Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

Inter-University Network of Remote Laboratories ⋆

M. Domínguez * J.J. Fuertes * P. Reguera * M.A. Prada * A. Morán *

* *Instituto de Automatica y Fabricacion Area de Automatica y Control, Campus de Vegazana, Universidad de León, León (SPAIN) 24071. e-mail: mdomg@unileon.es, prega@unileon.es, jjfuem@unileon.es, mapram@unileon.es, moranalvarez@gmail.com)*

Abstract:
New technologies provide means and tools to develop new ways of communication, organization, work, etc. that have an impact on all the scopes of the society. Higher education has also experienced those changes. In the last years, the Internet has made possible to explore new teaching strategies. In this paper, the development of a Inter-University Network (IUN) of remote laboratories is proposed. The purpose of this network is training in automatic control using the Internet to work remotely with industrial equipment. This network is supported by a technological platform developed by the research group in Automatic Control at the University of León.

Keywords: Control Education; e-learning; Internet-based teaching technologies; Remote and distributed control; Controllers.

1. INTRODUCTION

The great advances achieved in the last decades, concerning the expansion and use of communication networks, have caused important changes in our society, which now relies on Information and Communication Technologies (the renowned Knowledge Society). Whereas the field of manufacturing has experienced significant changes, higher education still faces numerous challenges (UNESCO, 1998). The directives issued by the European Union regarding these challenges are clear (Hackl, 2001). Their main goal is the transformation of the higher education so that it can become more open, flexible, dynamic, multidisciplinary and, above all, able to adapt according to the changes experimented by the society. Nowadays, any professional must be aware of technological innovations, and technological skills and know-how are very valuable competences for any career (Penfield and Larson, 1996). In order to achieve these skills, it is extremely important to encourage innovation in educational methodologies, so that these methods stimulate cooperative and individualized learning, self-learning and new ways of interrelation between the different participants in the educative process. Control Education faces specific challenges (Dormido, 2004) and remote laboratories are useful resources to confront them.

⋆ This work was supported by the project *Inter-University Network II for validation of new educational methodologies based on Remote Laboratories* under grant EDU/1968/2006 of the *Consejeria de Educación de la Junta de Castilla y León*. M. A. Prada was supported by a grant from the *Consejería de Educación de la Junta de Castilla y León* and the European Social Fund.

2. BACKGROUND

The research group in Automatic Control of the University of León has been working in supervision of industrial processes for several years, focusing some of its research efforts on remote process monitoring through the Internet. In 2001, this group presented a work of a remotely supervised industrial pilot plant (Domínguez et al., 2001). In this meeting, a proposal to start the development of Remote Laboratories via Internet for training in this area was issued by the Spanish Committee on Automatic Control. Our group started working then in the transference of knowledge and developments on supervision, with the aim of creating a Remote Laboratory in the University of León (http://wwwlra.unileon.es), to provide access to industrial equipment, including both general equipment (PLC's, DCS's, etc) and industrial scale models developed as education equipment for technological learning (Domínguez et al., 2005).

During 2005, the group received funding from the *Consejería de Educación de la Junta de Castilla y León* (Regional Government of Castilla y León) to conduct research in new educational strategies, based on the use of Remote Laboratories, within the project *Red Interuniversitaria para Validación de Nuevas Metodologías Docentes Basadas en Laboratorios Remotos* (Inter-University Network for validation of new educational methodologies based on Remote Laboratories). During 2006, the project was developed, creating an Inter-University Network (IUN) that received a positive evaluation to be continued in 2007. This network is constituted by 4 research groups of the areas of Automatic Control and Systems Engineering of the following Spanish universities: University of León, University of Oviedo, University of Almería and UNED.

It takes as a initial basis the use of 4 identical industrial scale models (Domínguez et al., 2004) which are located in the 4 Universities. The purpose is to study the problems that arise when the scale models are used for training, having into account with the new educational directives established by the Bologna Process in the European Higher Education Area (Declaration, 1999).

