Remote Automation Laboratory Using a Cluster of Virtual Machines

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***Abstract*—This paper presents a remote laboratory for industrial automation comprising different programmable logic controller (PLC) manufacturers. This facility provides an environment for remote users to learn many automation topics while using different PLCs together with several types of sensors, actuators, and industrial communication networks. The laboratory architecture that makes up the remote automation laboratory (RAL) is based on a Moodle-server master PC (MPC), which also manages the booking system of PLC benches available in the laboratory. There exist a cluster of virtual machines (VMs) running on several slave PCs (SPCs), four VMs per SPC. Each VM can manage a type of PLC bench of the automation laboratory. The MPC server balances the load of SPCs allowing the implementation and easy upgrading of the RAL offering different PLCs at the same time within the same remote interface. The remote laboratory has Internet protocol cameras providing a view of the real environment of each PLC bench to the remote user. The authentication system and management of remote users and PLC benches are made via Moodle plug-ins and hypertext preprocessor (PHP) scripts. Two external/internal routers dynamically configure the remote users' access to a particular PLC bench. RAL architecture can be applied to other e-learning areas.**

***Index Terms*—Moodle, programmable logic controller (PLC), remote laboratory, virtualization.**

I. Introduction

THE industrial environment is still suffering from the fallout and ramifications of a major technological revolution, the machinery of which remains largely in place to this day. Due to a highly competitive globalized market, companies have been forced to adapt their old systems of industrial production to an evolving new world requiring modern systems to improve their benefit rates while increasingly offering more safety at work. Thus, the products manufactured have higher quality at competitive prices. However, this adaptation to new technologies involves the automation of many systems.

These causes produce an ideal framework for providing education in the field of industrial automation. Because of the wide variety of possibilities present in different types of industries, many commercial solutions have been offered for the industrial automation market (programmable logic controller (PLC), communication protocols, visual inspection systems, etc.). Engineering students must be made familiar with the concepts of industrial automation. Each manufacturer of automation systems introduces relevant concepts not present in other companies; thus, the interoperability of multiple PLCs is a requisite for a future automation engineer.

The cost per student of automation equipment from an academic point of view is quite high, increasing even more if PLCs from different manufacturers are used, making their acquisition very difficult. The need for an affordable method has driven this work and has motivated the development of a remote automation laboratory (RAL), which allows online operation of the industrial equipment. The physical architecture of RAL is designed for an easy and convenient upgradation, which converts the laboratory into a highly flexible and versatile facility.

Due to the high demand within the field of industrial control, the Department of Electronics, University of Alcalá imparts, from the academic year 2007/2008, an M.Sc. degree in industrial process automation (MIPA)[9] with a semiattendance timetable. The RAL is complementary to the regular classes, being able to offer remote access to laboratory facilities at any time of the day, through a Web booking system of PLC benches, combining remote and present users [20]. The MIPA is a one-year course requiring 600 h of course attendance. The approximate number of students per year is 20, primarily comprising industrial engineers.

Whenever there are adequate resources along with the registration of the students, the RAL allocation policies and maintenance will function, with up to 100% reliable service. The operating architecture designed in this work opens up the possibility of sharing resources and workbenches between different laboratory entities/organizations, thus tackling the demand for the use of expensive laboratory equipment. Another option that opens with the RAL is the online rental of the classroom for training in automation systems and industrial control.

In addition to the use of remote laboratory in the MIPA, many online resources are used in teaching other subjects such as distributed control and automation in electronic engineering or short training courses about automation for students who cannot physically access the laboratory because of various reasons, including incompatible schedules or remote workplaces. This latter idea is worth mentioning because of the growing interest in industrial automation systems in Latin America. The different time zones allow the use of RAL facilities at night (local time) increasing the use of the automation resources. This provides a large return on investments for RAL equipment.

