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A multi-user remote academic laboratory system

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ABSTRACT

This article describes the development, implementation and preliminary operation assessment of Multiuser Network Architecture to integrate a number of Remote Academic Laboratories for educational purposes on automatic control. Through the Internet, real processes or physical experiments conducted at the control engineering laboratories of four universities are remotely operated. Through an internet connection to the Manager Administration Server, a remote experiment to design and test a modeling and control algorithm can be performed.

The suggested Network Architecture is based on the Singlet-Server model and uses a database server to record important information that helps create a new remote experiment, including a Graphical User Interface (Applet) developed with Easy Java Simulation, which allows the simple integration of new processes to the Manager Administrator. Results of a real-physical-process remote manipulation through the proposed network architecture are presented as well as results of an academic pilot test conducted to measure functional aspects related to the operation of the remote system when carrying out remote-laboratory work.

1. Introduction

Nowadays, the importance of practical experiences for the development of competences in engineering is of common knowledge. Suggesting a solution to real situations in the context of automatic control is no exception. On the other hand, Information Technologies (IT) have provided great support for learning and teaching academic processes, enabling the development of activities which were previously restricted to attended environments. In this sense, remote laboratories that use this kind of IT, and apply remote operation to real processes, extend their teaching capabilities beyond the scope of conventional laboratories when teaching a specific subject, which are often limited in time and in the number of physical experiments available.

Alternative proposals on this topic suggest the remote operation of physical processes, which often lack a structured didactic-and-pedagogical framework that is essential to adequately conduct remote experiments on automatic control. Another proposal is to replace lab-experiments with simulations, which by definition are reduced models of reality, and as such, reduce the possibility to confront students with the complexity that arises when real physical systems are analyzed.

The present paper describes a collaborative project between four Universities, namely *de los Andes*, *Tecnológica de Bolivar*, *Nacional de Colombia* and *École des Mines de Nantes*, where the development of Remote Academic Laboratories using Information Technologies is proposed. The project is intended to share lab resources as well as evaluating the knowledge acquisition levels achieved by a specific student when compared to the learning process at a conventional laboratory. Via Internet, the proposal allows users to access several control processes located in different campus or in other universities. Different kinds of experiments provide support and enable other academic institutions to link up with the management system in order to use these resources directly.

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A variety of remarkable technologies is discussed to help found our proposed Network System Architecture. Firstly, the most appropriate technologies to develop a Single-Server Administrator structure are defined so as to provide the different universities with an easy-to-use, secure management system of real control processes. In this respect, the proposed Multiuser Network Architecture, structured as a three-independent-level system, allows user-client applications such as Moodle and Blackboard to access a diversity of remote experiments and carry out work-labs that are part of control courses at different universities; at the same time, these resources are managed with time scheduling and secure access to conduct the experimental practices. On the other hand, Academic Pilot Tests are conducted to measure the functional aspects of the remote operation interface and so develop remote experimental practices. To conduct the tests, a remote laboratory is designed and implemented with a selected group of control students, where the conditions of *Acceptance*, *Usability* and *Usefulness* are evaluated through a Survey.

This article is structured as follows: Section 2 is a survey of different kinds of network architectures, which are analyzed according to the IT techniques used to integrate remote academic laboratories; thus the final structural design for our proposed network system is defined. Section 3 is a description of the proposed Network Architecture to integrate Remote Academic Laboratories together with the functionalities of each constituent network-system level. In Section 4, the proposed Academic Pilot Test is explained, whose purpose is to measure functional conditions over the remote system used to carry out a remote experimental practice with a selected group of control students. Finally, in Sections 5 and 6, we present the results and conclusions from the implemented multi-user network architecture, which serves to manipulate a real plant, as well as the results from the academic pilot tests conducted to measure functional aspects of the remote system.

2. A survey of remarkable technologies

In this section we study the different approaches to remote laboratory architectures and the tools used to create them. Even though there are many works related to the architecture and construction of remote laboratories, it is possible to categorize most of the studies into four groups according to their technologies.

2.1. Remote desktop connection

This technology is widely used in virtual-lab systems. The idea is to connect to a computer, which controls practice assignments by using applications such as Virtual Network Computing (VCN) (Kahoraho Bukubiye & Larrauri Villamor, 2002). The purpose of VNC (Richardson, Stafford-Fraser, Wood, & Hopper, 1998) is to supply an entire desktop environment that can be accessed from any Internet-connected machine using the required software. Vicente, Muñoz, Galilea, and Del Toro (2010) created a remote laboratory for industrial automation comprising different programmable logic controller (PLC) manufacturers and allowed clients to access the system by using either VNC or ActiveX. Hu and Meinel (2004) implemented a security laboratory on the Internet using well-managed virtual machines which allow students to gain experiences of security technologies and tools in a reliable and secure way. The user interface of the platform employs VNC and a remote frame buffer protocol (RFB).

The main problem of this approach was the lack of security due various types of attacks such as man-in-the-middle, brute force and sniffing. Moreover, the delay of the application operation made it difficult to control the teleoperated plants and the installation of software such as TightVNC or other applications that were necessary to access the platforms. Therefore, architectures based on Remote Desktop Connection were rejected. The architecture proposed focused on resource management, restriction of the IPs that can connect to the platform and communication through TCP/IP protocol. These considerations and technologies decreased latency and increased security.

2.2. Web tools for LABVIEW/MATLAB

The second approach is based on web tools that use MATLAB® and LABVIEW® as platforms, allowing the use of some characteristics of these platforms through a webpage. Dixon, Dawson, Costic, and de Quiroz (2002) proposed a flexible architecture for operating real processes using MATLAB® software, the Simulink toolbox and the Real Time Workshop toolbox to develop software tools running over a platform called CACSD (Computer Aided Control System Design). Manchón, Jiménez García, García, and Peris (2002) presented a general architecture to control physical processes in real time using ®Web Server and PHP. On the other hand, Moudgalya and Arora (2010) implemented a Virtual Laboratory that enables clients to design and implement algorithms by using the LABVIEW® networking capabilities. The virtual lab uses the LABVIEW® Data socket technology for communication and the Web Publishing tools to display the experiments.

