

Remote Laboratory for Learning of AC Drive Control

M. Domínguez, J.J. Fuertes, P. Reguera, A. Morán,
S. Alonso, M.A. Prada

*Grupo de Investigación SUPPRESS, Universidad de León, Escuela de
Ingenierías - Campus de Vegazana, León, 24071, Spain. (e-mails:
manuel.dominguez@unileon.es, jjfuem@unileon.es, prega@unileon.es,
saloc@unileon.es, a.moran@unileon.es, ma.prada@unileon.es).*

Abstract: In this paper, we present the incorporation of a new real industrial system to the Remote Laboratory of Automatic Control of the University of León (LRA-ULE). This system consists of an AC motor, a variable frequency drive and a PLC that performs two functions: to control the system and facilitate remote communication. A set of didactic contents and a user interface have also been developed to enable remote interaction with the system. A Drupal-based Content Management System that resides in the technological platform of the LRA-ULE has been used for the operation of the system by the students.

Keywords: Remote laboratories; e-learning; Internet-based teaching; AC Motor; Frequency inverters; PLC; Remote monitoring and control

1. INTRODUCTION

Information Communication Technologies (ICTs) have raised new research and development lines in recent years, with a strong presence in the new Society of Knowledge we are heading to. This has also led to new forms of work organization, relationship and collaboration (Penfield and Larson, 1996; Poindexter and Heck, 1999).

The academic world has not been oblivious to these changes. Indeed, it has been probably one of the first to engage intensively in research and development on these technologies for teaching. This has led to the development of new forms of interaction between teacher and student (Dormido, 2004). In this sense, many of the first implemented experiences were aimed to address the problem of practical training, i.e., the focus of research was how to access and use remotely, through the Internet, practice equipments that are in the labs (Gillet et al., 2005). The conclusions from those experiences has resulted in a work environment that has been called "Virtual and Remote Laboratories" (Nickerson et al., 2007; Lindsay and Good, 2005; Sicker et al., 2005).

The Remote Laboratory of Automatic Control of the University of León (LRA-ULE)(<http://lra.unileon.es>) was conceived as a work environment composed of some physical systems whose main characteristic is its industrial character and that can be accessed remotely through the Internet. Its main objective is to support the university education in the field of Industrial Engineering. (Domínguez et al., 2005). Its conceptual structure follows the guidelines set by the automation pyramid, trying to cover several of its levels (field, control and supervision level) and implementing some of the current available technologies within each of them.

In this sense, during this last academic year we have worked in the addition to the LRA-ULE of a basic automation constituted by an AC motor, a variable frequency drive and a PLC which is the binding element to a Profibus network. This way, the remote laboratory gets a new physical system with great flexibility to develop a wide range of work. It allows the development of basic automation strategies to control an AC motor and supervise and manage a Profibus industrial network.

This paper is organized as follows. In section 2, the physical system is showed. In section 3, the main features of Remote Laboratory of Automatic Control are presented. The integration of the system into Remote Laboratory LRA-ULE is explained in section 4. In section 5, a set of practices using this physical system are listed and explained. Finally, conclusions and further work are described in section 6.

2. PHYSICAL SYSTEM

The new physical system integrated into the remote laboratory is formed by a motor and a variable frequency drive, which is controlled by a PLC (see Fig.1) The technical characteristics of each of the components of this new resource are:

- **AC Motor:** it is a three-phase squirrel-cage induction motor manufactured by Siemens. The most notable features are: 0.37 KW, 230 V, 1.84 A, 50 Hz, 1370 rpm, 0.78 fdp. The motor has an encoder connected to the shaft.
- **Variable Frequency Drive Micromaster Vector 440:** it is a versatile drive whose manufacturer is Siemens. The drive has a power of 0.55 kW, enough for the motor that is connected. The input voltage is 230V single phase, 50-60Hz and three-phase output.

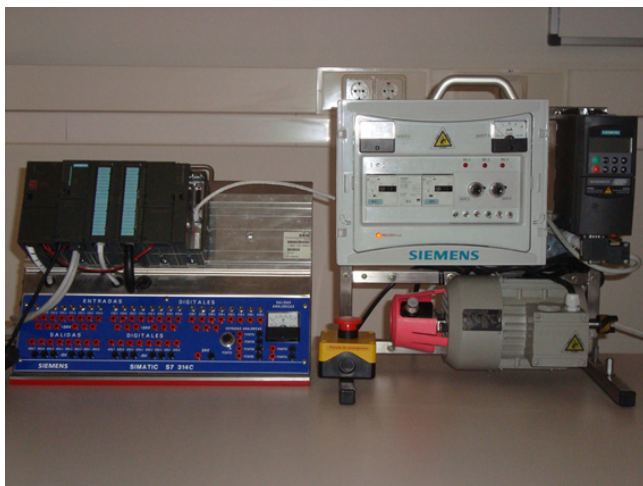


Fig. 1. Physical system.