Most of the strategies adopted for the development of remote laboratories, so far, have a point of view where a physical system or a set of decentralized systems is part of a certain laboratory that uses the Internet only as the entry point, also providing flexibility, decentralization, etc. (Candelas and Sánchez, 2005). However, the experience of these last years show us that several problems may appear in daily teaching, during the operation associated to remote laboratories.

The main problems are: content generation, necessity of revision of the syllabi, different operation dynamics, different control technologies, and management issues of the laboratory. All these problems must be considered and they require approaches much more global than those proposed by the groups that previously conducted research in this topic.

In fact, from the point of view of the *content generation*, the use of a remote laboratory in a continuous, broad and intensive way involves important methodological changes when it comes to teaching technological subjects (Dormido, 2004). Remote laboratories give professors a new and dynamic tool for either theoretical teaching or hands-on practice. It is also *necessary to review the syllabus* of the different programs to adapt them to the changes caused by the use of the laboratory.

The variety of physical systems that can be accessed (pilot plants, industrial scale models of process, robots, pneumatic and hydraulic drives, systems, etc.), each one with its *operation dynamics*, is the cause of most problems. For that reason, this is the area where it will be increasingly necessary to work in a coordinated way in order to be efficient and to ensure coherence, simultaneously with the learning objectives set within our area of knowledge.

In addition, *different control technologies* which can interact with physical systems must be considered: industrial controllers, PLCs, PCs, DCSs. They are expensive and it is necessary to make possible their connection to the physical systems. The idea of having hardware and software in an isolated remote laboratory and sharing resources with other laboratories arises as an alternative. This question makes us consider aspects of standardization of the different graphical representations which can be provided to each user, audio and video, data structure and its management, processing and storage to guarantee reusability and portability to third-party scientific and office automation applications, etc.

The *management issues* should be considered as well. When a remote laboratory is made accessible to the users through the Internet, it is necessary to set up not only safe access policies but also internal security measures on the different physical systems and the auxiliary management elements of the laboratory (cis, 2005). Preventive security measures must be considered to avoid that the illegal use or incorrect customization of the control systems makes these systems and, consequently, the remote laboratory unavailable (denial of service attacks). And the response in this situation must be aimed to guarantee the return to the initial conditions of operation of the system.

Fig. 1. Industrial Scale Model of 4 tanks used in the IUN.

On the other hand, it is necessary to guarantee *usability*, and provide, through the laboratory web pages, precise information and guides encouraging the student to use this structure. *Performance* is also an issue. Excessive waiting queues, delays in the data reception, temporary disconnections, etc. will lead to rejection of the system.

All the previous considerations make us believe that the operation of the remote laboratories would be much more efficient if the organizations in the network set a common objective, where shared and standardized structures that alleviate the work of both professors and students are defined. In order to tackle some of these problems, we have developed an experimental remote network of laboratories via the Internet whose physical systems are the industrial scale models located in the 4 above mentioned Universities, along with their respective control systems.

3. DESCRIPTION OF THE PHYSICAL SYSTEM

The physical system is constituted by an industrial scale model (see Fig. 1), designed by the group of Automatic Control of the University of León to perform experiences in this field, initially focused on the areas of Automation, Control and Industrial Instrumentation. The physical system is a quadruple-tank process. It is composed of four water tanks interconnected to each other in such a way that the exit of the water-drainage of the upper tanks ends at the lower ones. The flow is supplied to the tanks by two symmetrically placed pumps, and each one has a three-way valve that distributes the flow delivered by each pump between the upper and lower tanks. Therefore, the system has four inputs, which are the variables of the pumps ($\upsilon 1$, $\upsilon 2$) and the position of the three-way valves ($\gamma 1$, $\gamma 2$), and four outputs, which are the level of the tanks ($h1$, $h2$, $h3$, $h4$). The purpose of the process is to implement control loops of both SISO and MIMO systems.

