

Interoperability platform for virtual and remote laboratories

J. Fernandez², R. Bragós¹, M. Cabrera¹, A. Abelló², N. Arroyo²,
D. González², F. Garófano¹, A. Cortés³, A. Fabra³

¹Escola Tècnica Superior d'Enginyeria de Telecomunicacions de Barcelona/Telecom-BCN

²Facultat d'Informàtica de Barcelona

Universitat Politècnica de Catalunya – BarcelonaTech, Barcelona, Spain

³Everis, Barcelona, Spain

Abstract—This communication describes the interoperability platform that has been developed at the Technical University of Catalonia (UPC) to integrate the access to different virtual and remote laboratories. Up to eleven laboratories that belong to the GilabViR group of interest in virtual and remote laboratories in our University have been analyzed to generate a set of specifications and develop the architecture and the applications that would allow its access through the university LMS system. Although the current LMS platform (Atenea) is implemented over Moodle 1.9, the new modules have been developed using Moodle 2.2.1 given that the migration to this version will be done in the next months.

The interoperability platform defines new Moodle modules that allow the interconnection between the LMS system and a set of laboratories and provide the intrinsic LMS features (user identification, activity recording, educational materials repository, ...). There are modules that allow the interaction with a web service interface giving access to the laboratory, with Java applet virtual laboratories and others that make possible the link with LabView based remote laboratories, all of them with recording of experiment parameters in SQL databases placed in the experiment servers.

Index Terms—Remote laboratory, Virtual laboratory, Learning management system, Laboratory untegration, Secondary education, University education.

I. INTRODUCTION

In recent years, vocations have dropped dramatically in Engineering in Europe. Universities, companies and administrations have joined together in various initiatives to increase the societal implication of engineering and, specifically, to make the Engineering closer to young people. The collaboration between Everis and UPC through the schools ETSETB (Escola Tècnica Superior d'Enginyeria de Telecomunicació de Barcelona) and FIB (Facultat d'Informàtica de Barcelona) was established with the aim of promoting the Engineering in the Information and Communications Technology sector (ICT). Through a Spanish Industry Ministry project we submitted a proposal to improve the accessibility to University based laboratories and, among other goals, allow the access of users from outside the University to virtual and remote laboratories. A clear target is the high

schools science and technology area, but also the professional training education and even the continuous education.

Virtual and Remote Laboratories do not represent anymore a novel methodology in higher education, given its use as learning tools has been extended in many technological Universities. Several published works contain tutorials related to this topic [1][2] and their teaching applications [3][4][5]. Most of University Remote Laboratories for engineering are applied to automation teaching [6][7][8][9] or to electronic circuits teaching [10][11][12]. Some of Remote Laboratories have been designed to improve accessibility to hard powerful servers or work stations [13].

There are also some initiatives of remote laboratories for secondary school teaching but their use is less extended than University experiences in this field [14][15]. However, both students and teachers have widespread access to the use of virtual and simulated experiments. Most of them are based on Java applets or Flash interactive online designs.

Several virtual and remote laboratories have been developed at the Technical University of Catalonia (UPC) to improve the versatility of its educational resources and adapt them to new learning methodologies. Eleven of these laboratories are put together in an interest group [16] to share their common technological and educational aspects. A project with public funding has been set-up, together with the technological consulting firm Everis, to define and build an interoperability platform which unifies the access and management of the virtual and remote labs.

Primarily, this project aims to design and build an advanced and efficient management system of the remote educational resources available at the University which should also allow its aperture to other areas. Therefore it is essential that this model meets the following basic requirements:

- Must be a versatile, modular and scalable platform, since the teaching resources are diverse in nature and have been and will be developed by different teams over different platforms.
- Must be secure and robust; provide educational resource booking management and record several parameters of the activities to ease the assessment.
- Must be adapted to different types of users and supplemented with educational materials

Up to date, twelve virtual and remote laboratories have been studied and classified. They are used in courses corresponding to curricula of: Electrical Engineering, Telecommunications Engineering, Computing Engineering, Industrial Engineering and Civil Engineering. The experiments in the different laboratory courses usually follow the next three steps sequence: 1.- The student designs the experiment and configures the parameters on-line, either at distance or in the computer classroom. 2.- The experiment is executed. 3.- The different results (numerical, graphical, images, etc.) are displayed and optionally stored in the student computer and are also optionally recorded at the UPC LMS Moodle based system called Atenea.