This academic initiative helps attract students from business and engineering working on tasks related to industrial

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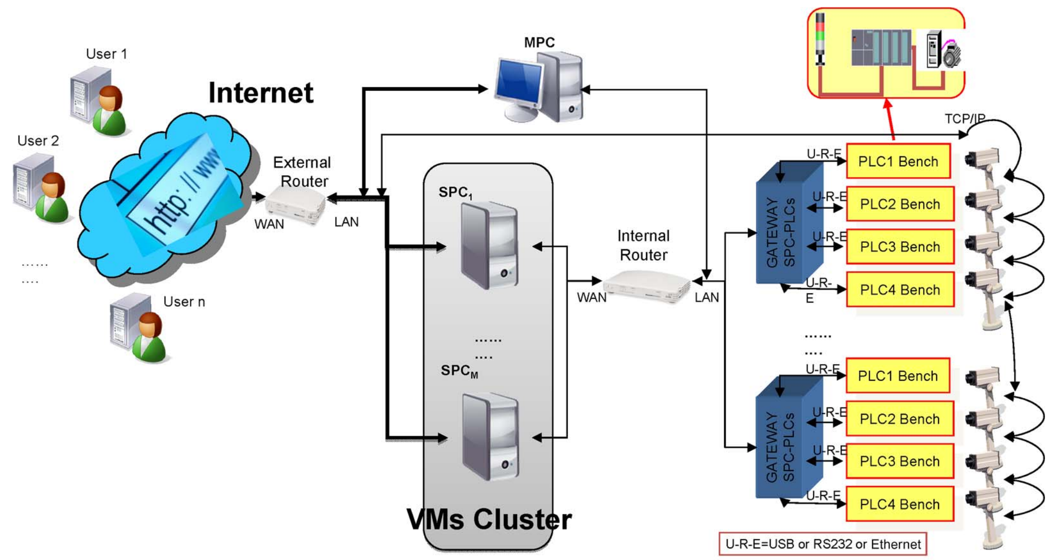

Fig. 1. Block diagram of RAL.

automation. The RAL facility can be used as a distance-learning tool, and the users can remain in their preferred location. These training procedures complement the higher education provided in schools.

The developed laboratory boasts of an integrated system environment based on Moodle [10] that allows a student to remotely manage the various industrial automation resources available physically in the Department of Electronics, University of Alcalá. For the proper management of RAL, a comprehensive resource management system has been designed by using a Moodle framework. Only authenticated remote users can use the virtual resources offered in the RAL Website.

RAL is divided into two interconnection areas using an external and internal router. A master PC (MPC) stores the RAL Moodle Website and manages the booking of automation resources. The remote user is connected from the external router to a preassigned virtual machine (VM) running on a slave PC (SPC) and connected to the PLC workbench via an internal router. Different Ethernet gateways serve to manage and control the PLCs from the SPCs depending on the configuration bus: serial, universal serial bus (USB), etc. The interconnections of RAL devices are shown in Fig. 1. The details of the architecture are explained in Section III.

This paper is divided into the following sections: Section II shows the most significant work on the primary systems. Section III describes the most significant benefits of RAL explaining in detail the architecture implemented as well as the benefits of the facility. Section IV presents a section of results and Section V concludes with the most important results of this paper.

II. Related Works

The implementation of a remote laboratory is described in numerous works. Some of them allow remote access to laboratories for control of industrial processes [4], [5]. Other works such as [1], [3], [7], and[12] are developing RALs. All these works offer the possibility of using PLC workbenches either locally or remotely, thus allowing the e-learning of industrial automation concepts [2], [11], [14] and therefore the adaptation of the different university degrees to the convergence of the European system of education (Bologna Agreement).

The vast majority of remote laboratories cover the client/server Internet methodology, where the customer is materialized in the user who wants to access electronic equipment such as a PLC, and the server is the one that allows the authenticated user to use a particular physical resource. There are different applications such as Labview [13], Lookout [6], Visual Basic [1], or WinCC [8] that includes remote human–machine interface (HMI) services. A complete survey with different proposals to develop an HMI is shown in [19]. All these tools offer many benefits for developing graphical displays in a very simple and intuitive way. However, despite incurring high economic cost, these tools bring few benefits for learning objectives. The open-source tool Moodle is gaining popularity in e-learning because it provides a comfortable Web environment to develop applications that manage documents, forums, chats, etc. In this field, several works such as [2], [11], and [13] deploy applications on servers based on Moodle.

Moodle and WebCT (Blackboard) [15] are the two main e-learning tools. Both tools have similar features with one significant difference—Moodle is an open source, while WebCT needs a license to run.

