Testing Bench for Remote Practical Training in Electric Machines

M. R. Sánchez Herrera*. J. M. Andújar Márquez**.
A. Mejías Borrero***. M. A. Márquez Sánchez****.

* Electrical Engineering Department, Huelva University, Huelva, Spain, (e-mail: reyes.sanchez@die.uhu.es)
** Electronic Engineering Computing Systems and Automatic Department, Huelva University,
Huelva, Spain, (e-mail: andujar@uhu.es).
*** Electronic Engineering Computing Systems and Automatic Department, Huelva University,
Huelva, Spain, (e-mail: mjias@uhu.es).
**** Pintor Pedro Gómez Secondary School, Huelva, Spain (e-mail:
marcoa@iesppg.net)

Abstract: Remote labs are emerging as a necessary tool to support practical classes in engineering studies. It is due to the increasing number of students who combine their studies with work. In fact, there are numerous developments in areas such as electronics and automatic. However, there are only a few of them in the area of electrical machines. This paper presents a testing bench for remote practical training in electric machines. The security challenges presented by these experiments are overcome by software within the remote lab. In addition, a friendly interface has been designed including augmented reality to identify the different elements and to provide information on these items if the student requires it. The testing bench has been developed to be used in different kinds of electrical machines test.

Keywords: Remote Practical Training, Testing bench, Electrical machines, Class Lab, Engineering Studies.

1. INTRODUCTION

Practical training is an essential part of the engineering studies. Thanks to them, the students take contact with the devices that they will handle in their professional development, allowing them to know their real behaviour. To achieve this, practical classes have traditionally taught in the laboratory classroom. However, the continuous education, strongly encouraged by European Higher Education Area, European Comission (2009), has allowed the number of students who combine their studies with work to increase in the last years. To overcome the problems of these students to attend classes, other way of teaching is being developed.

For example, virtual laboratories including simulation exercises constitute a common practice, as those technologies are mature enough. However, this development is not entirely suitable to complete teaching in engineering disciplines (and others), where hands-on laboratory experimentation is essential for enhancing and completing classroom lectures.

Therefore, during the last years, a number of remote laboratory projects have been proposed, aiming to teach fundamental concepts in different engineering fields through the remote operation and control of specific experimental facilities. Different activities towards the development of virtual and remote laboratory systems, Andújar and Mateo (2010), are carried out by many academic institutions, covering several engineering fields ranging from electronics, Bagnasco et al. (2009), Indrusiak et al. (2007), Sousa et al. (2010) and Andújar et al. (2011), to the automatic, Vargas et al. (2011), Santana et al. (2013) and Rodríguez et al. (2009). The robotic is also an area where remote laboratory has been

deeply developed, Tzafestas et al. (2006), Jara et al. (2011), Marín el al. (2005). In addition, there are some mechanical and chemical engineering experimental set-ups, Cmuk et al. (2008), Restivo et al. (2009) and Rojko et al. (2010).

Within the electrical engineering, there are some other remote platforms, Piers et al. (2008), Cao and Zhu (2010), Lewis et al. (2009), Ferrater-Simón et al. (2009), Andria et al. (2007) and Chandra and Venugopal (2012).

With respect to the electrical machines practical training, the usual material in the laboratory is a bank that works at the voltage of the power system. On the one hand, these machines have a high price. On the other hand, the teacher has the responsibility to ensure the students safety and the machines security. These two facts have made that, in many cases, the laboratory is composed of an only bank. For that reason, and taking into account that the time of practical classes is limited, there is no time for all the students and also those who carry out the practise must inevitably be in the presence of the teacher.

Up to now, those problems have been overcome by virtual laboratories, where there is an engine bench for each student and, also, there are not security or safety problems. Nevertheless, in this way, the contact with the devices is lost. Therefore, remote lab emerges as a more suitable solution to the problem than the virtual. There are only a few remote labs in the Literature dedicated to electrical machines experiments. For example, in Chandra and Venugopal (2012) remote experiments with a DC engine are proposed. LabView^{TM}, a not free software, is used to develop an interface to a remote laboratory. The experiments proposed in

this reference are designed to be automatically carried out, without an active interaction by the student.