The model keeps the original structure of the quadruple-tank process proposed by Johansson (2000) but it is built using common instrumentation in industrial environments:

- Grundfos UPE 25-40 flow pumps equipped with a frequency inverter (Grundfos MC 40/60) to control it by means of an analogical signal. These pumps

TAG	Variable	Type	Span	I/O
LT01	Level D01	4-20 mA	0-100	Input
LT02	Level D02	4-20 mA	0-100	Input
LT03	Level D03	4-20 mA	0-100	Input
LT04	Level D04	4-20 mA	0-100	Input
LV05	Level Valve D01-D04	4-20 mA	0-100	Output
LV06	Level Valve D02-D03	4-20 mA	0-100	Output
SZ01	Pump Converter P01	0-10Vdc	0-100	Output
SZ02	Pump Converter P02	0-10Vdc	0-100	Output
ES01	Confirmation Pump ON P01	24Vdc	N.C.	Input
ES02	Confirmation Pump ON P02	24Vdc	N.C.	Input
ES03	Pump Failure P01	24Vdc	N.C.	Input
ES04	Pump Failure P02	24Vdc	N.C.	Input
ES05	Voltage Presence 24Vdc	24Vdc	N.C.	Input
ES06	Voltage Presence220Vac	24Vdc	N.C.	Input
FY01	On/Off Pump P01	24Vdc	N.C.	Output
FY02	On/Off Pump P02	4Vdc	N.C.	Output
LY03	Valve LV03	24Vdc	N.C.	Output
LY04	Valve LV04	24Vdc	N.C.	Output
LY05	Valve LV05	24Vdc	N.C.	Output
LY06	Valve LV06	24Vdc	N.C.	Output

Table 1. Variables of the industrial scale model

DCS	PLC	PLC
Control:	**Control:**	**Control:**
Opto	Siemens	Schneider
LCM4	SIMATIC S7 314C-2 DP	TSX P57254

Table 2. Control Systems of the Industrial Scale Model

can work in both proportional and constant pressure mode. In addition, they can be controlled by a bus signal.

- Samson 3226-3760 three-way valves with a positioner Samson 3760 to allow the regulation of the opening of the valve by means an external signal. The valve distributes the flow between the tanks.
- Endress & Hausser PMC 731 pressure transmitters, for acquisition of the liquid level. The configuration can be changed easily.
- SMC digital electrovalves, used to simulate perturbations on the tank level. They only have two positions: open and closed.

Table 1 shows all the electric signals provided by the instrumentation installed in the scale model.

An objective is to provide great flexibility in the control system selection. Users can choose at any moment the control system that they are going to use for the accomplishment of their tasks. Information about the control systems used in our laboratory is illustrated in Table 2.

4. OBJECTIVES

The experience described in this paper takes as the starting point the developed technological platform that provides service to the physical systems of the University of León. Quadruple-tank Industrial Scale Model of the 4 Universities have been added to the platform.

The proposed objectives are, in general:

- To test the flexibility of the technological platform of the laboratory regarding the incorporation of external physical systems. The objective is to determine how long it takes to make a physical system, initially inaccessible from the University of León, available through the web to other departments or organizations without the necessary equipment to offer these services by themselves.
- To validate the structure of logging, access and security, using data files provided by the Data Process Centers (DPC) of other Universities.
- To evaluate the effectiveness of the user interfaces at different levels, obtaining measures of typical bandwidth of users, usability, typically-used browsers, location and time of user connections, time of usage, number of connections, CPU load and RAM usage of the different applets in the interface, etc.
- To provide the professors of the Universities with a set of utilities to develop educational contents in a fast, simple and agile way. Thus, the professors will focus on the content, not on the infrastructure.
- To define a flexible structure of information exchange between the controller of the scale model and the database of the laboratory.
- To study the behavior of the laboratory technological platform under massive remote insertion of data. This is a problem that has to be analyzed to determine the effect of the Internet delay on data acquisition.
- To implement a procedure to export data of the experiences to Matlab and send them by e-mail to the user, so that the users can work with data from the real physical system in their own PC.
- To develop an online help system for the users that allow them to access to appropriate contents regarding the hands-on practice. The objective is to obtain an easy-to-use help system, having into account not only the problem, but also additional technical/theoretical documentation and related links.
- To validate a structure based on package filtering techniques and NAT (Network Address Translation) management, where physical systems located within the local network of the University of León can admit external incoming connections to this network. The purpose is that the users can connect software applications of different controller manufacturers to controllers that are located within the local network of the University of León, just as if they were directly connected to them.