Another important aspect is adding students to courses: It is easier in Moodle than in WebCT because students are enrolled automatically in the former. The possibility of modifying and extending the capabilities of a Moodle Server is a great advantage of this tool. An interesting comparison between both tools is described in [16]–[18].

A very important point to address in the design of a remote laboratory is its hardware architecture. In our case, the laboratory is focused on the automation area (PLCs); thus, the priority is to take into account issues such as PLC–PC communication, software management/control of the PLC, and the number and types of PLCs to be used. The authors of this paper made a prototype of a RAL system based in OMRON PLCs (Fig. 2) as

Fig. 2. Remote PLC bench based on a three CJ1M PLCs, IP camera, and router.

an earlier experience. This previous system did not have a lot of versatility, but it was an important starting point in order to develop the current RAL. The RAL from Fig. 2 had an MPC, an SPC, peripherals wired to the PLC, and a router. This system was capable of working with only one student at a time, and it was not possible to extend the functionality to other type of PLCs.

The PC–PLC communication must be analyzed from two different points of view: hardware and software. While focusing on the hardware side, it is important to emphasize that, currently, there is no unique standard to connect and configure different brands of PLCs. Some manufacturers use the USB and other bus configurations via RS232/485 interfaces and Ethernet. One goal of the RAL work was to make the configuration of the PLCs uniform using Ethernet gateways to the particular buses, thereby reducing the dependence on the type of PLC in designing the hardware architecture of the laboratory. With respect to software, most manufacturers of PLCs have proprietary software for configuring, programming, and downloading the application that will run on the PLC. The capabilities of this software range from management functions to hardware diagnosing, troubleshooting, control, and unloading of PLC applications. This makes it necessary to use these software applications whenever the PLC is handled from any location. They normally run only under Windows operating system (OS) platforms, the latest being WinXP-SP3.

All these features make the architecture of the laboratory highly dependent on a single manufacturer with low flexibility to use different types of PLCs, as this would involve specialization of the communication solutions, management, and control of PLCs. Therefore, most of the remote laboratories that implement multi-PLC systems only deal with a single PLC manufacturer [8], which is overtaken with our proposal.

III. System Overview

As mentioned earlier, the primary objective of this paper is the design of a RAL. Some important considerations are the following.

1) Use PLCs from different companies and several types of central processing unit (CPU) connections to the programming PC. This facility could be used to give automation courses using any PLC seamlessly.
2) Use Moodle as the e-learning tool. More and more resources on education Websites are based on Moodle, making it a *de facto* tool for e-learning.
3) Implement scripts and plug-ins into Moodle for booking PLCs and configuring the local devices appropriately.
4) Use an Internet protocol (IP) camera for each PLC workbench to remotely monitor the practices made for that PLC and sensor/actuator peripherals.
5) Configure a multi-PLC network, allowing remote users to manage different PLCs within the same interface and automation laboratory.
6) Use VMs to quickly and easily deploy the software suites for configuring and programming the PLCs.
7) Each VM should control a PLC workbench type.
8) Use an Ethernet gateway between a VM and a PLC (see Fig. 1). It allows the system any standard connection to the CPU of the PLC (USB, RS232/RS485, and Ethernet are supported).
9) Real separation of automation resources and programming PCs, using Ethernet communication and switches/routers.
10) Easy upgrade and extension of the multi-PLC network.
11) No need for special HMIs other than the software suites available from PLC manufacturers. Use of remote desktop (rdesktop 5.1) to access the PLC programming software installed on each VM to manage/configure a PLC type.
12) Laboratory according to the Bologna Declaration. Due to the great advantages offered by RAL, many students have enrolled in our e-learning course based on Moodle. Many elementary exercises/practices have been proposed for the students as homework, letting the students test from anywhere if the different proposed exercises by the teachers work correctly in real systems. This is an important contribution of our proposal because majority of the homework of standard courses is based on simulators and not on real equipment. Our proposal allows integrating students in working groups to develop more complex practices.

The basic architecture for the developed RAL is shown in Fig. 1. This architecture needs different management software for each device that comprises the system: MPC, cluster SPC, VMs, routers, PLC gateways, etc. The following sections describe the hardware and software characteristics associated with the different parts of the developed RAL following the schema shown in Fig. 1.