The main disadvantages of this approach are the mandatory use of MATLAB® or LABVIEW®, depending on the license obtained by universities, and the installation of different plug-ins for the end-clients of the platform. In contrast, the architecture proposed here is independent of the technology used to locally teleoperate the plant. Thus, some processes at universities can be controlled regardless of whether applications run on MATLAB® or LabVIEW®, being transparent to the user or student that remotely operates the plant.

2.3. Easy Java Simulation-software control connection

Easy Java Simulation (EJS) is a free software tool that allows creating scientific simulations in Java. The simulations are structured in the model and the view, and it is not necessary to know how to write Java programs due to its "Drag-and-Drop" characteristic. Therefore EJS is an excellent tool for developing virtual and control laboratories. EJS has been widely used to develop Remote Laboratories for Automatic Control. For example (Dormido et al., 2007) used this tool to teleoperate three processes, namely a three-tank system (Dormido et al., 2008), a heat-flow apparatus and an electrical drive servo motor. Additionally, Sánchez et al. (2005) discussed a new way of teaching by using interacting and dynamic simulations and also how to develop the corresponding interfaces with Easy Java Simulation. Finally, Delgado and Lopez (2009) developed a virtual laboratory of intelligent control for a level process; the interfaces were developed in EJS and control was performed by using fuzzy logic, neural networks and PID strategies.

This approach is very interesting because Easy Java Simulation makes the development of interfaces easier and is independent of the application used to control the processes. Furthermore, the end client only needs the Java Run Environment and a web Browser in order to use the plants. The main disadvantage, however, is that it is necessary to find a way to manage the resources and the different plants due to the number of students and institutions that access the control processes.

2.4. Other approaches

There are other architectures to develop virtual and remote laboratories. We have mentioned some works that we consider relevant when deciding to adopt or discard some approaches.

Domingues, Otmane, Davesne, Mallem, and Benchikh (2009) presented an extension of existing distributed software for collaborative teleoperation based on networked human-scaled mixed reality and mobile platforms, in which the first teleoperation system is composed by a C++ VR application with the use of OpenGL library, and the second system is composed by an applet-format JAVA Web Application.

Tripicchio, Ruffaldi, Avizzano, and Bergamasco (2008) presented a distributed platform that provides researchers with a framework to develop and deploy multi-modal-enabled experiments and share them on the network with other research institutes. Moreover, tele-operation allows cooperation between partners at different geographical locations during the experiments. This permits collecting and visualizing significant data to be analyzed so that it is possible to achieve scientific results. Some recent approaches propose the use of a widespread widely-known architecture based on Web Services and SOA (Services Oriented Architecture). Buiu and Moanta (2008) implemented a remote laboratory for motion control of mobile robots, where Web Services were used for application-to-application communication over the network.

Several architectures have been studied and evaluated, and it is clear that each architecture has disadvantages, so there is no “silver bullet” for the development of remote laboratories. Here we evaluated the different architectures and looked for the most suitable one to meet the integration requirements of new universities and practices as well as the correct resource management criteria. We decided to create a three-layer architecture based on the application of Easy Java Simulation. The principal addition is a layer that allows managing the resources and integrating new plants and universities by filling out a simple form, so our architecture is not limited by a fixed number of processes or universities participating and there is also a notion of global and local administrators that control the resources and the use of practices by avoiding problems with the appearance of many users.

3. Proposed multiuser network architecture

The proposed multiuser network architecture has been structured in three independent network layers. The 1st network layer, called “*User-Client Applications*”, refers to the Learning Administration System (LMS) that each university uses to carry out the academic management of its own control courses. In level 3, there is a remote operation interface to manipulate the “*Lab Process Applications*” associated to the real control processes from each academic institution. In order to allow the easy integration of new academic institutions and control processes, a “*Management and Administration System* (MAS)” located on the 2nd network layer is proposed. Its main function is to be in charge of the lab resources at the same time that it acts as an intercommunication bridge between the first and the third network level. Fig. 1 shows the global relationships for each of the three proposed network layers.

The general interaction process between each of the network levels for the proposed system might be described as follows (see Fig. 1). For the 3rd network layer, the remote operation interface (GUI) is developed. This interface is linked up with a local control application for manipulating the real process through a TCP/IP protocol with Data Sockets. Once the remote interface is ready, it can be uploaded onto the 2nd network layer and managed by the MAS in terms of accessibility and time scheduling. To apply it to a control course through the LMS in the 1st network layer, the remote operation interface needs to be reserved in advance, and be accessed so that the final user can carry out his/her remote laboratory assignment. The main features of each layer in the system architecture are explained below.

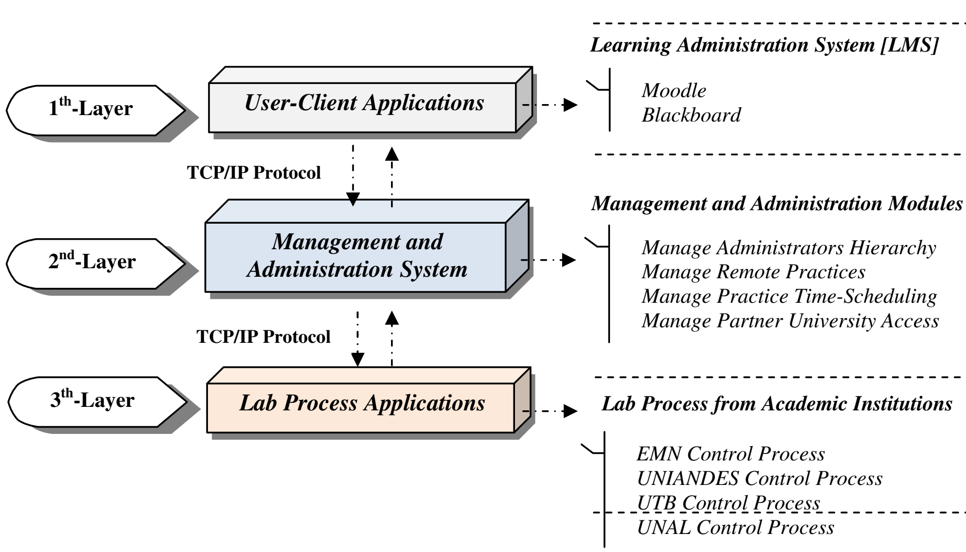

Fig. 1. Global relationships for the proposed network system architecture.