In this paper, a testing bench for remote practical training in electric machines is proposed. Its core is an engine bench constituted by a synchronous machine driven by a DC engine, both coupled to a tachometer. Driven current going to the continuous machine and field current going to the synchronous machine are remotely controlled by the student. To do that, the necessary signals have been measured and a friendly interface has been developed, into the framework of Easy Java Simulations (EJS), Esquembre (2013), a free authoring tool written in Java. Specifically, in this application, EJS is used to connect the user interface with the real hardware elements that control the engine bench in the lab. Augmented reality (AR), Mejías and Andújar (2012), has

been used to improve the interface by identifying each element that provides the view of the camera. In addition, AR provides information on these items if the student requires it. The view of the camera is also improved with the direct sound from the experimental system (engine bench). It brings on the student's perception of being interacting with a real system. In fact, the rotational speed variations have a direct effect in the sound produced by the electrical machines. The experiment is available for students 24 hours a day by means of a reservation system.

The paper is organized as follows: section II explains the structure of the remote testing bench. Section III presents a list of possible experiments to be performed on the remote testing bench. Finally in section IV some conclusions are drawn.
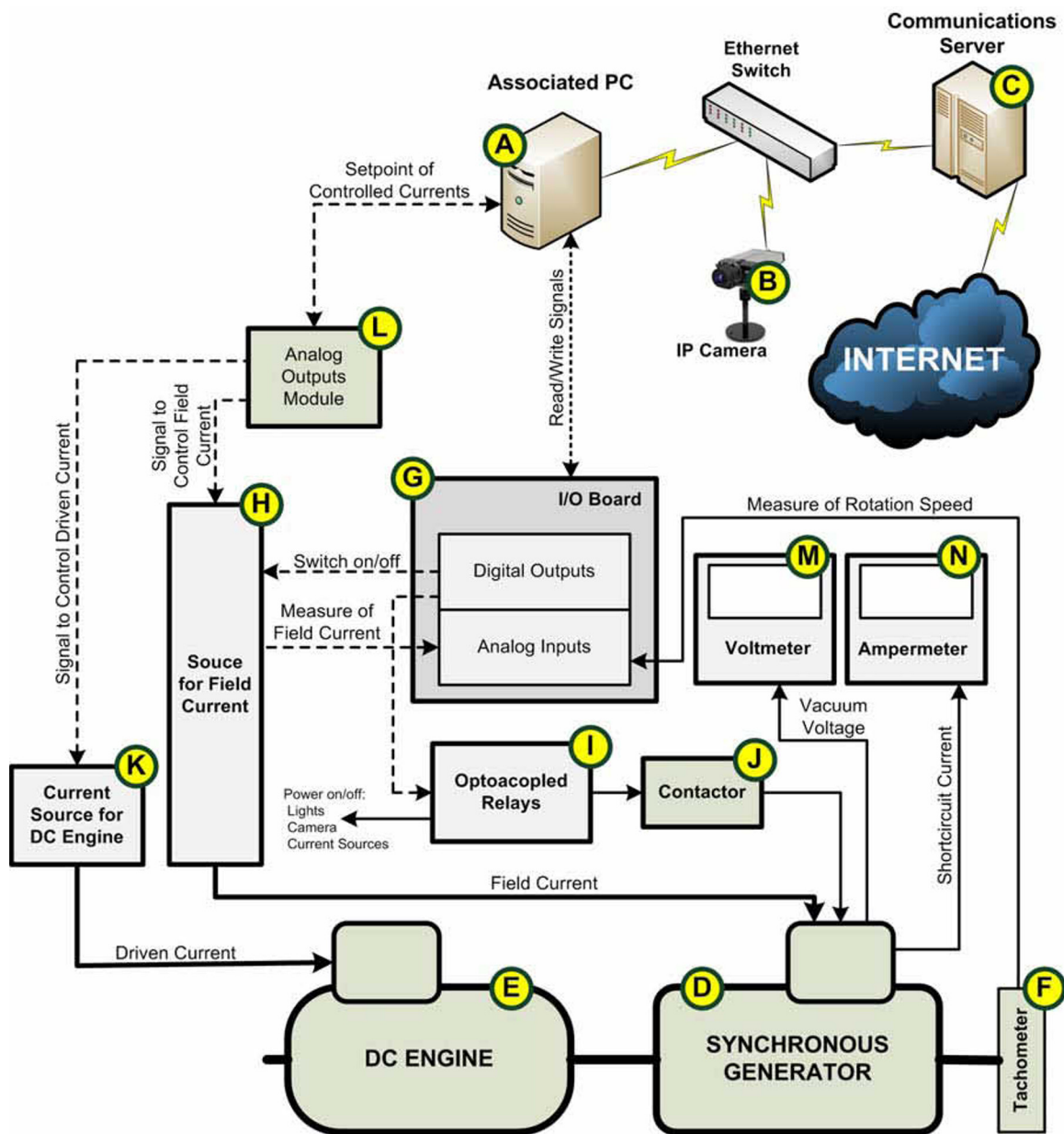

Fig. 1. Diagram of the remote testing bench including the different elements that composes it.