This type of converters are controlled by a microprocessor and use IGBT (Insulated Gate Bipolar Transistor) technology. This allows applying high switching frequencies, which ensures quiet operation of the motor. This drive has a large number of parameters, so different configurations can be applied depending on the application. It has several digital and analog inputs/outputs to facilitate its integration with other equipment. It also has a local panel to display status information and enter commands by a user. In terms of communication, this drive can be connected to a PC directly or integrated into a Profibus network, as it was done in this case.

- **PLC S7-300:** This PLC, also manufactured by Siemens, is modular and is composed of the following blocks: CPU module CPU314C 2 DP, which includes modules for digital and analog inputs/outputs (24 to 16 / 5-2), 4 channels of fast counting and frequency measurement at 60 KHz, 1 channel positioning and Profibus interface. The network module, model S7 CP343-1, is also necessary for ISO Industrial Ethernet and TCP/IP.

3. LRA-ULE ARCHITECTURE

The technological platform of the LRA-ULE is based on a complex network structure that determines the local communication and the internet connection. This structure also takes into account the security requirements imposed by the corporative network of the University of León. The architecture of the remote laboratory is based on a three-layer structure. It manages from the **local level**, with different industrial resources to the **operating level**, which is accessible from remote computers (See Fig.2).

3.1 Physical system layer

All the industrial real systems that are available for remote practices are located in this layer. Nowadays, the working physical systems are:

- Three industrial scale models for control of 4 variables (pressure, flow, level and temperature)(Domínguez et al., 2004).

- A 4-tank industrial scale model to study MIMO (*Multiple Input-Multiple Output*) systems (Domínguez et al., 2007).
- An industrial pilot plant with two reactors, one of them of high efficiency, and three utilities circuits associated with the reactors (heat, steam and freeze)(Domínguez et al., 2001).
- A set consisted of a DC motor, angle detectors, and Feedback controllers (M.Domínguez et al., 2010).
- The motor drive system presented in this article.

In addition, an electro-pneumatic system with an ABB IRB 1400 S4 robot is being mounted.

A virtual local Ethernet network interconnects all PLCs, distributed control systems, data acquisition systems, controllers and network cards of the equipments.

3.2 Server layer

This layer consists of 4 servers (Domínguez et al., 2007) that handle different tasks. The **Controller server** runs an OPC (*Object Linking and Embedding for Process Control*) client to connect to the selected system and read, modify and/or write the value of its physical variables. Furthermore, LabVIEW software is running on this server to be able to publish the programs created with this graphical software to the Internet. This server is connected to the virtual local network (VLAN) to access to all physical systems of the laboratory.

Another server found in this layer is the one containing the database that stores all variables from the systems. The **DB server** uses Microsoft SQL as database manager. The storage of historical data allows the remote user to obtain data from the experiment for late analysis.

The third server is the **Proxy server** that handles network filtering, connection tracking, and network address translation. It is connected to the Internet and it is used for two reasons: to ensure the safety of laboratory systems and to enable access to these systems from outside their virtual network. This is possible thanks to the generation of a temporary tunnel between a remote client and the physical system. This connection is transparent to the user.

Finally, the fourth is a **Web server** that provides the Web interfaces (environments of operation and additional educational content), which have been implemented in PHP and HTML with a Content Management System based on *Drupal*. The CMS is responsible for the users authentication and the execution of all the intermediate operations between the user and the physical system. The dynamic elements of the interfaces, such as graphs, synoptic charts and video have been implemented using *Java applets* or *LabVIEW virtual instruments*.