The interoperability platform defines new Moodle modules that allow the interconnection between the LMS system and a set of laboratories and provide the intrinsic LMS features (user identification, activity recording, educational materials repository, ...). There are modules that allow the interaction with a web service interface giving access to the laboratory, with Java applet virtual laboratories and others that make possible the link with LabView based remote laboratories, all of them with recording of experiment parameters in SQL databases placed in the experiment servers.

Paper Outline — after an introductory section, a brief description of each virtual or remote GILABVIR laboratory is presented in section II. Then, objective (Section III), design and implementation (Section IV) of the interoperability platform are described. Finally, sections V and VI are devoted to result and conclusions.

II. VIRTUAL AND REMOTE LABORATORIES INVOLVED IN THE PLATFORM

In this section we give a brief description of each laboratory (virtual or remote) included in GILABVIR and connected or in process of connection through iLabViR platform to UPC campus Atenea. The different laboratories are also classified attending to diverse criteria. Extended description of each one can be obtained in GILABVIR website [17]. While a Virtual Laboratory is defined as an interactive environment for designing and conducting simulated experiments, with a Remote Laboratory students remotely program and supervise real systems as if they were working locally on the real installations.

A. Remote and virtual laboratories for mechatronics and electronics students.

The working team who teaches electrical engineering courses related to automation, mechatronics, motor control, renewable energy generation and power systems has developed both types of laboratories, virtual and remote.

Remote laboratories include: Automation and motor control laboratory [18], Flexible manufacturing cell [19]. Power Quality laboratory, measurements of harmonics for different loads, power system laboratory, protection, fault detection and restoration of electrical power systems.

Virtual laboratories include: DC motor control laboratory, Hotel automation laboratory, Chemical process automation [20].

Most of them are used to complement the local laboratory session.

B. LAVICAD

The virtual laboratory of analog and digital communication systems is a useful tool to verify the performance of different communication systems and signal processing techniques, topics typically integrated in undergraduate courses of the curriculum of telecommunications engineering. The communication systems have been implemented and designed as Java applets and are free available. The different communication systems present different levels of user interactivity with a high degree of flexibility [23].

C. Project: 62, an interactive tool to study discrete time signals and systems.

62 is also an interactive tool written in Java that allows, first, to define discrete time signals and systems, and then to work with them. Signals, systems and operations are specified by means of menus or dialog windows without the need of knowledge of any programming language. One of these menus is devoted to specifying digital filters (FIR and IIR) both in the frequency and in time domains. The tool includes a graphic interface to show the sequences, their Fourier transform and the characterization of linear invariant systems (frequency response, impulse response). The tool uses the A/D and D/A converters of the PC sound card.

D. iLabRS: Remote laboratory for Secondary Education.

iLabRS is built over a Modular platform to perform remote experiments in sensors and signal conditioning. This remote Laboratory is aimed for Secondary Education students, to allow them to perform online real experiments, with remote access through Internet. The aim is triple: giving a tool to increase the experimentality in scientific and technological subjects, demonstrating the potential of the ICT's use and establishing a bridge between the secondary school and the university.

E. LEARN-SQL

LEARN-SQL is a tool whose main goal is helping in learning the use and design of relational databases in different subjects of schools of the UPC. This is a system conforming to the IMS QTI specification [22] that allows on-line learning and assessment of students on SQL and other database skills in an automatic, interactive, informative, scalable and extensible manner.

This tool facilitates the definition of virtual laboratories or remote questionnaires that are used by students of subjects to learn design and use of relational databases in the UPC.

The tool has efficiently served to adapt the subjects where it is used to the European Higher Education Area (EHEA) and to innovative education methodologies [23].

F. Circuit and Communications Systems Simulators

The aim of this virtual laboratory is to develop monitoring tools for homework based on running software simulators. The monitoring tool will automatically send a report to a Moodle platform. It will be based in a Python module with functions to write ASCII text, formatted text, results tables and figures in the report together with the answer to questions asked to the student.

This project has provided a tool to assist some activities of the UPC “European Master of Research on Information and Communication Technologies”. The involved Master courses are: “Antennas for Communications”, “Waves and Systems”, “Electromagnetics Engineering” and “Design and Analysis of RF and Microwave Systems for Communication”.