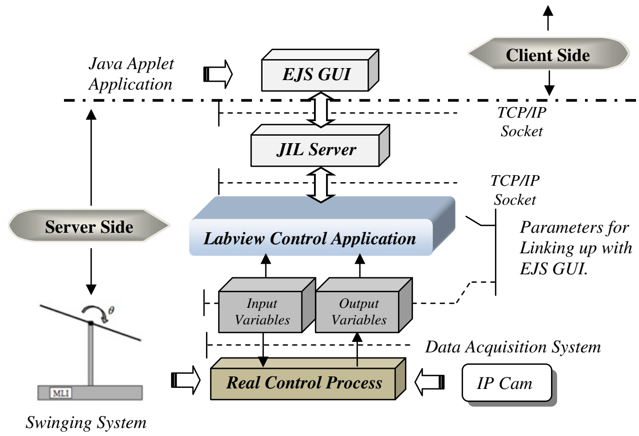

Fig. 2. General interconnection structure for the 3rd-layer/level network components.

3.1. Layer 3. Practices control system

The main goal of this layer/level is the implementation and control of real processes in the laboratory. As local applications, the most commonly used software packages for this purpose are MATLAB®, LABVIEW® and some freely redistributable software packages such as Octave. The architecture allows using any of the educational software packages thanks to the independence of this third level when interconnecting them with a Java Applet application.

In order to remotely operate these real processes, an interconnection between the Java applet and Labview application must be established. The Java applet is developed using the Easy Java Simulation environment. This programming tool allows building Graphical User Interfaces (GUI) based on java. The advantage is that applications can be manipulated as an applet, which might be distributed through the Internet, reading and writing data through the network and also controlling the use of scripts or HTML command instructions. To develop this interconnection, the JIL (Java Internet Labview) Server (Vargas, 2010) application was used. JIL Server application is based on the use of a generic communication module which implements the necessary communication layer to make local control Virtual Instruments (VIs) public through the Internet. Using this approach, the Java applet can connect and control remote VIs through JIL Server. Fig. 2 shows the general structure interconnection system that was deployed to remotely operate the "Swinging System for Position Control", a real control process for a remote laboratory that is physically located in the automatic laboratory at École des Mines de Nantes-France.

In Fig. 2, it can be observed that in order to achieve interaction between the local control application – running over the Labview platform – and the java applet – or GUI developed with Easy Java Simulation (EJS) – it is necessary to link up the desired parameters to be manipulated on this remote operation interface. To accomplish this objective, an input–output variable exchange between these two applications must occur. To do so, the Labview local control application must be built primarily in such a way that the input and output variables that are executed over the real control process can be specified for the exchange, taking into account the type of variable (i.e. *Boolean*, *Integer*, *Double*), the number of exchanged variables (*n number of Booleans*, *m number of Integers*, *w number of Doubles*) and the kind of function performed (either *Numeric Control* or *Indicator*). Once this is done, the next step corresponds to the development of the graphical user interface with EJS. The design of the GUI also requires the specification of the exchanged variables to link up with the developed Labview application, in order to create the *get* and *set* functions for commanding the *Numeric Indicators* or *Numeric Control* variables on Labview. Fig. 3 summarizes this interconnection process for the variable exchange between the described applications.

In order to allow the EJS java applet to remotely interact with the Labview local control application, the latter must be created as a *Source Distribution File*. Thus, the JIL Server can call it, execute it and control it as a public VI through the TCP/IP communication protocol, as presented in Fig. 2. Using this approach, the Java Applet for the remote laboratory can be developed and implemented to operate from the Internet. Once this is done, the applet can be uploaded onto the Management and Administration System (MAS) in order to be used at the specific experimental practice with access permissions and time scheduling; at the same time, the IP Cam might be accessed either from the Java applet or from the MAS. Thanks to the use of a Database Server, relevant information about a remote laboratory can be saved and

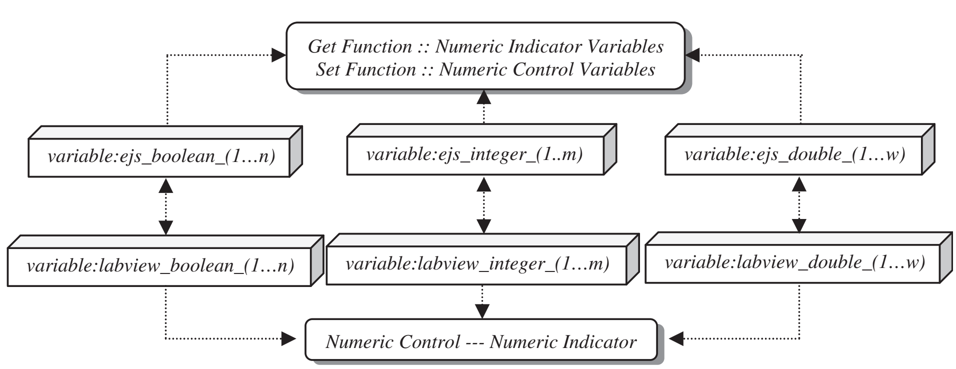

Fig. 3. Interconnection scheme for variable exchange between the Labview local control application and the graphical user interface developed with EJS.

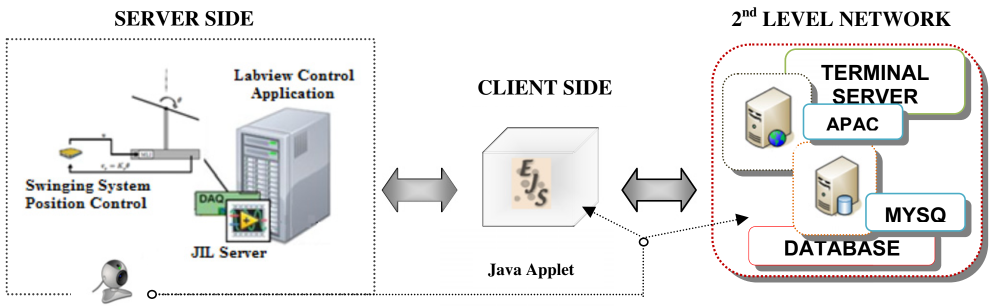

Fig. 4. General structure between the 3rd-level components and the MAS in the 2nd layer/level.

managed for future use through the MAS (See more information in Section 3.2). Fig. 4 shows the general structure defined for the interaction between the 3rd level/layer network components and the MAS.