5. STRUCTURE OF THE LABORATORY NETWORK

In this section, the logical and physical architecture where the IUN was built is described.

The *logical structure* of the IUN is based on the MVC (model-view-controller) pattern or three-tier software architecture: Data-Layer, Business-Layer, Presentation-Layer (Domínguez et al., 2007; Gamma et al., 1995). There are several commercial packages designed to implement laboratories using specific software extensions or tools; a clear example is Matlab and its extensions Matlab Webserver and Matlab Real Time. These packages offer an easy, fast and simple solution, but, like in other commercial software packages, some problems appear: version updates, non-available drivers, slow connectivity to databases, low request-response time, great amount of computational resources, oversized package in tools not directly related to the application, exclusive dependence on a software provider and, of course, high cost. In addition to that,

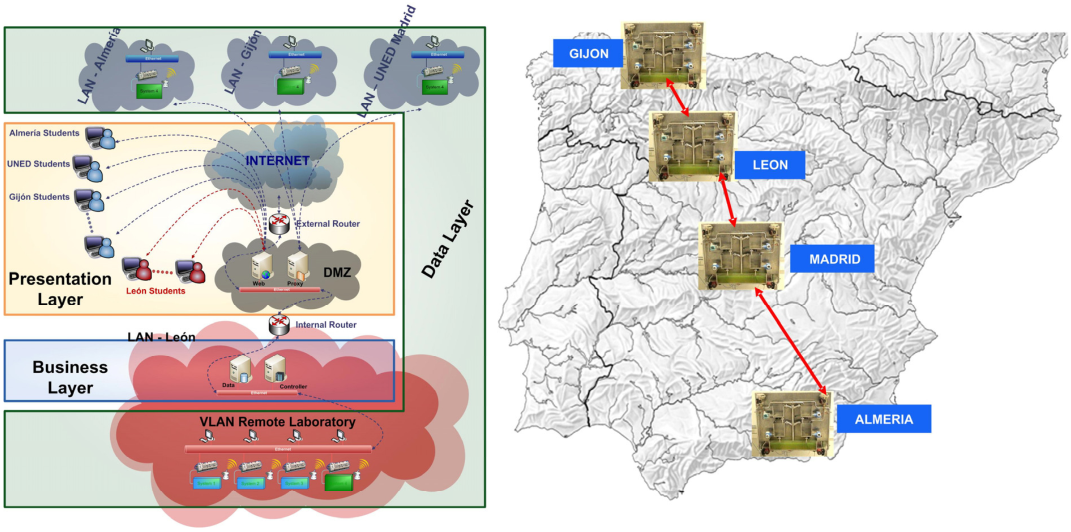

Fig. 2. Structure of the layers in the IUN and location of the different remote laboratories.

there are several physical systems with limited connectivity, which are not web-enabled. These systems are old physical systems without TCP/IP NICs, such as industrial robots, PDAs, modems, remote video cameras, POS (Point Of Sale) terminals or industrial scale models. This problem forces us to configure a logical structure where those problems are solved and to improve the active learning using a reliable and efficient logical structure.

The Data-Layer corresponds to the physical systems that are shared via Web, so the physical systems act as data sources and recipients. It is important to understand that the physical systems integrated in the IUN are located in distant places, but this is transparent for the final user. The three-tier architecture makes possible that physical systems work as data sources/recipients.

The Business-Layer is the layer where tasks of data storage are carried out, access policy to the physical systems is implemented, usage limits are controlled and tasks of maintenance and computations on the stored data are performed.

The Presentation-Layer is the layer offered to the end users. In this layer, the users authenticate and can make hands-on practices on the physical equipment. They can also access to theoretical and practical documentation and instrumentation data-sheets and visualize data of previous experiences.