G. Modular platform to perform remote experiments in sensors and signal conditioning.

This remote laboratory is based on a custom acquisition board which includes an Ethernet capable microprocessor, so that every board has its own IP address. The experiment server runs specific applications made in LabView that control the experiments. Every application generates a remote panel that allows its use with a web browser. Four different experiment boards have been developed up to now, which allow performing 6 different laboratory activities around the sensor characterization and the set-up of conditioning and acquisition circuits. The use of the remote laboratory is focused as a complementary tool to add flexibility to the laboratory courses, mainly with the semi-distance students [24].

H. VirtuaLab: remote workbench for instrumentation and sensors.

Remote laboratory based on a web server and a VXI modular instrumentation system connected to a circuit board with experiments and to a weather station. The access is made through a website (virtualab.upc.es) using a password. It only admits a single simultaneous user, who can use the resource during 20 minutes. Seven different laboratory activities can be carried out, from system identification and control, sensor calibration and remote control of instrumentation. In operation since 2003, the user interface was designed with the criterion of minimizing the data exchange and ensuring the system robustness. Because of this, the control applications in LabView that control the experiments are running in the server and they just exchange parameters and results with the user dialogues in the web pages [25].

I. rWLaB-Remote WaveLab

The goal of this laboratory is to convert an experimental setup (wave channel) into a platform for teaching, research and dissemination of knowledge using all the advantages offered by today's information technologies. Thus, we propose the creation of a knowledge portal based on experimentation with small-scale physical models within the field of Maritime Engineering. The purpose of this portal will serve as the container of those remote and virtual laboratories that can be developed from this initiative. It is envisaged to provide the necessary content to the portal in order to, either through simulation, experimentation or study, achieve varying knowledge

levels of methods and technologies employed in the experimental scale.

J. SEC Virtual Laboratory

This project addresses the development of a virtual laboratory for control system experiments. The goal is to emulate the classroom experiments that can be done with real equipment. The prototypes include a magnetic levitator simulator, an inverted pendulum mounted on a cart, a DC servomotor and a model of two helicopter rotors. To give flexibility to the platform the applet communicates with a calculation engine using SSH, this interface also allows connecting to other programs and platforms [26].

K. OnLine Robotic Lab.

This remote laboratory allows to control and program a robot manipulator arm. The system offers editing and syntax checking facilities without using the real robot. When the program is completed, it is executed on the real robot, while it is monitoring using IP cameras and text messages [26] [26].

A summary of the type, main use and educational environment of the previous laboratories is shown on table I.

The educational scope and use from each of the laboratories definitely cover a wide-range of applications; however, at the group start-up all of them shared a common challenge. They needed to be connected to an educational campus from where to control an experiment, including configuration, execution and results monitoring steps.

TABLE I. SUMMARY OF GILABVIR REMOTE AND VIRTUAL LABORATORIES

Laboratory	Type	Main Use	Education
A. Mechatronics and electronics	Remote	To complement a Lab Session	Grade Master
B. LAVICAD	Virtual	Laboratory Session	Grade
C. 62	Virtual	Laboratory Session	Grade
D. iLabRS	Remote	Special classes	Secondary
E. LEARN-SQL	Remote	Laboratory Session Homework	Grade Master
F. Circuits	Virtual	Homework	Master
G. Modular Sensors Platform	Remote	Semi distance sessions	Grade
H. VirtuaLab	Remote	To complement a Lab Session	Grade
I. rWLaB	Remote	To complement a Lab Session	Grade
J. SEC	Virtual	To complement a Lab Session	Grade
K. OnLine Robotic	Remote	To complement a Lab Session Homework	Grade

III. OBJECTIVES

The main objective of this project is the development of an interoperability platform for the promotion, dissemination, exploitation and management of virtual and remote laboratories. To achieve this goal, it was necessary to:

- Study the requirements for the integration of virtual/remote labs (related to the project) in an e-learning system.
- Make a realistic proposal that allows the integration:
 - Easily upgradeable to support new virtual or remote laboratories.
 - Follow the software standards (i.e., coding, security and legality) for the development of LMS components (the basic platform didn't have to be modified, the components should be plug-in).
 - Communication between the virtual / remote laboratories and the LMS had to be as generic as possible and independent of the technologies used in each system (i.e., web services, Java applets, etc.).
 - The necessary modifications in the current laboratories should be the minimum possible. These laboratories are already implemented and they already support learning activities.
- Make use of open source tools and resources.
- Consider all the laboratories of the GiLabViR group to ensure the integration of all of them.