Regarding the intercommunication structure presented above, it can be observed that both the JIL Server and the Labview application run on the same local machine, hence a public IP must be assigned it in order to accomplish remote operation. After this, it is possible to interconnect the Java Applet, developed with EJS, and the JIL Server through the TCP communication protocol. In order for the MAS to properly manage the timely scheduling of a group of users enrolled in a course, it is important to specify a customized function called "*_disconnect()*", which belongs to the model page of Easy Java Simulation.

This function contains the code line "*(jil.Jil)vi).disconnect()*", which is executed by the MAS once the time range, defined for the administrator to interact with the remote practice (see Section 3.2), has finished.

To execute this function the JavaScript command *document.{applet_name}._model._disconnect()* is used into one of the PHP scripts that interacts with the Management and Administration System.

3.2. Layer 2. Management and administration system

Most of the research works studied consist of three control labs at most, and are located in the same university (Domingues et al., 2009; Moudgalya & Arora, 2010). On the contrary, the proposed Network of Control Remote Labs consists of several processes, many universities, and therefore, many users from different countries with different time zones, and it is expected to grow exponentially according to the number of universities and new processes linked to the System. Thus, we propose an architecture that not only allows simple organization of the practices and correct management of the resources, but also the possibility of using several practices from remote universities, promoting the improvement of the control courses and the exchange of knowledge between the different institutions involved. Hence one of the main requirements in the second layer for the Management and Administration System is to allow the integration of new universities and new remote practices. This involves adequate resource management (to avoid problems with time zones), prevention of user collisions (when two universities attempt to access the same practice), and access restriction to potential intruders.

The Management-and-Administration System has been developed based on the Model-View-Controller (MVC) software architecture. The system is centralized in the use of Apache and MySQL Database server located in a remote institution, and it consists of the following four specific modules, namely Manage Administrators, Manage Practices. Manage Universities and Manage Reserves. Each module has a specific task and is divided into two options; one option is to create a resource and the other one is to see the resources already created. The two options for the Module "Manage Universities" are shown in Fig. 5; a detailed description of each module is provided next.

3.2.1. Manage administrators module

In order to manage the resources of the Management and Administration System, it is necessary to have an account. There are two kinds of accounts for the administrators of this system, namely Global Administrator – who grants all permissions over all the resources – and Local Administrator – who has all permissions only over its institution practices and cannot change the properties of the modules "Manage

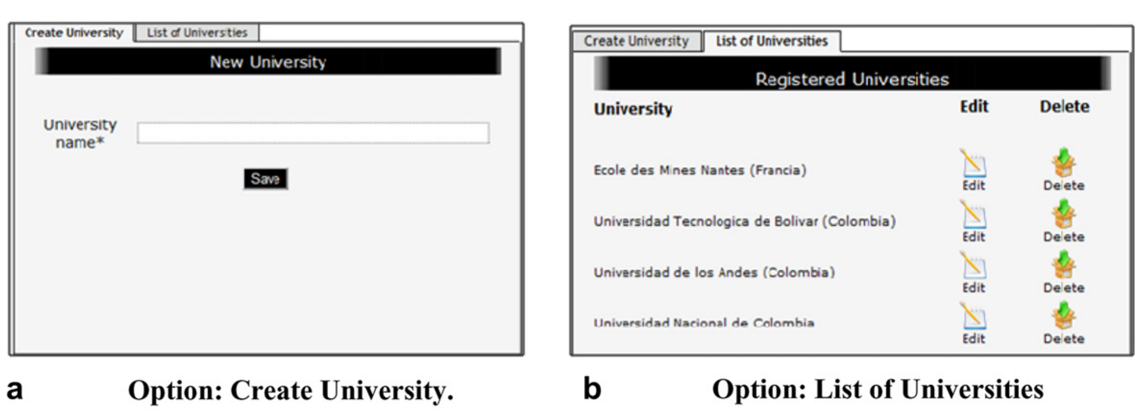

Fig. 5. Management and administration system options template. (a) Option: create university. (b) Option: list of universities.

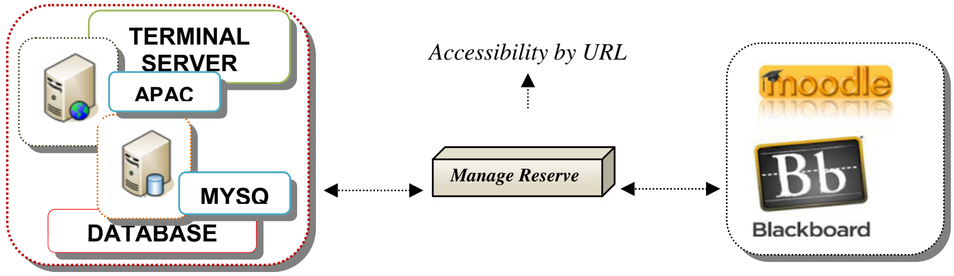

Fig. 6. Interaction between the MAS and the LMS for using a remote laboratory through the system.

Administrators" and "Manage Universities". The Architecture suggests that each university integrated into the system should have at least a Local Administrator, therefore administrators can independently create and upload practices on the system for his/her own university, which can be used by other institutions. On the other hand, the Global Administrator is the only one who can integrate new universities and new administrators into the System.

3.2.2. Manage universities module

In this module the main objective is to create, edit and delete new universities or institutions. In order to integrate a new university into the Management and Administration System, it is necessary that the Global Administrator selects the tab "Create University" and sets the name of the new university. In this first phase, there are already four universities integrated but it is expected that new universities and institutions (technical and/or technological) join the network of remote laboratories.

3.2.3. Manage practices module

This is the most important module of the Management and Administration System, because the Administrators can upload the practices developed in Easy Java Simulation just by selecting the applet generated and filling out a simple form. The Administrators do not have to worry about programming or creating a webpage to set the applet because the system dynamically creates a webpage with the data introduced in the form.