A. Hardware Architecture

The industrial automation devices are the heart of the RAL. The RAL offers training on several PLC types to show automation concepts from several points of view.

This plurality of hardware leads to different problems resulting from the unnecessary utilization of different buses for communication and configuration, as well as installation of specific software for each manufacturer. Initially, the classroom is set up to work with several PLC types, but flexibility and versatility will allow the future addition of new PLCs from other companies.

Hence, it should be noted that the laboratory design has taken scalability into account, allowing an increase in the number of available seats and their maintenance. Thus, the number of PLCs that can be handled in the RAL is not limited, as shown next, because the building of an internal local area network with a cluster of VMs from the different SPCs allows the use of a very large number of PLCs. Currently, the following types of PLCs and industrial equipment are available.

1) Siemens: CPU 314IFM, MPI connection via USB. Configured using Step7. Communication practices PROFIBUS-DP (master CP-342) with a MicroMaster Control Vector.
2) Schneider: CPU Modicon M340, configuration protocol Modbus via USB using Unity Pro Software (SW). Remote input/output (I/O) using Modbus/Ethernet with the Advantys OTB. CAN communication with an Altivar31 frequency inverter.
3) Omron: PLC CJ1M, Toolbus via RS232, configuration with CX-Programmer. Dedicated I/O digital/analog, communications with Devicenet and Ethernet. The communication practices require two racks to transfer data between them.
4) Phoenix Contact: PLC ILC150, CPU connected via Ethernet to the configuration SW PC-Worx. Interbus communication of remote I/O.

From this list, it is clear that the laboratory offers the ability to remotely program the CPU of a determined PLC, in addition to managing/controlling various peripherals that are connected to the PLC. The remote laboratory could be described as an advanced simulator/emulator automation solution.

The RAL allows the definition of practices involving automation hardware from different companies, using their I/O capabilities as well as the setup and use of industrial communication buses. The architecture based on VMs makes it easy to check the data transmission and operation of practices developed by the user. The user can operate two or more PLCs requesting more VMs to the MPC server.

The training systems are prewired, providing the student with information about the installation of all automation equipment used. The user has a known platform, and the training objectives are met fast and efficiently, without any mistakes in the connection of the different elements that make up the practice. For example, the DeviceNet practice needs the termination resistors connected on both ends of the cable communications, and an external power supply is also connected to the bus. A photograph of the RAL configured with different automation PLC benches is shown in Fig. 3.

The RAL server has several available videos showing the preparation of the automation equipment to be used in remote practices. Thus, the student gets all the required information without losing perspective of a real automation system. The developed system gives the remote user the same control and power over an automation system disposed in a usual laboratory as an in-place worker. This facility does not exist in the existing e-learning systems. The developed system, with all these capabilities, helps in producing nonattendant engineers in the field of industrial automation.

Fig. 3. RAL with different automation PLC benches.

The RAL booking system is used indistinctly for local and remote users. The use of VMs does not differentiate between local and remote users. Local users connect to the RAL via thin clients or laptops. The Website balances and divides the available PLC benches among students, arbitrating their access to the automation facilities using the Moodle server of e-learning in both cases.

Attendance to the laboratory is not important. There is no possibility of interaction with the equipment, and the state of remote practice is preserved. The cluster of VMs used by any type of user (remote or local) is separated from the automation equipment, connected only by Ethernet network, so that local users are converted into remote users. By connecting directly to the SPCs, local users will have higher speeds, but both the experiences will be more similar than current digital subscriber line (xDSL) remote connections to RAL. Another advantage of the system is that automation items, such as PLCs and peripherals, are not handled directly by the users/students. As a result, the developed practices are effectively carried over from one user to another. The material has lower faults, a higher lifetime, and needs less maintenance.

The programming and management of a PLC, along with its remote sensors and actuators, need an OS configured with the corresponding software from the PLC manufacturer. This is accomplished with a cluster of VMs running on SPCs. Our RAL handles up to four different PLC types. To reduce the deployment costs and simplify the topology of the laboratory, each SPC is equipped with a QuadCore (currently, Intel Q9400) allowing to run seamlessly up to four VMs transferring the computer load of the different VMs on each of the four CPU cores from each SPC.