The *physical structure* is implemented using 4 high-performance servers located in the DPC (Data Processing Center) of the University of León. The network is 10/100Mbps Ethernet. A simplified scheme of the structure is shown in Fig. 2

The 4 servers have different functions: Web-Server, Data-Server, Proxy-Server and Controller-Server. A screened subnet architecture is used (Dubrawsky et al., 2006); i.e., the Web-Server and the Proxy-Server are located in the DMZ (De-Militarized Zone) network of the University of León. The Proxy-Server and the Controller-Server are located in a VLAN (Virtual Local Area Network) network within the University Network, but independent of this one.

The architecture suggested in the previous paragraph is the safest (and the most complex as well) because it is able to reduce the effects of an external attack. Usually two routers are used: one inside and another outside. Outer router must block the junk traffic in both ways: towards the Internet and towards the DMZ. The inner router blocks the junk traffic towards the DMZ and the VLAN. An attack has to break the security of both routers.

The features and functions of the servers are as follows:

Data-Server.

Number of processors: 2, Processor: Xeon 3060 Series, Cache: 4MB L2, Memory: 2GB, Internal Storage: 439.2 GB, Operating System: Microsoft Windows 2003 Server R2, Form Factor: 1U Rack.

This server is located in the VLAN within the University Network. Data of the changes of the physical variables of all the physical systems shared by the IUN are stored in this server. In addition to that, all the profiles of users are also stored. The use of physical systems is logged. There are policies for backups and data-shrinking implemented in the server, which guarantee that the number of registers does not imply degradation the performance of the DBMS (Data Base Management System). The DBMS used is Microsoft SQL Server 2000.

Controller-Server.

Number of processors: 1, Processor: Xeon 3060 Series, Cache: 4MB L2, Memory: 1GB, Internal Storage: 146.4 GB, Operating System: Microsoft Windows 2003 Server R2, Form Factor: 1U Rack.

This server is located in the VLAN within the University Network. This server is mainly used to manage which controller is used for a certain physical system.

At present, the physical systems of the Remote Laboratory of the University of León can be controlled with controllers of the following manufacturers and models: Schneider TSX

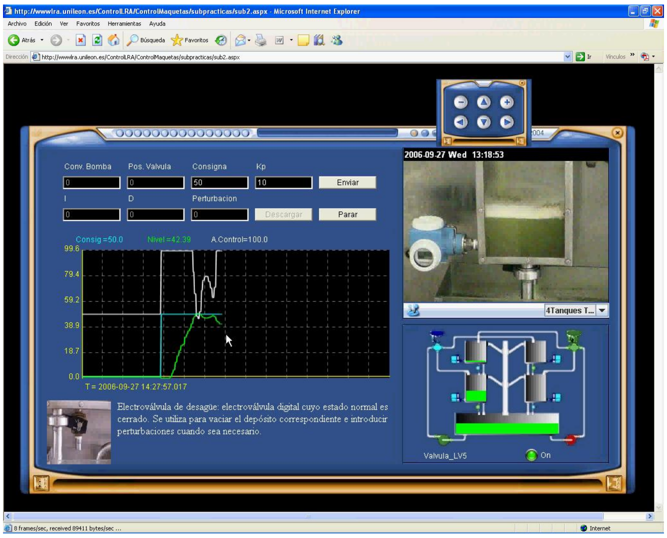

Fig. 3. Interface used to do hands-on sessions in remote laboratories.

Premium, Opto 22 LCM4 and Siemens S7-314C 2DP. The user can choose controller and the task of this server is to guarantee that it can be programmed, and is available in perfect condition for the user (ensuring that it could not be blocked by previous users) and that, while the user is working with this controller, other users cannot access to the physical system.

Web-Server.

Number of processors: 1, Processor: Xeon 3060 Series, Cache: 4MB L2, Memory: 1GB, Internal Storage: 292.8 GB, Operating System: Microsoft Windows 2003 Server R2, Form Factor: 1U Rack.

This sever is located in the DMZ. It is used to run the Presentation Layer. It is the one that responds to the final users. The selected web server is a IIS 6.0, running on Windows 2003.

From this Web server, the users can access to the physical systems offered by the IUN. They can load or unload control strategies in the available controllers. They can also access to historical data logs and export those data to different formats: *.txt, *.csv, *.xml, *.m. Theoretical and practical documentation is also offered

Proxy-Server.