3.2.4. Manage reserve module

This module is intended to manage the resources of remote practices by allowing making a reservation for a period of time to ensure the exclusive use of a particular process by a group of students or users. The reservation can be made for different time zones regarding the location of the universities.

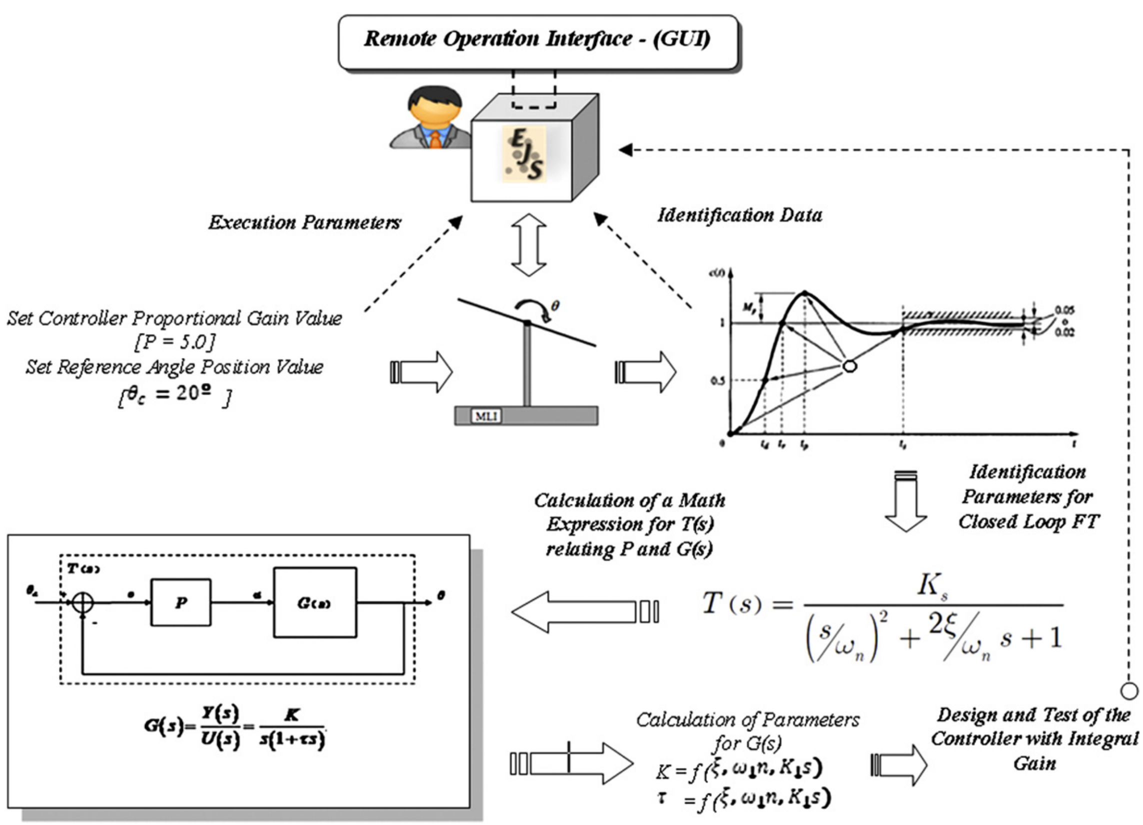

Fig. 7. Schematic diagram that summarizes the steps followed by students in order to carry out the proposed remote laboratory.

Table 1
Four-point level for Likert scale used for the evaluative survey.

Four-point level	Numeric valuation
Totally disagree	1
Disagree	2
Agree	3
Totally agree	4

Currently, there are four universities in the system, located in France and Colombia, therefore the options available to reserve resources are “France Summer”, “France Winter” and “Colombia”. This system of reservations avoids collisions between different courses and students from different countries or universities. The Management and Administration System is the core of the architecture, ensuring the correct use of the resources and working as a bridge between the control processes level/layer and the user application level/layer.

3.3. Layer 1. User-client application

The objective of this layer/level is to present the remote practice to the final user regardless of the device being used. Normally, the interface can be used as an independent webpage or it can also be integrated into other platforms such as Learning Management Systems (LMS). In order to use the practices within Moodle or Blackboard, the Management-and-Administration System dynamically creates a URL address with the information typed and the applet uploaded by the Administrator. This URL contains the address of the practice, it also contains the period of time scheduled by the reservation management for students to perform the practice. Hence, the instructor’s single concern is to create the activity or assignment in Moodle or Blackboard and introducing the URL to access it.

Fig. 6 shows a description of this interaction. The interface of practices consists of the applet developed with Easy Java Simulation, which allows remotely operating the practice, and a real-time video streaming to see the reactions of the manipulated control process.

4. Academic pilot test

In order to measure functional aspects of the remote interface for developing remote academic lab practices, an Academic Pilot Test was conducted. To run the test, a work-lab guide was designed for the remote plant “Swinging System Position Control”. A specific group of students from an undergraduate control course was selected to interact with the system and perform the proposed experimental practice. The proposed pilot test is not intended to be the conventional evaluation of a remote laboratory as an education tool (García, Díaz, Taquet, & Canivell, 2008), but rather an academic evaluation of technical aspects of the proposed remote experimental practice carried out in a control course; something similar was presented in (Lang et al., 2004).