2. STRUCTURE OF THE EXPERIMENTAL SYSTEM

In figure 1, a general diagram is shown, with the different elements which compose the developed remote testing bench. In this laboratory, the engine bench is connected to a PC, item A in figure 1 (named associated PC). The PC is directly connected to the control elements presented from now on. An IP camera (Axis mod. 211), item B in figure 1, gets the video and audio signals from the laboratory and sends it to the user interface, after the user has accessed to the experimental system with the corresponding reservation.

A communications server, item C in figure 1, is connected to the laboratory intranet as well as to the University corporate network, by means of a communications software designed for the purpose. This server guarantees the necessary links for the students to communicate from their computers to the engine bench located in the laboratory. This software provides, automatically, the necessary connections based on the reservations made by the students and on the experiment connection requests. With guaranteed connections, it can be said that the access to the laboratory resources is ensured, as well as their correct use.
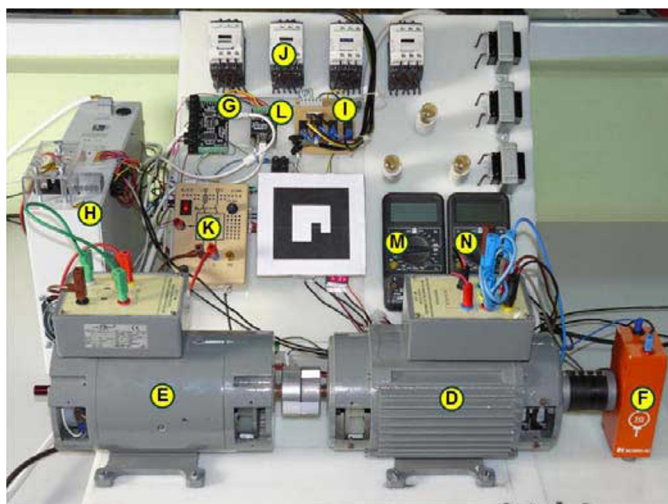

Fig. 2. Part of the remote testing bench located in the physical laboratory.

The core of the experiment is the engine bench, which is constituted by a synchronous generator, item D in figure 1, driven by a dc engine, item E in figure 1. The generator nominal values are 360 W, 380/220 V, 1500 r.p.m. and a power factor of 0,72. The engine nominal values are the next: 440 W, 220 Vdc, 1500 r.p.m. Both electrical machines are coupled to an analog tachometer, item F in figure 1, which sends the rotational speed signal to an I/O board, Phidgets Inc. (2013a), item G in figure 1, with analog inputs and digital outputs. This I/O board is directly connected to an USB port of the associated PC. Its functions are:

- Measurement of the rotation speed.
- Measurement of the field current from the current source which supplies it, item H in figure 1.
- Switching on/off current source H.

- Turning on/off the experiment supply, according to the instructions received from the PC, through a set of optocoupled relays, item I in figure 1.
- Configuring the connections suitable for each test of the synchronous generator, through a contactor, item J in figure 1.

The current going into the DC engine rotor is supplied by a current source, item K in figure 1, which is controlled by an analog output board, item L in figure 1, Phidgets Inc. (2013b). This device is also the controller of field current supplied by the current source H.

Finally, a voltmeter is used to show the measure of vacuum voltage in the vacuum test, item M in figure 1, and an ampermeter is used to show the short circuit current in the short circuit test, item N in figure 1.

The part of the remote testing bench located in the physical laboratory is shown in figure 2, where the devices presented in figure 1 are indicated.

Figure 3 shows the general scheme of the complete scenario for the class lab by the developed remote testing bench, including all the implicated agents. The laboratory infrastructure, located in the University, is constituted by the experimental system, item 1 in figure 3, the associated PC, item 2 in figure 3, and IP camera, item 3 in figure 3. The two last elements are directly connected to the laboratory intranet by means of an Ethernet switch, item 4 in figure 3.