As mentioned in Section II, our proposed schema for RAL introduces the standardization of the communication channel to the CPU PLC. This aspect confers the laboratory with the ability to easily interact with different communication channels of the PC–PLC. Thus, for maximum flexibility, each port of communication for a particular CPU from a PLC type is connected to an Ethernet (ETH) gateway, i.e., ETH-USB with Schneider or Siemens CPUs, ETH-serial in Omron, ETH directly to Phoenix-Contact PLCs, and so on. Currently, the network used to program and configure the PLCs is physically separated from the automation communication buses and networks used in practice

An IP camera is connected and forwarded by the external router to the remote user, watching the corresponding PLC, the I/O configuration, and any other information from different displays such as measurement devices or external power sources. RAL is upgrading the fixed lens cameras to pan-tilt-zoom cameras to control the viewing details of the corresponding PLC bench.

The proposed architecture makes remote automation systems accessible without any difference from the real system in a laboratory. Actions such as reset of automation equipment that would require the presence of the user in the classroom are resolved by home automation devices based on Siemens EIBUS, controllable by the remote user through the Moodle Website. This facility is used by the MPC to be energy efficient, turning the PLC benches on/off as required.

B. Software Architecture

The management of RAL requires different software. Depending on the device analyzed, there exist open-source software and applications more or less configured to suit the RAL requirements and some specific software from PLC companies. Thus, the deployment of RAL schema on any current laboratory is cost effective and fast to install. The following classification can be made to list the different software as a function of the location in the RAL schema shown in Fig. 1: the remote client (RAL user), RAL server/resource management (MPC), and VMs cluster on the SPC processors.

The remote PC only needs a Web browser and a remote desktop client application to access a RAL PLC bench. The access to the remote desktop can be made from a Virtual Network Computing (VNC) viewer program or by using the ActiveX inside the Internet Explorer browser. As stated in [19], there are different access methods, protocols, and new Web technologies such as Web 2.0 [21].

To preserve and maintain along the time the SW configuration, the VMs are configured as a snapshot hard drive. Due to it, a nonintrusive configuration is used in remote virtual PCs [19]. Users could make virtual changes on the configuration, system files, and so on, but upon rebooting the VM, the "frozen" state is restored, recovering the original configuration needed by other users. It is worthy to note that the students have their own network disk space to manage private data.

The *MPC* server manages the access to the VMs cluster on the SPCs taking into account the booking system on Moodle—meeting room booking system (MRBS). It also configures the access of the VM to the corresponding PLC for a particular remote user. The MPC server has a Linux OS installed (Ubuntu 8.10) running an Apache Server, a hypertext preprocessor (PHP) interpreter, and a MySQL database server. This configuration is the most recommended for e-learning Moodle Websites. Several PHP scripts redirect the user Web browser to the VM session; internal to the RAL, it manages the PLC access from the VM(s) assigned and also handles

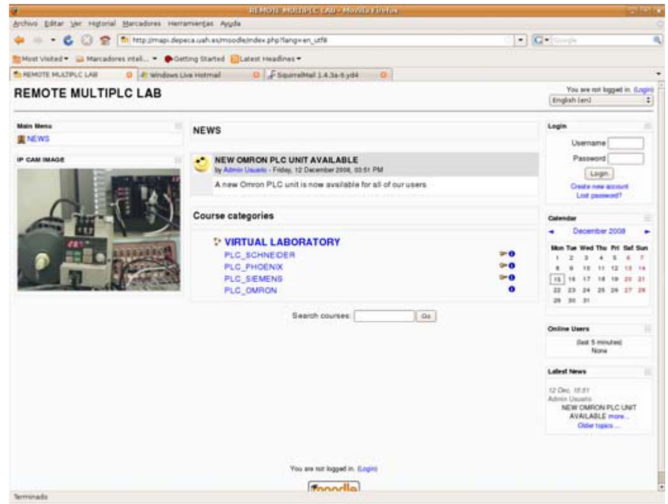

Fig. 4. Main window of the remote multi-PLC laboratory Website.