From the early stages of the project, Moodle was chosen as the best option to be used as the supporting LMS to build over the interoperability platform. This decision was based mainly on the fact that Moodle is the system that was used to implement Atenea (the Virtual Campus of the UPC) and it is the LMS most widely used worldwide.

IV. DESIGN AND IMPLEMENTATION

The initial situation was the previous work developed in the GiLabViR group [1], and the existing virtual & remote laboratories. After an exhaustive analysis of the 11 laboratories associated to the GiLabViR group, the use cases were identified (a use case typically defines interactions of a system with users or other systems to achieve a goal) for each laboratory. These use cases were unified when they were equivalents. So, seventeen unified use cases were defined that are organized into 7 groups: Laboratory configuration, Experiment configuration, Booking, Experiment execution, Video camera access, Experiment results access and Students grading. Also the following four roles were identified and defined: Manager of the learning management system, Student, Teacher and Laboratory manager.

In order to simplify the system implementation and maintenance, component reuse, future expansions and the integration of all existing remote and virtual laboratories with a little effort, a modular system was adopted. The interoperability platform was implemented in four main components, as shown in Fig. 1 and described below.

- The iLabViR module. This is the component that is integrated as a plug-in in Moodle (version 2.2.1 or higher). This module allows adding in an existing course, one or several activities carried out in remote or virtual laboratories (Fig. 2, 3 and 4). Faculties and students use this component to interact with laboratories, to monitor them, to carry out and evaluate experiments.

- The experiment repository module. It is a list with the description of the experiments available in the laboratories and the information each require. It is only necessary to define the activity once (in the repository), even in the case that different courses include it many times. The system automatically updates the activity in the different courses that contain it, guaranteeing the consistency. The repository manages all the information about the infrastructure (on-line laboratories, available experiments, booking system, communication protocols, etc.).

- Resource booking module. Some remote laboratories use real equipment to carry out the activities. In order to achieve a suitable subject planning, it's important to book the required resources to do lab classes. This module allows faculties and students, to work in the remote laboratory at the planned period. It is a separate module but in order to improve simplicity and consistency, the booking system is accessed from the iLabViR module (Fig. 4).

- Remote and Virtual Laboratories. On-line labs can work in an independent mode (without relation with the other modules, in this case we don't take advantage of the benefits of the platform) or in an integrated mode. In this case, each laboratory has to implement an interface component (a web service) that responds to requests from the iLabViR module.

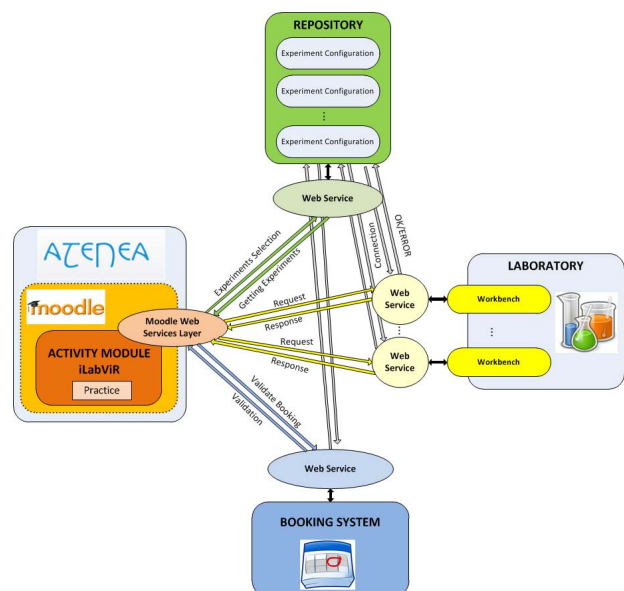


FIGURE 1. SYSTEM ARCHITECTURE OF THE INTEROPERABILITY PLATFORM.