The main communications system, item 5 in figure 3, is a server running specific software. This software has been designed to automatically generate, from the reservation made by the student, the communication links necessary for the user to have transparent access to the experimental system located in the laboratory.

By means of EJS, a file is generated. It is named Augmented Reality Remote Laboratory application (ARRL application) and it includes:

- The live image corresponding to the video signal from the IP camera located in the laboratory.
- Overlapping elements to the video image that improve the Human-Machine Interface (HMI), using AR technics. Figure 4 shows this interface with AR labels that indicate each of the main elements of the experimental system, as well as the instantaneous rotation speed of the engine bench. In addition, the labels are interactive, so that the student can access to specific information about each element by clicking on the corresponding label. Figure 4 also shows the window displayed when the student selects the DC motor label.
- The control of the input/output elements of the experimental system according to the signals introduced by the student and to the requirements of each experiment.
- Safety extent necessary to ensure the correct use of the engine bench.
- A table where the student must enter the data directly obtained from the engine bench. These data

will be used for calculations necessary to obtain the linear model of the synchronous generator, as indicated in section III.

- A figure that presents the evolution of the controlled signals along the experiment.

The ARRL is then integrated in the Learning Management System (LMS), item 6 in figure 3, to which the student can access through a web browser, item 7 in figure 3, to perform the lab work. In this case, the LMS used in this lab is Moodle, figure 4, whose learning potential is very useful to manage the different experiments designed.

In order to do that, previously, the student must have authenticated to the LMS and perform an experimental system reserve.
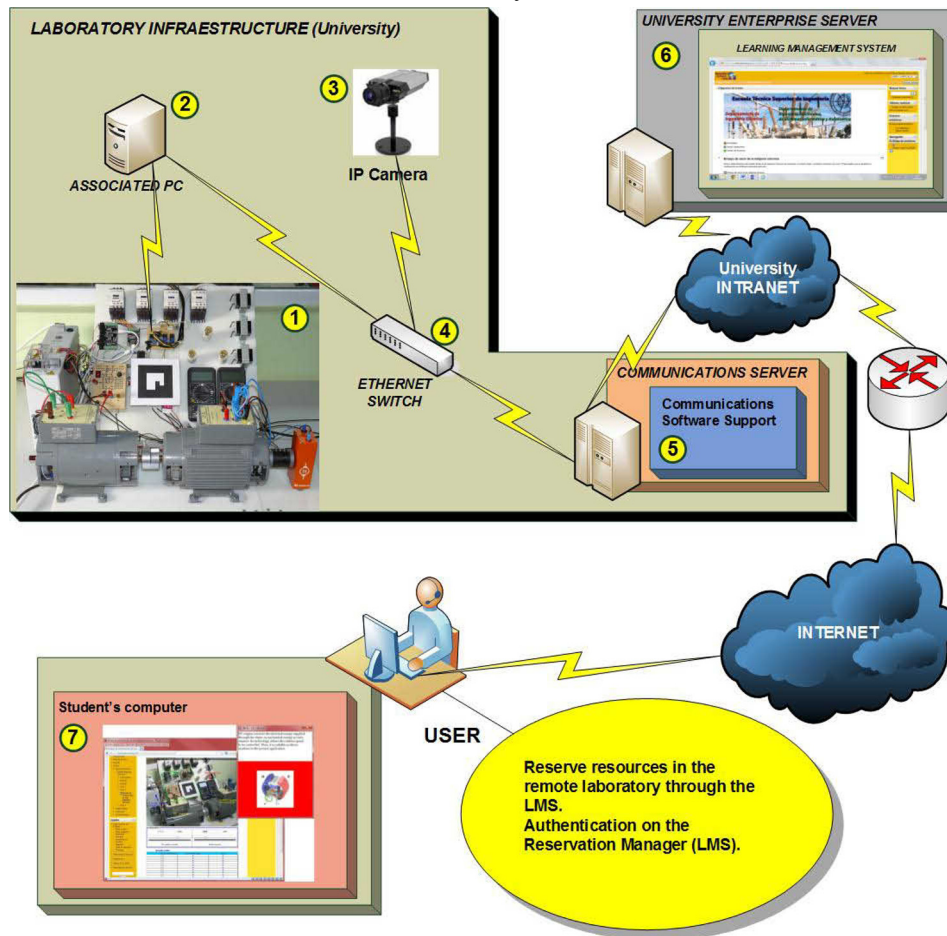

Figure 3. General scheme of the class lab by the remote testing bench.

