of students have positively evaluated their development in terms of user functionality. The negative results can be a consequence of the quality of the Internet connections because they introduce delays. Moreover, the majority of students think that *RobUALab* is a suitable tool for the learning of Automatics and Robotics concepts and for the training on a robotic cell programming, as Fig. 6(e) shows. Finally, Fig. 6(f) shows how the queries to the teaching staff and the documentation about the practical exercises are essential resources for the student performance.

The results obtained are satisfactory and they can be summarized as follows:

- *RobUALab* is an efficient and useful tool in the learning process that encourages their ability to understand Automatics and Robotics concepts.
- Remote experiences increase the student's curiosity and motivation to learn and allow them a better analysis of the physical phenomena.
- The educational methodology proposed, which is based on a blended-learning method, has been effective. The most used and important learning resource was the questions to the teacher. This also validates the previous results obtained, where students requested for working in coordination with their classmates and for having the support of a teacher. Moreover, this method has allowed the students to enhance their constructive and collaborative practical learning using a virtual and remote laboratory, a powerful tool for engineering students.

Table 2
Questionnaire performed to obtain students' feedback.

Satisfaction degree of students
In general, do you feel satisfied with the practical experiences through the Internet?
Learning in relation with traditional methods
Did RobUALab help you to visualize the theoretical concepts to be learned?
How would you rate the outcome of your learning using RobUALab if compared with "traditional methods"?
Did RobUALab enhance your ability to understand the theoretical concepts about Automatics and Robotics in a new way?
Facility of using RobUALab
Did you find easy the use of RobUALab?
Did you understand the description of the virtual and remote laboratory?
Did you think that the laboratory was well structured and organized?
Were you able to use RobUALab by following the instructions provided?
Quality of the virtual and remote laboratory
In which grade will you score to the quality of the virtual laboratory and its simulation?
In which grade will you score to the quality of the remote connection?
Was the response time of the remote laboratory suitable?
Most important learning resources
Which of the learning resources you have learned more with?
The suitability of RobUALab in the learning of relevant concepts
Did you the virtual and remote laboratory help you for understanding the concepts of kinematics and path planning of the lectures?
In which grade do you think that RobUALab can be used for the training of automation system programming?