General

Nombre de la actividad labvir *

Descripción *

Ruta: p

Instrucciones

Tiempo

Fecha de apertura * 23 enero 2012 11 30

Fecha de cierre * 23 enero 2012 11 30

Repositorio

Selecciona el protocolo de comunicación con el repositorio *

Base de datos PostgreSQL

Servidor

Puerto

Nombre de la Base de Datos

Nombre de usuario

Contraseña

Ejecución de la actividad

Navegación

- Ejecución lineal de la actividad entre los experimentos:
- Ejecución libre de la actividad

Visibilidad de los mensajes de la solución

Tipo de mensajes *

- Mensajes solución
- Mensajes información extra
- Mensajes de error

Políticas de corrección

Política de cálculo de la nota *

Método binario

Nota válida *

La nota más alta

Reservas

Tipo de reserva *

Sin reserva

Duración máxima del evento

0 minutos

Seguridad

Direcciones restringidas

Clave de acceso

Ajustes comunes del módulo

Modo de grupo

No hay grupos

Visible

Mostrar

Número ID

FIGURE 2. iLabViR MODULE. ACTIVITY CONFIGURATION PARAMETERS

Ejemplo

Vista Resultados Reservas Puntuación Edición Monitorización

Instrucciones

Siguiente

Esto es un ejemplo de práctica de laboratorio virtual o remoto.

Actividad abierta desde las: 21/10/11 10:05:00

Cierre de la actividad a las: 21/10/14 10:05:00

Configuración de la actividad:

Nº	Título	Peso	Intentos	Penalización por intento
1	SQL56- Quantes ciutats de departament per projecte.	25	100	0
2	SQL02- Obtenir els noms dels empleats ...	25	100	0
3	SQL03- Obtenir números i els noms dels departaments....	25	100	0
4	AL01- Obtenir el nom i el sou dels empleats	25	100	0

FIGURE 3. iLabViR MODULE. VIEW, USING STUDENT ROLE, OF A PREDEFINED ACTIVITY

Tipo de reserva

Reserva individual

Grupos

Elige un grupo

Fecha de inicio

23 marzo 2012 12 35

Fecha de finalización

23 marzo 2012 12 35

Duración máxima de una reserva: 60 minutos

Reservas

Guardar Reserva

FIGURE 4. BOOKING USER INTERFACE (IN THE iLabViR MODULE)

The system uses web services for the interaction between modules. This design decision was obvious since Moodle 2.x used this mechanism, and it is a technology oriented to implement modular and/or distributed systems, as in the case of this project. The system supports the main internet protocols: SOAP, REST and XML-RCP. In all cases, the iLabViR module acts as service requester, and the communication between modules is always asynchronous (the requester is not blocked waiting for the response or confirmation of the provider).

Thus, the main system module is iLabViR (the others provide it some services). The functions offered by this module are: connection to the repository, user authentication, experiment configuration and execution, definition of evaluation policy, experiment booking, to get results from the experiment execution and display them, experiment evaluation and monitoring of system components and information transfers,

For platform operation, only five functions (web service calls) have to be implemented in each laboratory that wants to be integrated in the platform:

- getWebserviceStatus: Check the status (availability) of the interface component of a laboratory.
- beginTransference: Send to the on-line laboratory, the student solution to an activity. Then, the laboratory runs this solution, and obtains some results that are stored until the user collects them.
- getTransferenceOutputs: Request the results from the execution of the activity solution that was sent previously with the function beginTransference.

- `getCurrentTransferencesStatus`: Monitor the status of all transactions between the iLabViR module and the online laboratory.
- `deleteTransference`: Delete an activity transfers (usually this action is carried out when an error happens in the system, because communication between modules is asynchronous).

V. RESULTS

The system is successfully implemented and it is in operation. In the final phase of the project (project design and development was 24 months duration), several actions for validation and dissemination were carried out among the educational community. It has been tested in real conditions of use in a university setting, as in the field of secondary education. These tests have allowed us to validate the level of reliability, robustness and usability of the platform.

Among the collected data we highlight the results of two surveys. The first was addressed to university students in the context of a course of electronic control systems, using a virtual lab –a magnetic levitator described in section II.J-. The second was addressed to secondary school teachers attending a workshop on on-line laboratories, where the interoperability platform project was presented and they carried out a practical session using several laboratories included in the platform.

The results of these surveys and the meetings and interviews that we had with various actors in the educational community (in high school, professional training and university) expressed the interest and utility that virtual and remote laboratories have in the learning process. In this way, the developed interoperability platform allows to unify the laboratory interface and usability, and provides a set of common services, making the process, from conception to the use of an on-line laboratory, simpler, faster and cheaper.