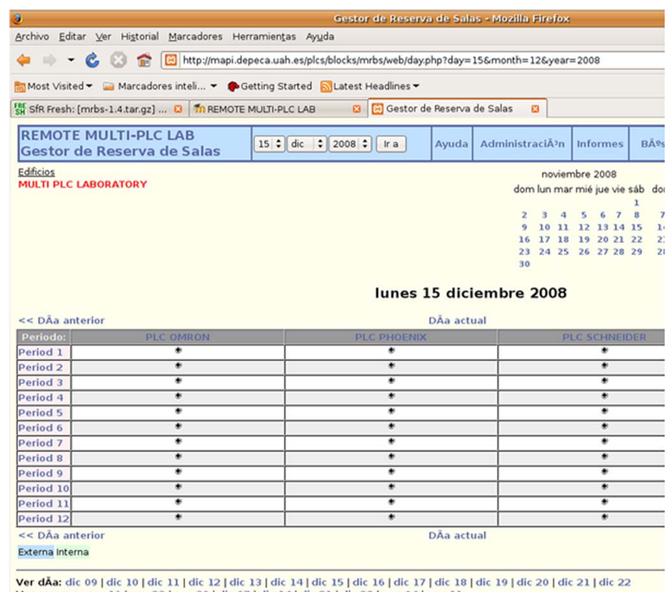

Fig. 5. MRBS window.

workbench reserves along with the educational material to be used in various practices with PLCs (see Fig. 4).

The MRBS plug-in has been used in the Moodle Website to manage the PLC reserves taking into account the disposal of PLCs and dynamically updating the number of free resources for a given date. It is important to note the difference between a PLC reserve and a PLC bench. The user does not know the PLC to be used in practice. The MRBS shows the number of free PLCs within a time interval (see Fig. 5).

There are a number of PLC benches available and the application assigns them a sequential order as users enter and request for a certain type of PLC. In this way, RAL is flexible and allows an easy schedule of maintenance, equipment reparation, etc. without varying the normal operation.

The MRBS tables validate if a user can use a certain PLC type at a given time. The PHP scripts configure the use of a corresponding VM on an SPC following a balanced policy. It enables the external router redirection (using *iptables*) from the user IP to the remote desktop IP of the VM just started. In addition, the internal router is configured in a way that allows the VM to access one PLC of the chosen type. There exists a VM/PLC table that shows their state: in use, maintenance, or free. Thus, the state of the VM and PLC assigned are changed to "in use" status.

A scheduling task, a *cron daemon* based on the MRBS data, deletes the redirections made on both routers and writes the VM/PLC table to indicate the release of these resources to reuse them.

The SPC processors form a cluster of VMs. They are configured from the MPC server: connected to Internet remote user via the external router and connected dynamically to the PLCs via an internal router. This architecture (cluster of VMs plus routers) is the main technological novelty of this work. Instead of reprogramming to a Web interface, the PLC programming the remote desktop connection is used. By introducing the VM concept, the flexibility of the RAL has no limits other than physical resources, as in the case of a normal laboratory. The cluster of VMs created onto the SPCs serves all the requests from authenticated remote users

It is a fact that PLC companies deliver their programming and configuration software only for Windows OS. Thus, the VMs have installed a Window XP-SP3 OS. Following the open-source schema, the VirtualBox application for running VMs has been used in RAL. It is worth noting that up to four VMs can be run on each SPC on the QuadCore SPCs, without noticeable lowering of speed. The balance policy obtains the maximum performance from the RAL considering the SPCs as a global processing capability, a cluster of VMs, distributing the load among different SPCs.

RAL has been constructed with SPCs running on Linux OS, it being a reliable, lightweight, and open source. The other test has been performed using Windows Server 2003 with the terminal server configured to serve multiple connections to remote users. The main problem is that Windows server OS itself consumes more machine resources, is difficult to configure and maintain, and has less scalability than the Linux OS counterpart on SPCs.

Inside the VM, Windows XP-SP3 is preconfigured with the specific PLC software. The remote user can access this facility using a remote desktop client (remote client software or ActiveX inside Internet browser). To gain access via an ActiveX inside the Internet browser, the Internet Information Service (IIS) has been enabled onto the Windows XP inside the VMs. The remote user has both links in the RAL Website.