This remote laboratory has been structured around two development phases. In the first phase, the real plant is presented for its remote operation. The second phase describes the steps that have to be followed to find the mathematical model of the real plant in order to design a controller for regulating the angle position by tracking a specific reference. In a more specific way, the work-lab guide asks to students to apply a particular value for the controller proportional gain (P) for acquiring an identification data. Based on these results, students are requested to obtain the closed loop transfer function that best represents this model (a second order system $T(s)$), specifying its damping

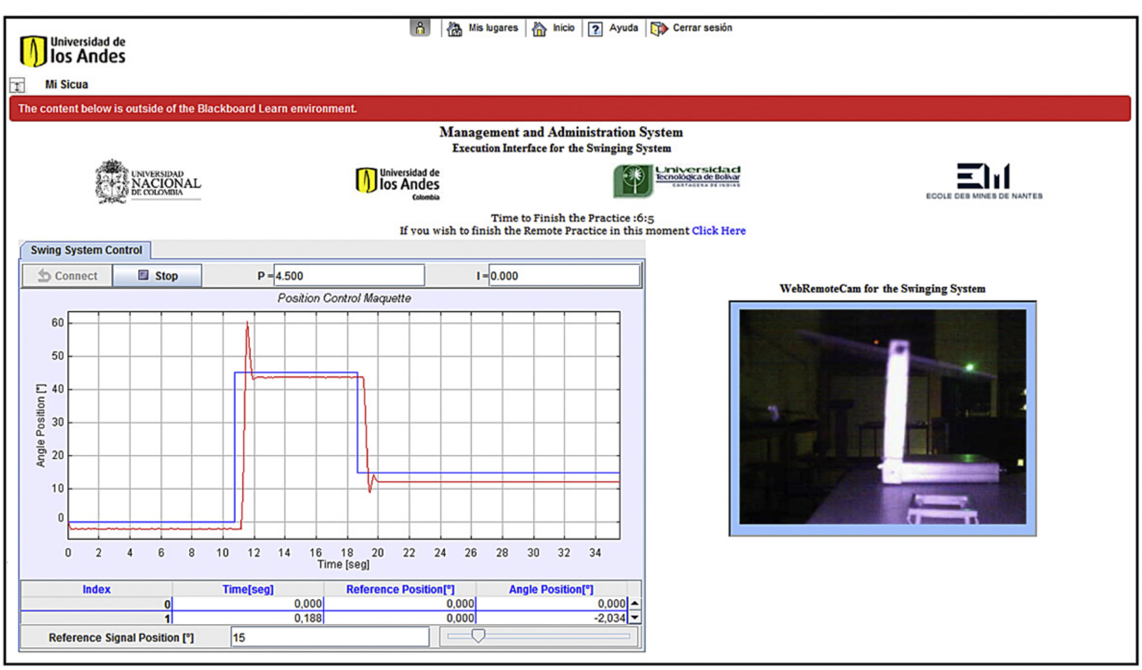

Fig. 8. Simple operation of the EMN remote practice conducted by a group of students enrolled in a control course at UNIANDES.

Table 2
Results obtained from the evaluative survey based on Likert scale.

Measured aspects	Item question	*M*	SD
Acceptance	The remote operation interface is appropriate and in line with the developed experimental practice	3.21	0.46
	I feel uncomfortable using a PC instead of being at a physical lab (*-)	1.64	0.49
	I enjoyed using the remote operation interface during the experimental practice	3.28	0.72
Usability	The remote operation interface used for the experimental practice is easily accessible and manageable	3.07	0.73
	Much effort is required to perform the experimental practice through the remote operation interface (*-)	2.35	0.63
	The instructions given in the work-lab guide are sufficient	2.85	0.66
	I would also prefer to access the remote system from an IPhone or Android Movil	2.57	1.09
Usefulness	This experimental practice allows me to better understand the modeling process of the remotely manipulated plant	3.21	0.8
	This experimental practice allows me to better understand the performance of the designed controller	3.5	0.51
	This experimental practice motivated me to learn more about the modeling and control topics presented	3.57	0.51
	The remote lab is a good preparation for my future works in the course	3.42	0.51
	Doing the experimental practice via remote access is a waste of time (*-)	1.14	0.36

(*-): Item of Question with reverse polarity for the result; *M*: Mean value; SD: Standard deviation.

ratio ξ, the natural oscillation frequency ω_n and the static gain K_c. Knowing that the transfer function of the process can be approximated as a first order model ($G(s)$), then students are requested to find a mathematical expression for the closed loop transfer function involving $G(s)$ and P. Based on this, students are then capable of expressing the mathematical parameters of $G(s)$ (*K: Static Gain; τ: Time Response*) as a function of the parameters of $T(s)$, previously presented. Finally, and according to the model already found, students are requested to calculate the controller integral gain and test it through the remote operation interface. Fig. 7 shows a schematic diagram that summarizes the steps followed by students in order to carry out the proposed experimental practice.

An Evaluative Survey was also designed. The purpose of this survey was to detect the functional aspects of the remote operation system, considering the personal single-student perception when performing an experimental practice via Internet (Remote Laboratory) by using the proposed interface. The four-point level Likert Scale (Reeves, 2007) was applied to the aforementioned Evaluative Survey in order to measure either the positive or negative response to a statement. In this questionnaire, the four-point level was proposed to be used instead of the five-point level of the Likert Scale, since the middle option "Neither Agree nor Disagree" was not available.

Thus a neutral answer to the statements can be avoided, allowing a reduction in the margin of uncertainty for each item question. Table 1 shows the four-point level used in the Likert Scale with its corresponding numerical evaluation.

In this respect, this survey was intended to evaluate the following three conditions over the remote system regarding the following aspects:

- ***Acceptance***: these items allow determining whether carrying out a remote practice experience is a good or a bad way of performing work-labs.
- ***Usability***: these items allow determining how easily students find the remote interface to handle the experiment while they are doing the work-lab.
- ***Usefulness***: these items allow determining if the remote practice achieves the proposed objectives and personal goals of the course.

However, not all the items in the questionnaire of this survey were evaluated based on the Likert Scale. For each of the three conditions presented above, there were also open-question items intended to explore the general students' perception of some specific operational aspects of the remote experimental practice. All the item questions that were defined to evaluate the proposed functional conditions are presented in Section 5 together with the corresponding result analysis. In summary, the established protocol to conduct the pilot test over the selected group of control students, using a particular remote real process, was defined as follows: First, design the work-lab guide for the control remote practice, including the graphical user interface (GUI) that can be accessed by students in order to manipulate the remote process. Second, let students access the remote system to solve the proposed work-lab guide, where both the verification and validation of the control design are requested. Finally, once the students have finished the work-lab guide manipulating the remote system, the Evaluative Survey has been applied. The numeric results of this questionnaire were evaluated taking into account the general average for all the answers of the 43 students selected for this test.