Two of the servers (Web and proxy server) are connected to the Internet, whereas the other two (Controller and Data Server) are connected to the internal virtual network. This is because the network security policy imposed by the University of León, which restricts the incoming connections from the Internet. This is made by placing the two visible servers from the Internet on a subnet called demilitarized zone (*DMZ*) or screened subnet. Furthermore, an

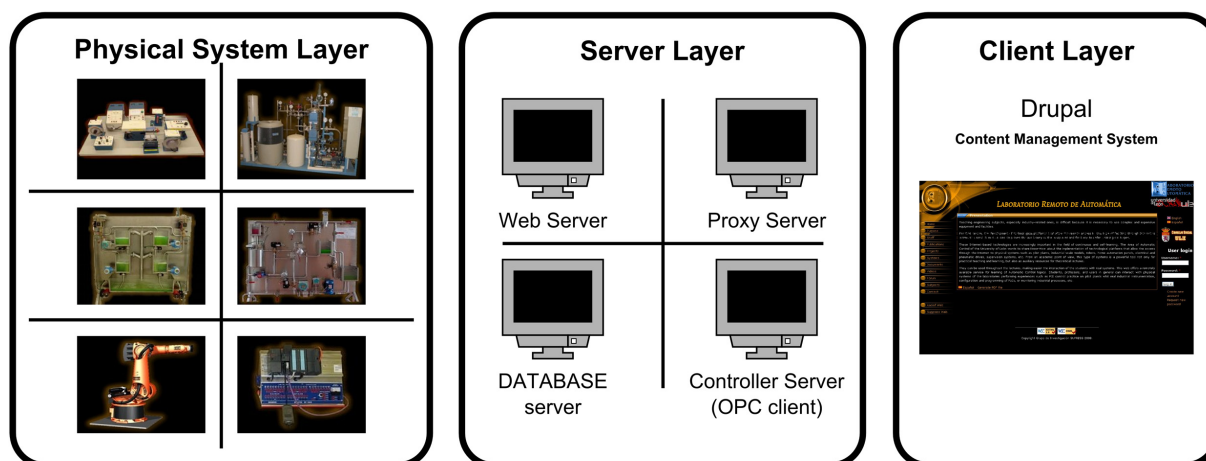


Fig. 2. LRA-ULE three-layer structure

external router filters the traffic between the DMZ and VLAN.

3.3 Client layer

This layer is composed of remote users who access the Remote Laboratory over the Internet using a standard web browser. To do this, the user must first register and be validated through the web. The users will have access to certain systems according to their profile. It is only needed a PC with the Java virtual machine or the LabVIEW Run-Time installed, both of them are free.

4. PLC-DRIVE-MOTOR SYSTEM INTEGRATION IN THE LRA-ULE

This section describes the specific actions that have been made in each of the three layers of the laboratory for the integration of the new resource PLC-drive-motor. The particularities of this new system, as well as the need for a PLC between the drive and the Controller server or to handle different protocols and data exchange standards, has forced to take the singular solutions described below. Fig.3 shows the physical and logical architecture of the plc-drive-motor system integration in the LRA-ULE.

4.1 Physical system layer

The communication between the variable frequency driver and the PLC is done using the Profibus protocol, where the drive works as slave and the PLC as master bus. This protocol is widely used in the field bus because it ensures a close to real time operation due to the mechanism of media access control (MAC) it employs, known as token passing (Tovar and Vasques, 1999). The communication configuration between the PLC and the drive is performed using the mode called PPO2, which establishes a cyclic channel between the system elements.

4.2 Server layer

A .NET application has been developed to link the physical system database with the remote client that accesses

through the web. This application runs on the Controller server.

The application, from the physical system side, is an OPC client that communicates with the Siemens OPC server SIMATIC NET, which is also installed on the server. This OPC server is linked with the controller S7-300 through the PLC communication port CP-Industrial Ethernet (using the proprietary protocol called S7). Through the OPC connection, the following parameters are read/write in a PLC table:

- **Read group** (mark-variable): MREAL200 intensity value, MREAL204 encoder value, MREAL208 power value, MREAL212 torque value, MREAL216 frequency value
- **Write group** (mark-variable): MREAL104 frequency, MREAL130 ramp time, MREAL140 break load value, M242.0 DC injection, M242.1 ramp load and frequency, M242.2 decreases speed, M242.3 increase speed, M242.5 reversing, M242.7 start/stop.

There are two types of parameters, read and write parameters. Read parameters store the status information of the drive. The OPC client reads these parameters in events with a minimum sampling time of 50ms for registration in the database. Write parameters can modify parameters of the drive configuration. In summary, the application has ability to query or modify drive parameters through an OPC communication with the PLC which is linked to the drive by the Profibus link described in Section 4.1.