The cloning of a new SPC is very easy. For a particular manufacturer, only one VM needs to be installed. Other VMs will be clones. The VirtualBox application has an extensible markup language configuration for the VMs using virtual disks (.vdi). Another feature of the configured VMs is that no modifications are written on disk by the current user. When restarted by the next user, the VM will appear as new and clean. The remote user starts the Window XP OS without administrator privileges for security reasons of RAL, not to interfere with other users or PLCs. The IP addresses of both adapters are obtained using dynamic host configuration protocol services from external/internal routers, configured via the MPC, knowing the fictitious media access control (MAC) address of each VM installed.

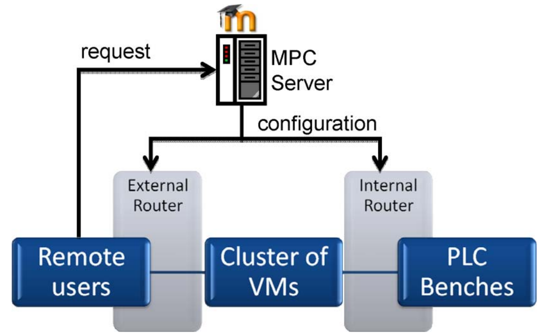

Fig. 6. Routing channels between different RAL agents.

The MPC server stores a table with data from the different VMs installed on the SPC cluster. Relevant data for each VM are the IP addresses and the corresponding PLC type. VMs are started dynamically on the SPC Linux cluster when the remote users access the RAL automation PLC benches. In this way, a dynamic routing schema supervised by the MPC Website is completed, forwarding the dataflow from the IP of the remote user to the started VM and connecting this VM with the corresponding PLC to allow the remote user to effectively program/configure the PLC.

While the VMs are very easy to clone onto the cluster formed by the SPCs, the PLCs and automation peripherals must be previously wired and configured with the I/O and communication facilities needed in the practice of RAL.

The details of the configuration of PLC connection to VMs cluster depend on the CPU interface. However, the PLC must be initialized with a known network address independent of the gateway interface to the VMs. The IP numbering schema is fixed based on gateway MAC address. The aim is to confirm that a VM does not capture packets from any PLC other than the one assigned by the MPC server. This prevents the remote user from disabling the communication from the PLC to the VM. A search broadcast of PLCs will only return the assigned PLC and enable the user to reconfigure the IP correctly.

Finally, we mention the use of flashed routers (see Fig. 1) with the OpenWrt Linux distribution. This type of device converts the router into a highly configurable router. It allows the dynamic reconfiguration of IP forwarding between the remote user, the VM, and the PLC/IP camera. Several companies distribute Linux-based routers. These routing devices include the powerful networking commands of Linux and are low-cost hardwares that are very useful for RAL objectives.

The schema developed is easy to deploy and does not introduce delays into the remote connections. The router is accessed securely via an authenticated Secure Shell session with a preshared key.

The routers implement an interconnection matrix between the three different parts involved in the RAL access: remote users, VMs, and PLCs. The routing channels are configured by the MPC server along the MRBS and allow Moodle Website access for RAL users (see Fig. 6).

It is worth noting that RAL intensively uses network-attached storage (NAS) disks to store user data. Thus, the user can access previously saved data from any VM once authenticated in the NAS server. This demonstrates again that there is no need to alter the contents of the VMs.

TABLE I
SHORT QUESTIONNAIRE FOR RAL EVALUATION

Key	Question
A	Was it easy to manage web platform?
B	Have you used the web platform for non-standard hours (nights, weekends, etc.)?
C	Has the speed of remote access to the VM/PLC been good enough?
D	Do you consider RAL useful for learning?
E	Would you recommend the use of RAL architecture for other courses?