5. Results

According to the proposed Multiuser Network Architecture, the remote experimental practice called "Swinging System for Position Control" was successfully implemented and carried out by the selected group of control students, taking into account the work-lab guide proposed for this aim. In order to have access to this remote experiment from the control course at Universidad de los Andes (UNIANDES), a resource for the Blackboard Learning Environment (*Sicua Plus*) was created following the scheduling of reservations defined by the local administrator to use this remote practice. Fig. 8 shows a simple operation of the remote system to develop the proposed work-lab through the network, as performed by one group of students in the evaluated course.

Table 3
Results obtained from the student open general perception of acceptance conditions regarding the role that a remote laboratory must play.

Not agree	0.00%
To replace physical labs	21.43%
A complement to the physical lab practices	78.57%

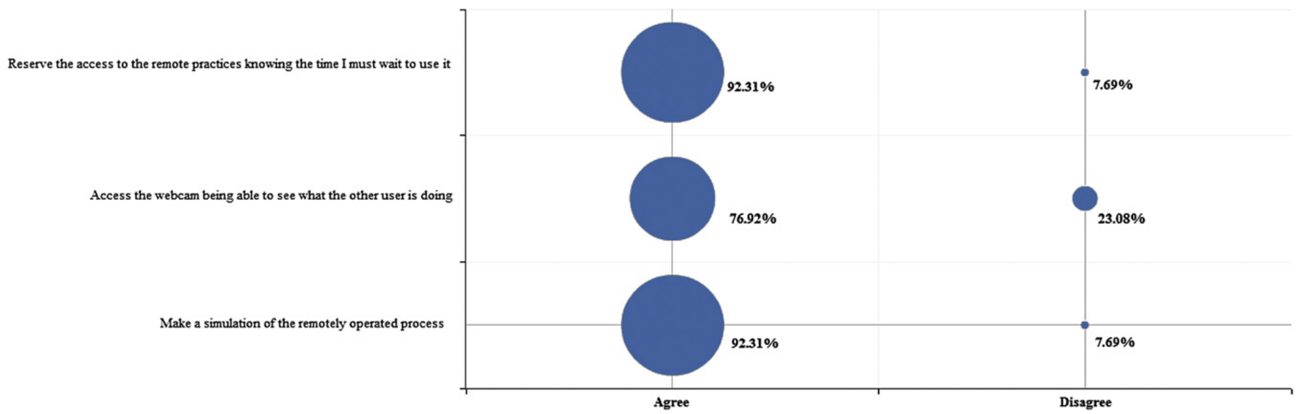

Fig. 9. Results obtained from student open general perception of usability conditions regarding the work options that a remote laboratory should offer.

Since the remote practice was successfully performed – despite some minor technical difficulties that had to be solved for the appropriate operation of the system – the Evaluative Survey could also be conducted successfully. Table 2 shows the results obtained for each of the item questions, based on the Likert Scale, according to the perception of the experience for every group participating in this remote experimental practice. The results are analyzed taking into account the numeric evaluation for each of the item questions presented above (Table 1).

Regarding the *Acceptance Conditions*, it can be observed that, in general, students found the remote operation interface appropriate to develop the proposed experimental practice ($M = 3.21$). They also enjoyed using this interface to carry out their work-lab. Moreover, students gave positive feedback, claiming that they felt comfortable with the way the practice was conducted (in front of a PC rather than in a physical lab). Regarding the *Usability Conditions*, it was interesting to see that, even though students think that the remote operation interface is easily accessible and manageable ($M = 3.07$), it cannot be assured that the effort required for them to perform the experimental practice be minimum; perhaps because not all students agree that the instructions given in the work-lab guide be sufficient ($M = 2.85$). Concerning the *Usefulness Conditions*, it was found that all evaluated items are really suitable for students, since values are clearly defined on the positive side of the Likert Scale. In general, performing experimental remote practices allow students to better understand the modeling and control design process, manipulating the real plant through the remote interface. They also think that remote lab practices are a good preparation for their future works in the course ($M = 3.57$), and such practices are clearly not a waste of time ((*-) 1.14).

As explained earlier, open questions were asked for every type of the evaluation conditions in order to explore the general perception that students might have of some of the operational items measured over the remote system. For the *Acceptance*, *Usability* and *Usefulness* conditions, the results of these items are shown below.

- Acceptance

For this first condition we wanted to explore students' opinions about the role that a remote laboratory must play in an academic environment. To do so, the following item question was asked: *From the following options, which do you think must be the role of the remote laboratories?*

The results presented in Table 3 show that most students believe that the remote laboratory must be a complement to the practical experience which takes place at a physical lab (78.57%), but should not replace it (21.43%). This is an important result for us because, based on it, we intend to design and develop an academic evaluation scheme to measure the utilization of a real laboratory compared to a remote one.

- Usability

Taking into account that in most cases the remote experimental practices are always limited to a single real plant, for this second condition we wanted to explore what students wish to do in the remote laboratory while the remote operation interface used to manipulate the real process is busy. Three possible options were considered for the following question: *While the remote operation interface is being used by another user, I would rather*…. Results are presented in Fig. 9.

The results above show that, in general, students would agree on doing any of the three work options offered by the remote laboratory, or even better, they would agree on taking these actions simultaneously. Thus, the remote laboratory becomes a more robust system; it would allow students not only to reserve the access to the remote practice knowing the waiting time, but also to do a simulation of the remotely operated process at the same time they see what is going on with the physical plant by means of a webcam.

Table 4
Results obtained from student open general perception of usefulness condition regarding the usefulness of the remote system.

Useless	0.00%
Shortly useful	0.00%
Quite useful	23.08%
Very useful	61.54%
Extremely useful	15.38%

Table 5
Technical and academic aspects compared with other related works.