From the remote client side, the application provides a link with the SQL database installed on the database server using ADO.NET. The "OPCData" table has a column for each parameter and values are stored in each row with a sampling period of 100ms.

4.3 Client layer

Remote clients modify and display drive parameters using applets embedded in Drupal pages. A Java library called SystemController and a Drupal module have been developed to enable the communication between the applets and the link application described previously.

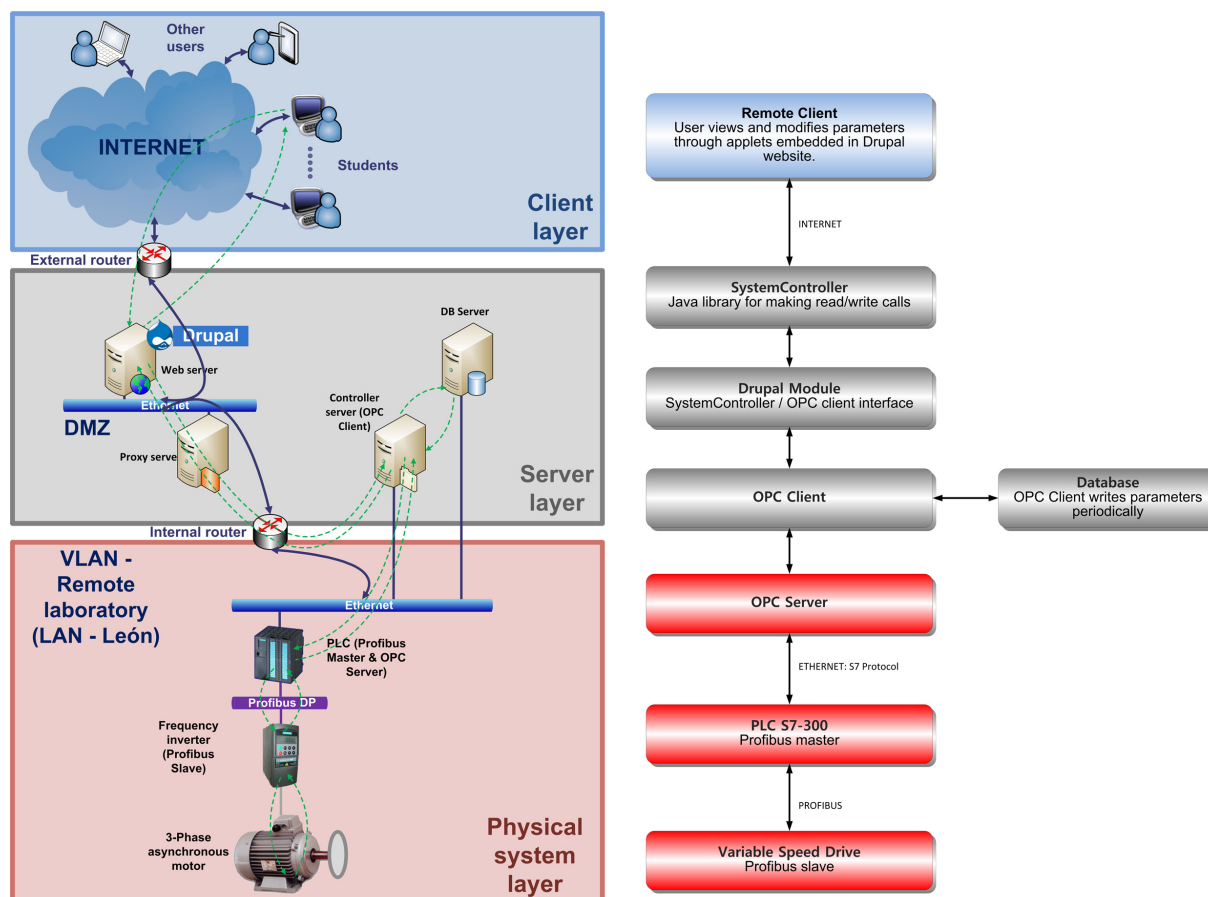


Fig. 3. Integration of the system within LRA-ULE technological platform.

The Drupal module communicates with the OPC client application, described in the previous section, using URL-connection. The Drupal module works as a gateway between the SystemController and the OPC client application, it authenticates against the Drupal users system, builds the final URL and returns the data stream obtained.