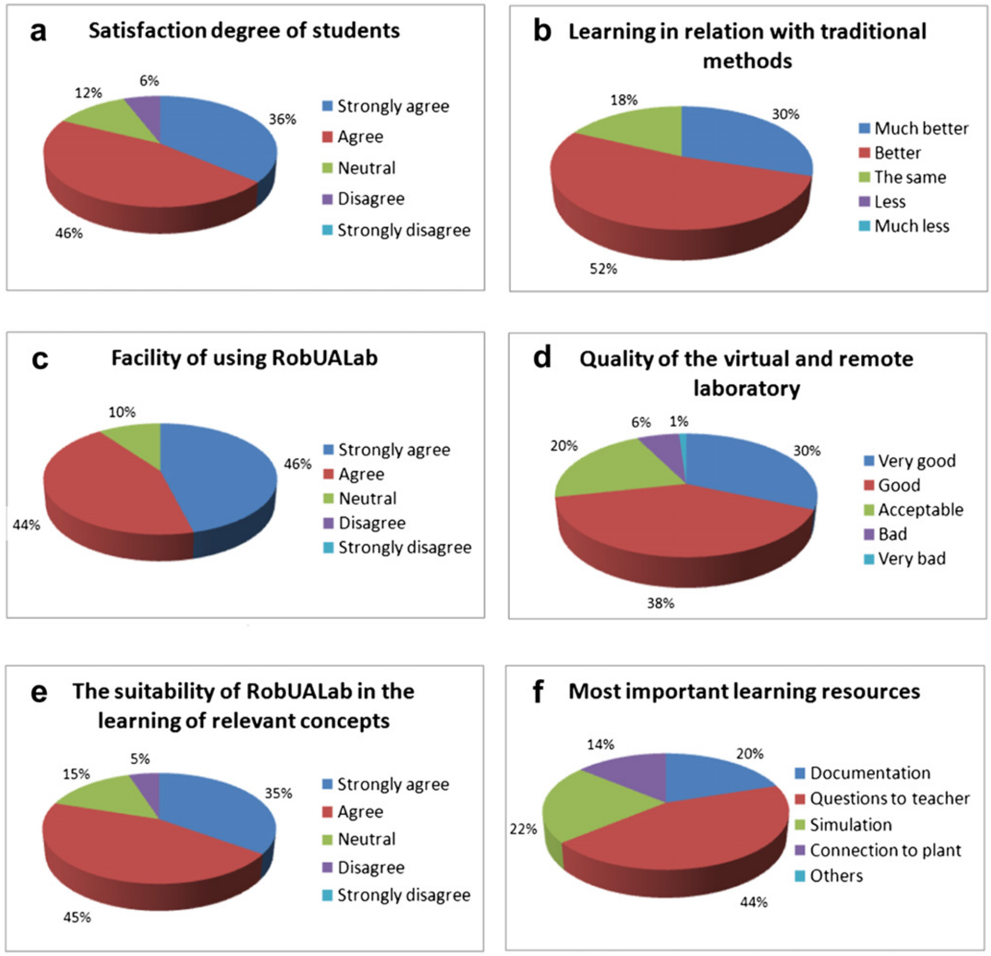

Fig. 6. Student questionnaire results obtained from the academic years 2009 and 2010 about the integration of the VRL *RobUALab* with a blended-learning methodology.

As it was mentioned in Section 5, although it has not been possible to define control groups of students who did not use the blended methodology in years 2009 and 2010, the results of this study can be compared with similar studies carried out by authors in previous academic years. In this way, if the results of the study presented here are compared with studies of previous courses, the following conclusions can be summarized. First, the student maintains a good opinion about using the VRL, its quality, and the utility in learning process. Second, the student's opinion about the learning improvement is better. And, finally, it is confirmed that the student attaches great importance to the documentation and teacher support.

7. Assessment of the approach efficiency

In order to assess the usefulness and efficiency of the approach, two studies were carried out with the undergraduate students. The first one is based on a comparison between the learning outcomes obtained by the students who experimented with RobUALab using the blended-learning method and another group of student who used *RobUALab* without employing the blended-learning method. The second study in only based on the use of the VRL and demonstrated that *RobUALab* allowed students to face better the real problems based on Automatics and Robotics.

7.1. Analysis of learning outcomes

The learning outcomes were analyzed by comparison of the results obtained in the final exam between the students who used *RobUALab* by means of a blended-learning method (academic years 2009 and 2010) and students who used it only by means of an e-learning method (academic year 2008). In the final exam of the subjects, teachers evaluated the most important concepts and topics related with Automatics and Robotics: kinematics, path planning, dynamics and programming.

With regard to kinematics, students had to compute the kinematics using the Denavit-Hartenberg algorithm (Denavit & Hartenberg, 1955) of a specific robot arm proposed in the exam. In the path planning issue, students were required to compute the parameter values of a specific joint trajectory from the planning constrain (position, velocity and acceleration of the robot arm in specific trajectory points). The exercise proposed about dynamics was based on computing the torques of each link of a robot when it is grasping an object. Finally, in regard to the programming item, student had to program an algorithm to automatize an industrial process composed by several sensors, a robot and some automatic devices.

Table 3
Comparison of the learning outcomes between students who used *RobUALab* with a blended-learning methodology and students who used *RobUALab* with a classic e-learning method.

Students/Learning outcomes	Kinematics	Path Planning	Dynamics	Programming
Students who used RobUALab a not employed the blended-learning methodology	7.75	7.15	5.45	5.96
Students who used RobUALab and employed the blended-learning methodology	8.91	8.16	5.92	7.35

Table 4
Assessment of the *RobUALab*'s influence evaluating hours of students' work.

Students' group/Issue	Hours of students' work (average ± standard deviation)
Using first RobUALab	7.03 ± 0.51
Without using first RobUALab	8.62 ± 0.44

Table 3 shows the comparative of the results obtained by the students in the final exam. The analysis is described using the arithmetic mean of the marks for each issue of the subjects (kinematics, path planning, dynamics and programming), which were evaluated from 0 to 10. This average value has been computed using 50 students of the academic years 2009 and 2010, and a group of 25 student of the academic year 2008.