2.1 Safety issues

In this subsection, the safety issues implemented in the ARRL application are presented. As mentioned before, in the experiments carried out with commercial electrical machines the safety issues become drastically important. The fact of using a remote testing bench erases the danger for the people: the user is at home while doing the experiment. However, the safety of machines goes on being necessary to consider.

In order to preserve the physical elements, software possibilities has been used. On the one hand, several protective measures have been implemented related to the machines rotational speed. These consist basically of avoiding an abrupt increase of this parameter, whose control is available in the ARRL application, and avoiding the rotational speed rises above 1700 rpm either by a direct command or by an abrupt decrease of the field current. On the other hand, the second parameter that can be controlled by the user, the field current, has been also involved in order to avoiding abrupt swings. Notice that a sudden drop in this parameter can result in a sharp rise in rotational speed.

Lastly, the evolution with time of both control parameters has been shown in the ARRL application and registered to be evaluated by the professor. This may be a deterrent for the student to misuse the system.

3. EXPERIMENTAL SYSTEM APPLICATIONS

The constitution of the experimental system is the base to design the class lab to be carried out through it. In this case, the experimental system is constituted by a synchronous machine driven by a DC engine. Therefore, the possible classes lab are related to its modelling, to the reproduction of its functioning within different conditions and, finally, to its control. All of them referred to the synchronous machine.

Firstly, with respect to the synchronous machine modelling, several classes lab may be proposed. Among others, the establishment of the linear model, according to the Behn-Eschenburg model, Mora (2003), the establishment of the

non-linear according to the Potier method, Mora (2003), and the testing of performance of both, with the alternator connected to a known load.
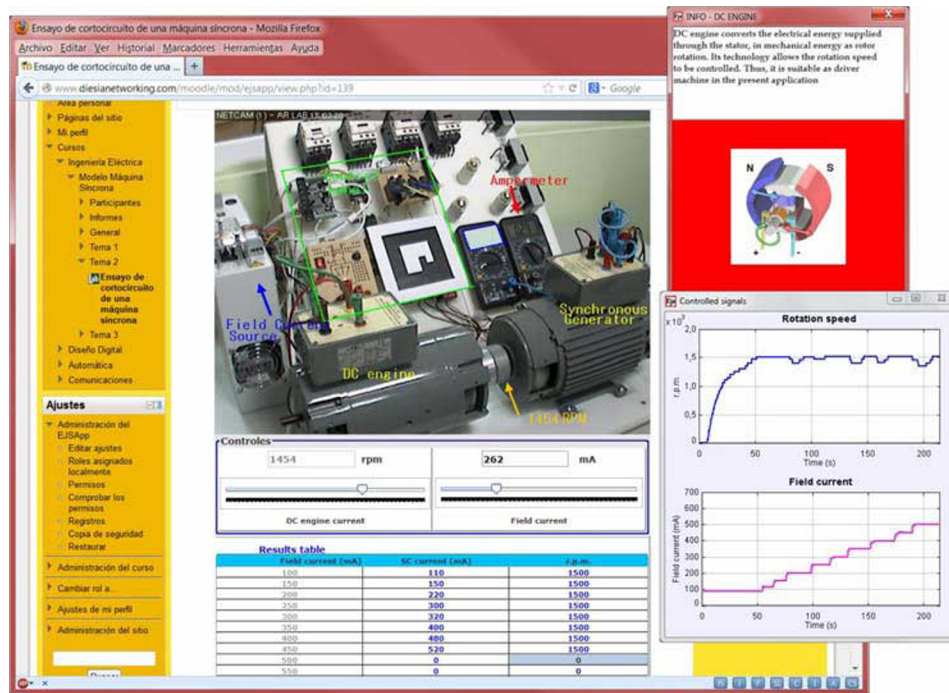

Figure 4. ARRL integrated in the LMS (Moodle).

Secondly, about the synchronous machine functioning, other set of classes lab may be proposed. For example, connecting the machine to a specific known load, the student may study the evolution of voltage and current in the point of connection, as well as the signals frequency, when field current is varying and/or the power coming from the DC engine. The relations field current / alternator voltage and DC engine power / signals frequency may be studied using the developed experimental system.