Title	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A Multiuser Remote Academic Laboratories System.	Three Levels: 1. Control Processes. 2.Administration System 3.User-client Application	Labview/Matlab or open source software.	Apache Server, PHP, Ajax, HTML, JavaScript, Easy Java Simulation.	Restricted.	Yes at all.	Moodle and Blackboard.	Yes.	Yes, based on both, Likert Scale and Opened Questions.	AT is carried out over the control area.	Acceptance, Usability and Usefulness.
RECOLAB: Control Remote Laboratory Using MATLAB and Simulink.	Two Levels: 1. Web Application. 2. Control physical system application.	Matlab.	Apache Server, CGI (Common Gateway Interface).	Simulations (Open). Physical system (restricted).	Yes, No, No.	No.				
Developing a remote laboratory for engineering education (Fabregas, Farias, Dormido-Canto, Dormido, & Esquembre, 2011).	Single Client-Server Architecture.	MATLAB/ Simulink.	Easy Java Simulation.		Yes, only at first.		Yes.	Yes, based only on Likert Scale Questions.	AT is carried out over the control area.	Learning value, Value Added, Design Usability and Technology Function.
A Virtual Laboratory for Distance Education.	Based on the technologies of Labview in all the levels.	Labview, Data Sockets Technology and Scilab.	Labview web publishing tools, HTML.		Not at all.	No.				
Using web-based laboratories for control engineering education.	Two main features: Client-Server architecture. E-Learning Layer Emersion.	Labview.	Easy Java Simulation.		Yes, only at first.					
Use of a Remote Laboratory to promote meaningful learning in the teaching of electronic devices (Marchisio, Lerro, & Pamel, 2010).	Single Client-Server Architecture.	Visual Studio 6.	.Net Framework Platform, HTML.	Restricted, with username and password.	No.	No.	Yes.	No.	AT is carried out over the Electronic Devices Lab.	
Virtual laboratory of intelligent control for a level process.	Composed of the GUI interface, the local control and the algorithms for intelligent control.	MATLAB.	JAVA, neural networks and fuzzy control.	Just simulations. Restricted to a course.	Not at all.	No.				
Using web services for designing a remote laboratory for motion control of mobile robots.	Service oriented architecture.	The software embedded in the robots.	ISS, ASP.NET, web services.	Registration and Authentication.						
Pedagogical Evaluation of Remote Laboratories in Emerge Project.			HTML, CGI.			No.	One part, the other part is carried out in a Virtual Lab.	Yes. Based only on Likert Scale.	AT is carried out in the Electronic Circuits Course.	Acceptance, English Language Skills, Usability, Usefulness and Self-assessed learning effect.

■ Usefulness

For this third condition, we wanted to examine the general conclusions drawn by students about the usefulness of the remote operation interface to perform remote work-labs. The following question was asked: *In general, I think that the usefulness of this kind of system is*:

The results presented in Table 4 suggest that the evaluated levels for this item questions are clearly on the positive side of the measuring scale. It means that, in general, students found the remote system very useful to perform this kind of experimental practice, regardless of the three actions that were considered to make the remote laboratory more robust and efficient.

Taking into account the results obtained from the operation, development and pilot testing of the proposed remote academic laboratory, a comparative table with other similar works in this field is presented. The following items are defined in order to provide a brief glance at the technical capabilities and academic aspects of the work described in this article. Table 5 summarizes the main technical and academic aspects that have been compared with other related works.

1) *Structure for the Network Architecture of Remote Laboratories.*
2) *Technology used for controlling Real Plants in the laboratories.*
3) *Other technologies used.*
4) *Access to the practices: Restricted or Open.*
5) *The system dynamically allows the integration of new control systems, new universities and the booking of remote academic practices.*
6) *The remote academic practices can be integrated into a Learning Management System (Moodle, Blackboard).*
7) *Conduction of Academic Testing (AT) over Remote Lab.*
8) *Survey applied; based on Liker Scale and Open Questions.*
9) *The academic pilot testing is carried out over a remote laboratory in the field of: Control, Physics, Electronic, etc.*
10) *Conditions evaluated in the pilot testing conduction.*

Looking at the technical and academic aspects presented above (Table 5), where the current work is compared with other related studies, it can be generally observed that the proposed network architecture for remote academic laboratories has been structured as a technologically flexible system, considering that the functional relationship between each network level has been made independent in order to achieve easy integration of any kind of computer technology into the network system. On the other hand, the academic aspects of this work are related to the functionality of the remote laboratory carried out with students enrolled in a control course. The aspects considered (*Acceptance*, *Usability* and *Usefulness*) are measured not only through the application of differential questions but also taking into account the personal perception of a selected group of evaluating students answering open questions.

6. Conclusions

The proposed remote system has allowed students to dynamically interact with a real process to carry out a remote experimental practice, guaranteeing the availability of lab resource to be accessed and scheduled in time. In this sense, a remote laboratory could be managed in a better way since the time that a user must wait in order to access the remote system is known as well as the time remaining to finish once students are engaged in their actual practice. Even though it can be mentioned that the system presents these kinds of advantages to make a remote laboratory more interactive, some technical disadvantages were also identified (e.g. the queuing problem was one of the major concerns).

Once problems were sorted, final-users or students could reserve the time for accessing the remote practice and do the experiments proposed for it.

Considering the results obtained from the programming and execution of the remote academic laboratory in France, it was possible to validate some aspects of the operation on the suggested network architecture, in which the Management and Administration System allowed scheduling the resources in order to use them correctly within the control course in Colombia through the Blackboard Learning Platform (*Sicua Plus*), once again including a functional pilot test on the system.

On the other hand, the pilot test conducted with control course students has allowed examining the functional conditions of *Acceptance*, *Usability* and *Usefulness* of the evaluated remote practice. For the *Acceptance Condition* from the Evaluative Survey, we conclude that the system used to develop the remote experimental practice can be regarded as suitable for the students selected in this test.

This suggests that we must keep improving the assembly of more complex physical processes for their remote manipulation in order to have a greater variety of control plants to develop experimental practices through the network.

Regarding the *Usability* and *Usefulness Conditions*, the findings obtained from the test show that although the system is quite easy to use and very useful when performing remote practices, there are operational aspects that must be adjusted in order to make the system more robust and efficient.

Concerning future work perspectives, a more ambitious scope is to achieve the integration of new control processes for remote operation in order to share these resources in the network, either with inter or intra academic institutions – the latter when institutions have different academic campus – and also to extend the system to other accessing media like smartphones. Also an evaluation test to measure the usefulness of the real lab in comparison to the remote lab is intended to be designed and implemented. In this test we want to examine in which modality of work-lab a student presents better academic results. The modalities of work-labs we intend to explore are *Real Lab*, *Remote Lab* and *Real plus Remote Lab*. Of course that in order to accomplish this task, at least one of the real control processes at the Colombian universities has to be assembled for remote operation.

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