Number of processors: 1, Processor: Xeon 3060 Series, Cache: 4MB L2, Memory: 1GB, Internal Storage: 292.8 GB, Operating System: Linux Debian, Form Factor: 1U Rack.

This server is located in the DMZ. It is used to peform net filtering, connection tracking and network address translation (NAT). It uses Iptables, a tool included in Linux, to manage the three previous tasks.

This Proxy-Server is the one that manages the change of control hardware working on a given physical system, i.e., this element guarantees that certain physical resources are assigned to a physical system (web-cam, controller, etc.), it hides the complexity of changes to the user.

6. EXPERIENCE DEVELOPMENT

To test this structure in an effective way and adjust it to new forms of work, different experiences with students from the universities that constitute the network have been made. The work sequence of the students in each one of the experiences was the following one:

- The students accessed to an environment, served by the Web server (located in León) of the laboratory, where they registered their account. Next, they received, by e-mail, both the user name and the password that allow them to authenticate in the laboratory with the restrictions associated with the subject for which they were registered.
- The students performed the experience via the Internet, on the physical system located in their University. Next, they did the same remotely on a physical system located in another University.
- For the accomplishment of each hands-on session, the environment supplied information about the task to develop, as well as a series of additional theoretical information. In addition, all the information about what it is being done is delivered through this environment: programming and/or parameterization of the control system, online visualization of all the variables of the system, interactive synoptic display of the physical system, real-time video of the physical system and remote control of the associated camera, etc.
- During the accomplishment of the experiment, all the values of the variables and the actions and events of the physical system are stored in the database server of the laboratory with a sampling period of 200ms. When the experience ends, students can retrieve data of the experiment, being able to select the time interval. Students must select among several alternative export formats of the data, depending on their needs: .xml, .csv, binary and text. The students can decide whether data are received as an attachment in an e-mail or downloaded to the local computer where they are working.
- After the students have finished all the tasks and obtained data in the desired format of their experiments, these data can be analyzed using scientific applications, e.g. Matlab. The student can perform new experiences adjusting and tuning them to obtain the required specifications in the practice.

Figure 3 illustrates an example of one of these interfaces implemented to do a hands-on session of parametrization or tuning of a PID. The student can evaluate the efficiency of the tuning watching in real-time the temporary evolution of the variables involved in the control. These variables (controlled variable, control action, error, set point or others) can be watched by means of graphs and with the visual aid of the video. The student can also introduce perturbations operating the interactive synoptic graphic displayed in the right lower part of the page (the student can operate the electrovalves of water drainage or modify the speed of impulsion of the pumps to do additional supply of liquid using the second three-way valve). The student can look up information about the interface in the tutorial in any moment.

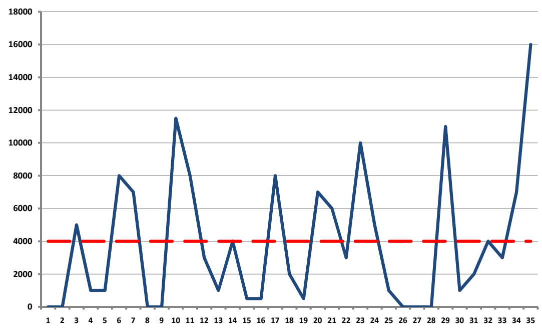

Fig. 4. Access bandwidth to the LRA-ULE for students of Industrial Engineering of Gijón.

The IUN provides students and professors with tools for the registry and authentication, measures of access times and quality of service, data processing, etc. It also provides statistical tools to evaluate the use of the IUN such as bandwidth of users, browsers, usage time, etc. The students that performed hands-on sessions in the laboratory study courses related to the areas of automatic control and systems engineering of the different universities. For instance, in Figure 4, it can be seen the access bandwith of 35 students of Automatic Control II of the Industrial Engineering degree at University of Oviedo. They performed a remote hands-on experience on the quadruple-tank industrial scale model located in University of León. The purpose of the experiment was tuning a PID control in a level control loop.