Into this set of experiments about the functioning of the machine, other classes lab may be also proposed. They are related to the study of the behaviour of the machine when it is connected to an infinite power net. To do that, the first step would be the connection of the alternator to the net. It is an interesting problem which involves restrictive security challenges to be overcome through software in the remote testing bench. Once the machine is connected to the net, the student may analyse the variations of active and reactive power injected to the grid when the DC engine power and the field current are modified.

Finally, with respect to the classes lab about the control of the machine, the possibilities are numerous and varied. They can be classified into two sets. The first one is related to the control of load voltage and frequency when the machine is connected to the load in an islanded way. The second one is related to the control of active and reactive power injected to the net when the machine is directly connected. For example, the V of Mordey curves representation, Mora (2003).

As an example, figure 4 presents the ARRL corresponding to the class lab in which the students must calculate the alternator synchronous impedance. To do that, they must carry out the vacuum and shortcircuit assays to the synchronous machines. Keeping constant the rotation speed, they progressively increase the field current and annotate the stator voltage and current values. Those data are used to make off-line the necessary calculations. This class lab has been proposed to the students of Electrical Machines, a course included in several degrees at University of Huelva.

4. CONCLUSIONS

In this paper, a remote testing bench to carry out lab classes with electrical machines has been presented. It allows an engine bench to be controlled and tested. The user interface has been improved by means of AR techniques to provide to the student additional information about the different elements of the system. The procedure to perform the lab work is very similar to the followed in the traditional laboratory classroom. As advantage, the developed remote testing bench make that the possibility of carrying out the lab class is available for all the students at any time. The necessary security challenges are overcome by software within the developed remote testing bench.

REFERENCES

Andria, G., Baccigalupi, A., Borsic, M., Carbone, P., Daponte, P., De Capua, C., Ferrero, A., Grimaldi, D.,

Liccardo, A., Locci, N., Lanzolla, A.M.L., Macii, D., Muscas, C., Peretto, L., Petri, D., Rapuano, S., Riccio, M., Salicone, S., and Stefani, F. (2007). Remote Didactic Laboratory G. Savastano, the Italian Experience for E-Learning at the Technical Universities in the Field of Electrical and Electronic Measurements: Overview on Didactic Experiments. *IEEE Transactions on Instrumentation and Measurement*, Vol. 56, No. 4, pp. 1135-1147.

Andújar, J.M., Mateo T.J. (2010). Design of virtual and/or remote laboratories. A practical case. *Revista Iberoamericana de Automática e Informática Industrial (RIAI)*, Vol. 7, No.1, pp. 64-720.

Andújar, J.M., Mejías, A., and Márquez, M.A. (2011). Augmented Reality for the Improvement of Remote Laboratories: An Augmented Remote Laboratory. *IEEE Transaction on Education*, Vol. 54, No. 3, pp. 492-500.

Bagnasco, A., Boccardo, A., Buschiazzo, P., Poggi A., and Scapolla, A.M. (2009). A Service-Oriented Educational Laboratory for Electronics. *IEEE Transactions on Industrial Electronics*, Vol. 56, No. 12, pp. 4768-4775.

Cao, X., and Zhu, S. (2010). IEELab Practice: A Hybrid Remote Laboratory for Distance Education in Electrical Engineering. *5th International Conference on Computer Science & Education Hefei*, China.

Chandra, A.P.J., and Venugopal, C.R. (2012). Novel Design Solutions for Remote Access, Acquire and Control of Laboratory Experiments on DC Machines. *IEEE Transactions on Instrumentation and Measurement*, Vol. 61, No. 2, pp. 349-357.

Cmuk, D., Borsic, M., Mutapcic, T., and Rapuano, S. (2008). A Novel Approach to Remote Teaching: Multilanguage Magnetic Measurement Experiment. *IEEE Transactions on Instrumentation and Measurement*, Vol. 57, No. 4, pp. 724-730.

Esquembre, F. (2011). Easy Java Simulations. [Online] Available at: <http://fem.um.es/Ejs/> [Accessed 10 february 2013].

European Commission (2009). Education and training. [Online] Available at: <http://ec.europa.eu/education/higher-education/doc1290_en.htm> [Accessed 13 january 2013].

Ferrater-Simón, C., Molas-Balada, L., Gomis-Bellmunt, O., Lorenzo-Martínez, N., Bayó-Puxan, O., and Villafafila-Robles, R. (2009). A Remote Laboratory Platform for Electrical Drive Control Using Programmable Logic Controllers. *IEEE Transactions on Education*, Vol. 52, No. 3, pp. 425-435.