For these reasons we believe that the interoperability platform for on-line laboratories must be an efficient initiative to promote the development and use of such laboratories in the near future.

VI. CONCLUSIONS

With the EHEA startup, new educational methodologies have intensified the challenge of introducing Remote or Virtual laboratory based learning activities in engineering courses. As a consequence of this stress the design of a common interoperability platform has surged as a result of detecting common needs of the technical solutions for the different laboratories at UPC.

This platform has also promoted the application of Remote and Virtual laboratories to secondary school, sharing resources and increasing collaboration. More information on this issue can be obtained at the project webpage [29].

The effort to define and develop a universal platform for the integration of remote and virtual laboratories in an LMS, like Moodle, promotes the interest in these resources, and initiates new collaboration. Indeed, the simplicity of integrating new laboratories is encouraging other groups to make and share their contributions.

REFERENCES

- [1] J. Ma and J.V. Nickerson, "Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review," *ACM Computing Surveys*, vol. 38, 2006.
- [2] E. Lindsay, P. Long, and P.K. Imbrie, "Remote Laboratories: Approaches for the Future," *Proc. 37th ASEE/IEEE Frontiers in Education Conf.*, 2007.
- [3] D. Grimaldi, S. Rapuano, T. Laopoulos. "Aspects of traditional versus virtual laboratory for education in instrumentation and measurement" IMTC'05 Conference, Ottawa 2005.
- [4] H.A. Latchman, Ch. Saltzman, D. Gillet, H. Bouzekri. "Information Technology Enhanced Learning in Distance and Conventional Education". IEEE Transactions on Education. Vol. 42, No. 4, pp247-254, November 1999.
- [5] Gravier C. et al., "State of the Art About Remote Laboratories Paradigms - Foundations of Ongoing Mutations," *International Journal of Online Engineering (iJOE)*, vol. 4, 2008.
- [6] B. Aktan, C.A. Bohus, L.A. Crowl "Distance learning applied to control laboratories". IEEE Transactions on Education. Vol. 39, No. 3, pp. 320-326, 1996.
- [7] M. Casini, D. Prattichizzo, A. Vicino. "The automatic Control Telelab : a remote control Engineering Laboratory." IEEE Conference on Decision and Control, Florida, USA, December 2001.
- [8] J. Henry. "LabVIEW applications in teaching control systems laboratories". ASEE, Anaheim, CA, USA, June 1995.
- [9] F.A. Candelas Herias and J. Sánchez Moreno. "Recursos didácticos basados en internet para el apoyo a la enseñanza de materias del área de ingeniería de sistemas y automática". *Revista Iberoamericana de Automática e Informática industrial*. Vol.2, Num. 2, pp. 93-101, 2005.
- [10] H. Shen, Z. Xu, B. Dalager, V. Kristiansen, O. Strom, M.S. Shur, T.A. Fjeldly, J. Lu, T. Ytterdal. "Conducting Laboratory Experiments over the Internet". IEEE Transactions on Education, Vol. 42, No. 3, pp. 180-185, August 1999.
- [11] A. Etxebarria, I. Oleagordia M. Sánchez, "Power electronics and basic electronics real experiments through the World Wide Web" *Frontiers in Education*, Reno USA, 2001.
- [12] I. Gustavsson. "Laboratory experiments in distance learning". *International Conference on Engineering Education*. Oslo, Norway, August 6-10, 2001.
- [13] F. Cennamo et al. "A remotely controlled measurement system for education and training of experiments in wind tunnel". IMTC'04 conference. Como, 2004.
- [14] D.van Schenk Brill and B.van Gestel. "Students' appreciation of an online lab-experiment – A case study". SEFI, 37th annual conference on engineering education. Rotterdam, July 2009
- [15] S. Paladini, J.B. da Silva, G.R. Alves, B.R. Fischer, J.B. da Mota Alves. "Using Remote Lab Networks to Provide Support to Public Secondary School Education Level". 11th IEEE International Conference on Computational Science and Engineering Workshops, 2008. Sao Paulo, 16-18 July 2008. Pp. 275 – 280
- [16] GILABVIR: Virtual Laboratories and Remote Laboratories in Engineering; Cabrera, M; Bragós, R, Casany, M. J.; Gironella, X; Gomis, O; Mariño, J B.; Pérez, M.; Rius, J. M. IEEE EDUCON, Madrid 2010, pp. 1403-1407.
- [17] GILABVIR website: <http://www.upc.edu/rima/grups/gilabvir/projectes-participants>
- [18] A Remote Laboratory Platform for Electrical Drive Control Using Programmable Logic Controllers. Ferrater-Simon C, Molas-Balada L, Gomis-Bellmunt O, Lorenzo-Martinez N, Bayo-Puxan O, Villafañila-Robles R.. (2009). IEEE Transaction on Education, 52 (3) : 425-435
- [19] A Distance PLC Programming Course Employing a Remote Laboratory Based on a Flexible Manufacturing Cell IEEE Transaction on Education, vol. 2, n. 49, pág. 278-284
- [20] A Chemical Process Automation Virtual Laboratory to Teach PLC Programming. The International Journal of Engineering Education, vol. 23, n. 2, pág. 403-410