7. CONCLUSION

The experience performed shows a different way of collaboration and use of the available technological resources, on which the remote laboratory of the University of León is sustained. This collaboration allows a better efficiency in the use of the educational resources, which are made available to students and professors. This situation opens a new approach in the development of collaborative educational strategies included in the objectives fixed by the new European Higher Education Space.

From the point of view of the students, even though this kind of experiences causes a certain rejection, they get more involved in the learning process. Since they handle all the technologies that are provided, they are not passive agents or mere consumers of information. They must take a more active role. A voluntary process is stimulated from the beginning of the proposed activities because they must activate *their* account, configure *their* control systems, control *their* equipment, download *their* data, etc. Therefore, the student becomes the central element, the subject of the learning process, and the professor is seen as an aid or expert to turn to.

The technological structure that supports the remote laboratory on Automatic Control has demonstrated its robustness, reliability, flexibility and scalability in all the tests conducted. Different procedures have been defined to evaluate load and access time, bandwidth, performance, etc. The IUN has allowed us to contrast different points of view, conduct technological and functional tests and, above all, have a debate about those aspects that link the operability of this type of technologies to the new educational strategies that can be developed.

REFERENCES

Securing networks with private vlans and vlan access control lists. *Cisco Systems*, 2005. http://www.cisco.com/warp/public/473/90.pdf.

Francisco A. Candelas and José Sánchez. Recursos didácticos basados en internet para el apoyo a la enseñanza de materias del área de ingeniería de sitemas y automática. [Educational resources based on the internet to support the learning of subjects in automatics and systems engineering area]. *Revista Iberoamericana de Automatica e Informatica industrial*, 2(2):93–101, 2005.

Bologna Declaration. The European higher education area. Joint declaration of the European Ministers of Education Convened in Bologna on the 19th of june 1999. 1999. http://www.europaeum.org/content/view/58/65/.

Manuel Domínguez, Juan J. Fuertes, Perfecto Reguera, José J. González, and Juan M. Ramón. Maqueta industrial para docencia e investigación [Industrial scale model for training and research]. *Revista Iberoamericana de Automática e Inf. Industrial*, 1(2):58–63, 2004.

Manuel Domínguez, Perfecto Reguera, and Juan J. Fuertes. Laboratorio Remoto para la enseñanza de la Automática en la Universidad de León (España) [Remote Laboratory for Training on Automatic Control at the University of León (Spain)]. *Revista Iberoamericana de Automática e Inf. Industrial*, 2(2):36–45, 2005.

Manuel Domínguez, Perfecto Reguera, Juan J. Fuertes, Ignacio Díaz, and Abel A. Cuadrado. Internet-based remote supervision of industrial processes using Self-organizing maps. *Engineering Applications of Artificial Intelligence*, 20(6):757–765, September 2007.

Manuel Domínguez, Perfecto Reguera, Juan J. Fuertes, David Marcos, and F. Blazquez. Connection pilot plant to internet. In *IBCE01 IFAC Workshop on Internet based control education*, pages 43–47, 2001.

Sebastián Dormido. Control learning: Present and future. In *IFAC Annual Control Reviews*, volume 28, pages 115–136, New York, 2004.

Ido Dubrawsky, C. Tate Baumrucker, James Caesar, Mohan Krishnamurthy, Thomas W. Shinder, Becky Pinkard, Eric Seagren, and Laura Hunter. *Designing and Building Enterprise DMZs.* Elsevier Inc., 2006.

Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides. *Design Patterns: Elements of Reusable Object-Oriented Software.* Addison-Wesley, 1995.

Elsa Hackl. Towards a European Area of Higher Education: Change and convergence in European Higher Education. *Robert Schuman Centre for Advanced Studies*, (2001/09), 2001.

Karl Henrik Johansson. The Quadruple–Tank Process: A Multivariable Laboratory Process with an Adjustable Zero. *IEEE Transaction on Control Systems Technology*, 8(3):456–465, 2000.

Paul Penfield and Richard C. Larson. Education via advanced technologies. *IEEE Transactions on Education*, 39(3):436–344, 1996.

UNESCO. World Declaration on Higher Education for the twenty-first century. Vision and action. *World conference on higher education*, 1998.