Indrusiak, L.S., Glesner, M., and Reis, R. (2007). On the Evolution of Remote Laboratories for Prototyping Digital Electronic Systems. *IEEE Transaction on Industrial Electronics*, Vol. 54, No. 6, pp. 3069-3077.

Jara, C.A., Candelas F.A., Puente, S.T., Torres, F. (2011). Hands-on experiences of undergraduate students in Automatics and Robotics using a virtual and remote laboratory. *Computers & Education*, Vol. 57 No. 4, pp. 2451-2461.

Lewis, N., Billaud, M., Geoffroy, D., Cazenave, P., and Zimmer, T. (2009). A Distance Measurement Platform Dedicated to Electrical Engineering. *IEEE Transactions on Learning Technologies*, Vol. 2, No. 4, pp. 312-319.

Marín, R., Sanz, P.J., Nebot, P. and Wirz, R. (2005). A Multimodal Interface to Control a Robot Arm via the Web: A Case Study on Remote Programming. *IEEE Transaction on Industrial Electronics*, Vol. 52, No. 6, pp. 1506-1520.

Mejías, A., Andújar, J. M., (2012). A Pilot Study of the Effectiveness of Augmented Reality to Enhance the Use of Remote Labs in Electrical Engineering Education. *Journal of Science Education and Technology*, Vol. 21, No. 5. pp. 540-557.

Mora, F. (2003). Máquinas síncronas in Máquinas Eléctricas, *5th ed. Madrid, Spain: McGraw Hill*, ch. 5, sec. 5.6.3, pp. 402–410.

Phidgets Inc. (2013a) PhidgetInterfaceKit 8/8/8. [Online] Available at: <http://www.phidgets.com/products.php?category=0&product_id=1018_2.> [Accessed 1 march 2013].

Phidgets Inc. (2013b) PhidgetAnalog 4-output. [Online] Available at: <http://www.phidgets.com/products.php?category=0&product_id=1002_0.> [Accessed 3 march 2013].

Pires, V.F., Martins, L.S., Amaral, T.G., Marçal, R., Rodrigues, R., and Crisóstomo, M.M. (2008). Distance-Learning Power-System Protection Based on Testing Protective Relays. *IEEE Transactions on Industrial Electronics*, Vol. 55, No. 6, pp. 2433-2438.

Restivo, M.T., Mendes, J., Lopes, A.M., Silva, C.M., and Chouzal, F. (2009). A Remote Laboratory in Engineering Measurement. *IEEE Transactions on Industrial Electronics*, Vol. 56, No. 12, pp. 4836-4843.

Rodríguez, F.J., Girón, C., Bueno, E.J., Hernández, A., Cóbreces, S., and Martín, P. (2009). Remote Laboratory for Experimentation With Multilevel Power Converters. *IEEE Transactions on Industrial Electronics*, Vol. 56, No. 7, pp. 2450-2463.

Rojko, A., Hercog, D. and Jezernik, K. (2010). Power Engineering and Motion Control Web Laboratory: Design, Implementation, and Evaluation of Mechatronics Course. *IEEE Transactions on Industrial Electronics*, Vol. 57, No. 10, pp. 3343-3354.

Santana, I., Ferre, M., Izaguirre, E., Aracil, R., and Hernández, L. (2013). Remote Laboratories for Education and Research Purposes in Automatic Control Systems. *IEEE Transactions on Industrial Informatics*, Vol. 9 , No. 1, pp. 547 – 556.

Sousa, N., Alves, G.R., and Gericota, M.G. (2010). An Integrated Reusable Remote Laboratory to Complement Electronics Teaching. *IEEE Transactions on Learning Technologies*, Vol. 3, No. 3, pp. 265-271.

Tzafestas, C.S., Palaiologou, N., and Alifragis, M. (2006). Virtual and Remote Robotic Laboratory: Comparative Experimental Evaluation. *IEEE Transactions on Education*, Vol. 49, No. 3, pp. 360-369.

Vargas, H., Sánchez, J., Jara, C.A., Candelas, F.A., Torres, F., and Dormido, S. (2011). A Network of Automatic Control Web-Based Laboratories. *IEEE Transactions on Learning Technologies*, Vol. 4, No. 3, pp. 197-208.