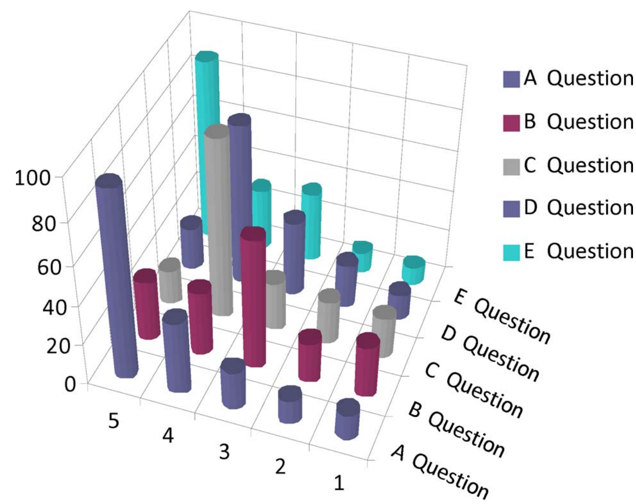

Fig. 7. Rating distribution of students answer to the RAL survey of Table I

IV. RESULTS

The remote laboratory RAL presented in this paper has been developed and used since the academic course 2007 to teach the associated MIPA degree. Most users of RAL are students from MIPA. In addition to MIPA students, RAL has been used in training courses for technicians of different automation companies.

The availability of a flexible and easily expandable laboratory with different workbenches has obtained a high degree of acceptance. This impression was confirmed with the survey results (see Table I) made at the end of each training/academic course by the students. Thus, Fig. 7 shows the results obtained from the answers of 120 people. The X-axis shows the score obtained for each question from Table I (a value one is the lowest score and five the highest). The Y-axis presents the percentage of students for each pair score/question.

Analyzing the results of Fig. 7, it can be noted that over 60% of students had no problem in managing the RAL Website and remote access to PLCs. This result validates our objective about making an e-learning environment easily accessible. With regard to question B, the results achieved show that the platform has not been widely used in nonstandard hours (nights or weekends). This is mainly because most of the RAL users currently work and study at approximately the same time; thus, the RAL has mostly been used during normal hours. Surely, when the RAL is used in Latin American areas where the time difference is remarkable, the resulting scores for this question will tend to be higher.

About the speed of remote access to the PLC benches, the survey shows that most students consider the access as fast. This is mainly due to the cluster of SPCs that optimize system operation and use the remote desktop integrated within WinXP instead of slower alternatives. In addition, majority of students have positively evaluated the use of RAL and recommend its use in future courses.

Concerning the access to the RAL system made by the students, it is important to remark that around 80% of students have been using this new platform. It is worthy to note that RAL system had an increase in demand close to the deadline of the requested exercises. In these dates, the amount of access was around three periods of time per week per student. This rate has been constant during the two courses in which the RAL system has been working.

One of the most significant contributions of e-learning tools such as RAL is the increase in autonomy for each student. This is due to the individual exercise/practice with different levels of complexity that every student is required to do continuously. On the other hand, the integration of standard tools, such as chats, discussion forums, or instant messages in Moodle, enables the sharing of information between students.

The increasing success of RAL every year commits us to do a continuous assessment to improve its negative aspects based on the students' suggestions.

V. CONCLUSION

This paper has presented the design of a remote laboratory to teach different types of PLCs. The developed architecture allows an uninterrupted use of any automation laboratory. This facility reduces the equipment depreciation and increases the performance of the laboratory, generating significant cost savings as it is not necessary to acquire one PLC bench for each student of a course.

Moreover, the high flexibility and versatility of the implemented architecture allows the addition of new automation equipment while simultaneously using the rest of PLC benches. The transformation of a regular laboratory into an e-learning facility is now very easy with the ideas proposed by our RAL. It opens up the range of potential users being able to study/practice at work or home, reducing the necessity of attending the course physically.

RAL consists of different types of PLC workbenches, which give the student a thorough knowledge about the current industrial automation systems in use.

Future works will take energy efficiency into account to reduce the power consumed by each device, lighting, etc., which is crucial in a laboratory available 24×7. Another aspect requiring attention is the remote operability with the equipment, I/O data, potentiometers, etc.[1]

[1]Visual Basic is a trademark or a registered trademark of Microsoft Corporation. WinCC and Siemens is a trademark or a registered trademark of Siemens AG. Phoenix Contact is a trademark or a registered trademark of Phoenix Contact GmbH & Company. KG. Schneider is a trademark or a registered trademark of Schneider Electric SA. Labview and Lookout is a trademark or a registered trademark of National Instruments Corporation. Blackboard is a trademark or registered trademark of Blackboard Inc.

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