The library SystemController makes read/write requests on the physical system:

- **Read:** SystemController performs periodical read requests that include the name of the physical system. It receives as response a string composed of as many pairs of key-value as variables are available for that system. This operation consists of making the call to Drupal page in question, collecting the data stream back and constructing a data structure that facilitates its use within Java programs.
- **Write:** The script requests also include the name of the physical system followed by the command "write" and the key-value pairs which will be modified. The writing do the reverse process: it creates a chain of key-value pairs for the variables to modify, constructs the URL and performs the call to the Drupal page.

The integration of the new system in the technological platform of LRA-ULE is shown graphically in Figure 3. In the left, the physical architecture is presented whereas the logical architecture is presented in the right.

5. REMOTE PRACTICES

The PLC-drive-motor system has been used experimentally in a remote practice with a group of 20 students who attended the subject "Electronic and Automatic Systems" of Industrial Engineering at the University of León during the Academic year 2009/2010. During the Academic year 2010/2011, the practice was included to the LRA-ULE environment permanently <http://lra.unileon.es/seapRACTICALS/drivecontroller> (See Fig.4). Therefore, the students make the obligatory practices of their subjects with this remote system ("Computer Control" of Computer Engineering, "Control Engineering" and "Electronic and Automatic Systems" of Industrial Engineering at University of León).

These practices are aimed at introducing the users in the management of variable frequency drives (Micromaster Vector model 440), as well as in the study of possible system responses to changes in the frequency setpoint. At the beginning of each year, the users are registered as follows. Firstly, an e-mail with the web page to register is sent to the students. Then, the student registers in the CMS-Drupal and an administrator validates the registration. From that time on, the user can access the system using login and password. The CMS manages the students' access transparently, redirecting them to the practice.

All practices have several parts that users have to do in a logical sequential order: A theoretical description of the equipment and its operation mode, a scheme of the



Fig. 4. Physical system web page.

practice that has to be done and an explanation of the tasks that has to be developed during the remote practice. The practices are detailed briefly below:

- **Practice 1: Configuration of the motor-drive.** In this first practice, the user is introduced to the field of variable frequency drivers. There is a theoretical explanation of the operation of a frequency converter, the internal stages (grinding, filtering, inversion, control), the technologies used in its construction and its most common applications. Later, the most significant characteristics and parameters of the motor-drive are explained, so that the user can make the configuration and start-up using a synoptic similar to the BOP panel used by the drive (see Figure 5). From here, the user can change the rotation, send the order to start and visualize the evolution of the variables, among other functions. The type of control used in this practice will be a V/Hz which is essential to make the student understand how the speed changes in the AC motors.
- **Practice 2: Use of the motor-drive with a load.** This practice is proposed to study the behavior of the system when a load is attached. In this situation, the conditions under which the system operates are substantially altered. For security reasons, the system must start and stop gradually. This is also beneficial to minimize the high current waste on startup. All this must be considered when the rotation changes. The user must modify the parameters of acceleration and deceleration ramp time. The various forms of braking available to the system (natural, free wheel lockup torque, injection of CC, etc) are also explained and the user are asked to implement them and compare each other. The type of control used in this practice will be the sensorless vector control. In fact, the frequency converter incorporates a mathematical estimation of the speed used for feedback.
- **Practice 3: Feedback system using the encoder.** In this practice the user is prompted to conduct a study of different types of encoders (mechanical, optical, absolute, incremental, etc). Later the user is asked to configure the system so that the variable frequency drive uses the encoder's signal and not the estimated one. The type of control will be vector control. In

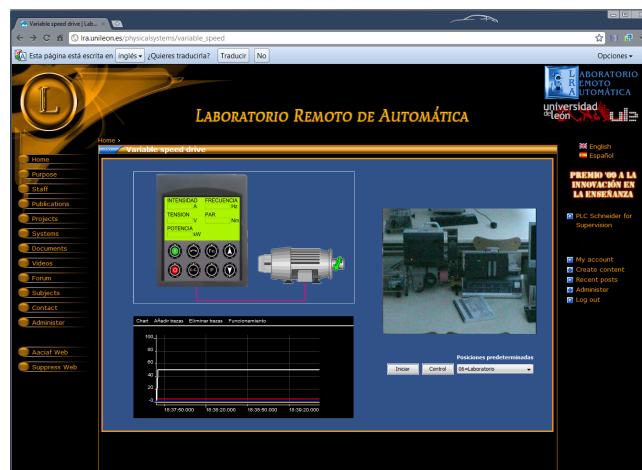


Fig. 5. User interface to perform remote practices with the physical system.

this case, the encoder will be used as a speed sensor system. To finish this practice, the user is asked to compare the performance of the system with and without the sensor and see how the load affects its behavior.