As it can be seen in Table 3, students got better results with the use of *RobUALab* by means of a blended-learning method in all the Automatics and Robotics concepts. The learning outcomes in kinematics, path planning and programming issues are very successful. Only in the dynamics issue, there was not much difference in the results, thus some aspects about learning dynamics must be improved.

As conclusion of this analysis, it has been statistically demonstrated that *RobUALab*'s hand-on exercises using the blended-learning methodology proposed have allowed to students to acquire more knowledge and skills about Automatics and Robotics than students who used *RobUALab* using a classic e-learning method.

7.2. *Influence of the virtual and remote lab RobUALab*

This empirical analysis proposed was performed using students from the same academic year 2010 in order to evaluate the influence of *RobUALab* in their learning and training performance about Automatics and Robotics. The study was based in choosing a group of 25 students who had to do first the practical exercise in the real laboratory (exercise 4, see Section 5) before using *RobUALab*. The rest of students did first the practical experiences using *RobUALab*, and afterwards they faced the exercise of the real plant. The main objective of the study is to demonstrate that students who used *RobUALab* faced better the final experiment of the real than students who not.

The efficiency was computed using the work hours employed by the students in the final experiment: programming the real plant. As Table 4 shows, students who previously experimented with *RobUALab* were able to complete and finish the final experiment in less time than student who not. The time given for the teachers in order to finish the last practical exercise is 9 h Table 4 shows the average value (and its standard deviation) of the time employed for each group of students.

Summarizing, students who used *RobUALab* were able to solve a real problem is a more efficient way. These results demonstrate that the virtual and remote laboratory *RobUALab* is an effective tool from an educational point because allows student to face better the real problems of the current technological world.

8. Conclusions

This paper is focused on showing how an educational method based on the use of a VRL such as *RobUALab* together with a blended-learning methodology can improve the student's experimental learning regarding traditional methods.

On the one hand, the VRL provides the student the necessary tools for developing practical experiments in a virtual environment, with the main advantages of a continuous ability of the virtual equipment for all the students, and the security of the equipment cannot be damaged. On the other hand, the VRL allows the student access remotely to the real equipment to execute his final algorithms, after validate them in simulation. In addition, the blended methodology grants that a set of recourses are available for the student, so that he can be introduced easily in the use of the virtual and real equipment. Among these resources, the most esteemed is the support of the teacher.

The VRL described in this paper, the system *RobUALab*, is targeted to the education of industrial Automatics and Robotics. In contrast with other proposals, this VRL includes many features that enable it to be used as a complete robotics laboratory, with allows student to experiment with many concepts, not only about basics issues about kinematics and dynamics, but also regarding the programming of advances algorithms to manipulate objects in a robotic cell. The real and virtual words are correlated by means of automatic object recognition and augmented reality techniques. Experiences based in a VRL such as *RobUALab* allows the student to compare theoretical results in the virtual world with the practical results in the real robotic cell.

With the aim of validate the above described advantages, authors analyzed the student perception during academic years 2009 and 2010 by means of a survey that students had to fill. This paper describes the main results of this study, which can be summed up in that students like to use the proposed blended environment and learn best with it. Moreover, students greatly appreciate the functioning of the VRL, and how it can increase the motivation to learn how a robotic cell works. Finally, two empirical studies have been presented in order to evaluate the efficiency of the approach: on the one hand, an analysis of the learning outcomes comparing the results obtained by the students who employed the blended-learning method proposed and whose who not, and on the other hand, an analysis about the work hours employed by the students in the real laboratory exercise. The first study reported that *RobUALab*'s hand-on exercises using the blended-learning methodology proposed allowed to students to acquire more knowledge and skills about Automatics and Robotics than students who used *RobUALab* using a classic e-learning method. The second study demonstrated that *RobUALab* influences on students from an educational and training point because allowed them to face better the real problems of the current technological world.

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