- [21] Margarita Cabrera Bean, Albert Mestres Sugrañes, Carlos Vargas Berzosa, Francisco Vargas Berzosa. Virtual Analog and Digital Communications Laboratory: LAVICAD: On line interactive tool for learning communications systems. IEEE Engineering Education 2010 - The Future of Global Learning in Engineering Education. EDUCON 2010. Madrid, 13-15 April 2010.
- [22] Alberto Abelló, M. Elena Rodríguez, Toni Urpí, Xavier Burgués, M. José Casany, Carme Martín, Carme Quer. *LEARN-SQL: Automatic Assessment of SQL Based on IMS QTI Specification*. Poster session in 8th International Conference on Advanced Learning Technologies (ICALT 2008). Santander (Spain), July 2008. Pages 592-593. IEEE, 2008.
- [23] Xavier Burgués, Carme Quer, Carme Martín, Alberto Abelló, M. José Casany, M. Elena Rodríguez, Toni Urpí. Adapting LEARN-SQL to Database computer supported cooperative learning. Adapting LEARN-SQL to Database computer supported cooperative learning. In Workshop on Methods and Cases in Computing Education (MCCE). Cadiz (Spain), July 2010
- [24] B. Sánchez, R. Bragós. "Modular workbench for in-situ and remote laboratories". IMTC'07. IEEE Instrumentation and Measurement Technology Conference. Warsaw, 2007
- [25] D. Anton, R. Bragós. "Remotely accessible laboratory for instrumentation and sensors". IMTC'04. IEEE Instrumentation and Measurement Technology Conference. Como, 2004.
- [26] A. Villar, S. Zarza, J. A. Lázaro, R.Mª. Fernández-Cantí. Multiplatform virtual laboratory for engineering education. International Conference REV. Bilbao 4,5,6 de Julio 2012.
- [27] Fernández, J.; Casals, "A. Open Laboratory for Robotics Education". IEEE International Conference on Robotics and Automation., 2004, p. 1837-1842.
- [28] Fernández, J.; Marin, R.; Wirz, R. "Online Competitions: An Open Space to Improve the Learning Process". IEEE Transactions on Industrial Electronics, Dec 2007, vol. 54, núm. 6, p. 3086-3093.
- [29] Interoperability Platform Project Website <http://ilabvir.upc.edu/>

AUTHORS

J. Fernandez is with the Department of Automatic Control, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona, (e-mail: josep.fernandez@upc.edu).

R. Bragós is with the Department of Electronic Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona, (e-mail: rbb@eel.upc.edu).

M. Cabrera is with the Department of Signal Theory and Communications, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona, (e-mail: marga.cabrera@upc.edu).

A. Abelló is with the Department of Service and Information System Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona, (e-mail: aabello@essi.upc.edu).

N. Arroyo is with the Department of Automatic Control, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona.

D. González is with the Department of Automatic Control, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona.

F. Garófano the Department of Electronic Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, C/ Jordi Girona 1-3, E-08034 Barcelona.

A. Cortés is with Everis, Av. Diagonal 605, E-08028 Barcelona (e-mail: antonia.cortes.linares@everis.com).

A. Fabra is with Everis, Av. Diagonal 605, E-08028 Barcelona (e-mail: alex.fabra@everis.com).

This work was supported by Plan Avanza I+D of the Ministry of Industry, Energy and Tourism (reference TSI-020110-2009-432).