- **Practice 4: Obtaining closed-loop response of the system.** In this practice, the different transfer functions of a system of this type are explained to the user. The user is asked to perform an experiment in which the user apply small steps to the setpoint frequency of different amplitudes (5 Hz, 10 Hz, ...). The stored data of the closed loop response (using the feedback from the encoder) will be analyzed offline using the Matlab toolbox for identification. The purpose is to obtain a transfer function that reflects the approximate behavior of the system.

6. CONCLUSIONS AND FURTHER WORK

In this paper, the integration of a new physical system within the remote laboratory has been exposed. This new system consists of a motor-drive controlled by a PLC which enables communication with the drive since it has no Ethernet interface. It also allows users to implement control strategies that guarantee safe operation of the motor-drive. For example, when it is applied a DC injection braking, the PLC follows the temperature of the engine and disables it temporarily if it reaches high values to avoid damage in its windings.

The LRA-ULE has already several industrial systems accessible through the Internet thanks to a technology platform that supports the laboratory and that it is common to all systems. In this paper, we describe how the new system was added and how the main structure of the platform was adapted to the special features of the new physical system. To incorporate the new system, modern standard techniques have been used and that has facilitated the creation of all communication links, user interfaces, network security and database structures for storage of the records and the content.

A set of educational content (of theoretical character) and remote practices (using the physical system), which are available for lab users through its web, have been also

developed. The main aim is to develop educational content for the variable frequency drive for AC motors.

The remote system was validated by a pilot experience with a group of 20 students during the Academic year 2009/2010. Throughout the academic year 2010/2011, these practices were offered to students of the Industrial Engineering and Computer Engineering degrees. Students are requested to use the remote platform instead of physically going to the lab as they do today. This will allow us to test and improve technological structure that supports this system.

REFERENCES

- 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.
- Manuel Domínguez, Juan J. Fuertes, Perfecto Reguera, and 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 Informática 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). *Revista Iberoamericana de Automática e Informática 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.
- Sebastián Dormido. Control learning: Present and future. In *IFAC Annual Control Reviews*, volume 28, pages 115–136. New York, 2004.
- D. Gillet, AnhVu Nguyen Ngoc, and Y. Rekik. Collaborative web-based experimentation in flexible engineering education. *Education, IEEE Transactions on*, 48(4):696–704, Nov. 2005. ISSN 0018-9359. doi: 10.1109/TE.2005.852592.
- E.D. Lindsay and M.C. Good. Effects of laboratory access modes upon learning outcomes. *Education, IEEE Transactions on*, 48(4):619–631, November 2005. ISSN 0018-9359. doi: 10.1109/TE.2005.852591.
- M.Domínguez, Juan J. Fuertes, Perfecto Reguera, Seraín Alonso, and Antonio Morán. Practical simulation environment using ejs in the remote laboratory of automatic control of the university of león. *9th Portuguese Conference on Automatic Control*, September 2010.
- Jeffrey V. Nickerson, James E. Corter, Sven K. Esche, and Constantin Chassapis. A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers and Education*, 49(3):708–725, 2007. ISSN 1073-0516. doi:10.1016/j.compedu.2005.11.019.
- Paul Penfield and Richard C. Larson. Education via advanced technologies. *IEEE Transactions on Education*, 39(3):436–444, 1996.
- S.E. Poindexter and B.S. Heck. Using the web in your courses: what can you do? what should you do? *Control Systems Magazine, IEEE*, 19(1):83–92, Feb 1999. ISSN 0272-1708. doi: 10.1109/37.745773.
- D.C. Sicker, T. Lookabaugh, J. Santos, and F. Barnes. Assessing the effectiveness of remote networking laboratories. *Frontiers in Education, 2005. FIE '05. Proceedings 35th Annual Conference*, pages S3F–7–S3F–12, Oct. 2005. doi: 10.1109/FIE.2005.1612279.
- E. Tovar and F. Vasques. Real-time fieldbus communications using Profibus networks. *IEEE Transactions on Industrial Electronics*, 46(6):1241–1251, 1999.