A Learning Management System Including Laboratory Experiments on Measurement Instrumentation

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***Abstract*—This paper presents a comprehensive approach to distance learning for electric and electronic measurement courses. The proposed approach integrates a traditional Learning Management System (LMS) with the remote access to real instrumentation located in different laboratories, without requiring specific software components on the client side. The advantages of using LMSs in distance learning of measurement-related topics are summarized describing some LMS characteristics. Then, the remote laboratory system relying on virtual instruments (VIs) developed in LabVIEW and its integration with an off-the-shelf LMS are described in a project financed by the Italian Ministry of Education and University.**

***Index Terms*—Didactics, Learning Management Systems (LMSs), measurement, remote laboratories.**

I. Introduction

E-LEARNING has been a topic of increasing interest in recent years. It is often perceived as a group effort, where content authors, instructional designers, multimedia technicians, teachers, trainers, database administrators, and people from other areas of expertise come together to serve a community of learners [1].

To simplify their joint work, a lot of software systems have been developed. They are generally referred to as Learning Management Systems (LMSs) and Learning Content Management Systems (LCMSs).

The primary objective of the LMS is to manage learners, keeping track of their progress and performance across all types of training activities. The LMS manages and allocates learning resources such as registration, classroom and instructor availability, instructional material fulfillment, and online learning delivery.

The LCMS usually includes an LMS and adds an authoring system providing an infrastructure that can be used to create, modify, and manage content for a wide range of learning to satisfy the needs of rapidly changing business requirements. The LCMS can retrieve detailed data on learner scores, question choices, and navigation habits and can use them to give content managers crucial information on the effectiveness of the content if combined with specific instructional strategies, delivery technologies, and learner preferences.

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These software systems also provide support for interaction between learning space participants, a mechanism to deliver course materials over the Web, administrative components to allow instructor tracking of student records and monitoring their progress, and collaborative components like bulletin board, chat, e-mail, etc. [1].

Most existing Web-based learning environments are based on basic instruction models. Their main functionalities are centered on the management and distribution of learning materials, synchronous and asynchronous communication, and progress tracking and reporting. Some of them address collaborative learning. However, the most part of such learning environments does not effectively support collaboration models used in modern working life [2].

One of the most interesting new teaching strategies in such a field is project-based learning (PBL) pedagogy [2], [3]. The approach provides teaching through the development of a project that involves the learners. The most relevant step in the learning process, in fact, especially in scientific and technological fields, is the application of acquired theoretical knowledge.

Basic and high instructions, as well as adult training, have been recognized to be at the center of the growth, innovation, and integration processes in democratic societies. In 2000, the European Union officially announced the mission of improving the education systems in Europe with the declaration of Lisbon. Two of the main objectives to realize such a mission are 1) giving to all citizens the same opportunities to improve his/her degree of instruction and 2) promoting the institution of a life-long learning system to update competences and to encourage new specializations of adults and to increase their capability of finding or changing their job. E-learning seems to be the best way to reach these objectives, as it removes the physical, geographical, and cultural barriers to education and enables learners to choose their own learning path and time.

However, huge practical training is absolutely essential to assure good knowledge transfer from teacher to students and to educate good professionals. Laboratory activity is an open challenge for online teaching applied to scientific domains.

The remote control of instrumentation and the execution of real experiments via the Internet are topics of interest for many researchers [4]–[10].

In particular, in teaching of electric and electronic measurement topics, from academic courses to continuous training in industry, learners should achieve an accurate practical experience by working in real conditions and on real instruments.

However, electric and electronic measurement laboratories (both public and private) are not widespread, due mainly to their costs, and this complicates the life-long learning of specialized technicians, especially in the field of process control, quality control, and testing engineering.

None of the above-quoted proposals of remote laboratories for electric and electronic measurement teaching includes the noticeable support that an LMS could give to learner-centric didiactic approaches. In particular, concerning the students, it is not possible to self-design their own learning process or carry out a collaborative or PBL. Concerning teachers, it is not possible to track the activities of students or carry out an interactive experiment in a virtual classroom.

In this paper, a distributed didactic platform based on an LMS is proposed to provide full courses of electric and electronic measurements including theory as well as practical experiments on real instrumentation. The proposed solution integrates the advantages provided by the off-the-shelf LMS, which is compliant with international standards for Web-based training, and a new approach for providing remote experiments on measurement instrumentation, based on the thin-client paradigm. The proposed approach relies on VIs developed in LabVIEW and ensures that the students access the instrumentation without downloading heavy plug-ins (software packages required for executing the VIs on the client side that need long download, powerful processors, or high memory capacity).

The work described in this paper has been carried out within the LADIRE project financed by the Italian Ministry of Education and University in the National Operating Programme (PON) 2000–2006 [11]. The project aims to realize a national measurement laboratory that will operatively provide the students of electric and electronic measurement courses with the access to remote measurement laboratories that deliver different didactic activities related to measurement experiments. The initial infrastructure is composed of the laboratories at the University of Sannio and at the University of Reggio Calabria "Mediterranea" under the patronage of the National Research Association on Electric and Electronic Measurement (GMEE) and the collaboration of about 20 Italian universities and some specialized instrumentation, e-learning, and publishing companies such as National Instruments, Tektronix, Agilent Technologies, Yokogawa, Keithley, Rockwell Automation, Didagroup, and Augusta Publishing.

Moreover, the work carried out until now has led to a second project, financed by the Italian Space Agency, aiming to design a distance learning system that uses satellite networks as the backbone, providing Web-based training to mobile as well as home/office learners located in all of Europe and North Africa [12].

This paper is organized as follows: Section II describes the main functions and the trends in the development of LMSs. Section III summarizes the most recent proposals realizing remote laboratories for didactic purposes. Section IV describes the overall architecture of the proposed platform and delivered functionalities, system architecture, and its hardware and software components. Section V illustrates the first evaluation of the proposed approach on real instruments.

II. LMSs

A general agreement seems to exist regarding roles played by people in a learning environment as well as regarding the core functionality of modern e-learning platforms [13]–[15]. The main players in these systems are the "learners" and the "authors"; others include trainers and administrators.

Authors (which may be teachers or instructional designers) create content, which is stored under the control of an LMS and typically in a database [14], [16]. Existing content can be updated, and it can also be exchanged with other systems. The LMS is managed by an administrator, and it interacts with a runtime environment that is addressed by learners, who in turn may be coached by a trainer. These three components of the e-learning system can be logically and physically distributed, i.e., installed on distinct machines in different sites, and provided by different vendors or content suppliers [13]. To make such a distribution feasible, standards such as the Aviation Industry Computer-Based Training Committee (AICC) [17] and the Instructional Management Systems (IMS) guidelines [18], the Sharable Content Object Reference Model (SCORM) [19], and the Learning Object Metadata (LOM) [15] specifications try to ensure plug-and-play compatibility and enable interoperability, accessibility, and reusability of Web-based learning content.

E-learning systems may be implemented in such a way that a customization of features and appearance to a particular learner's need is supported. Learners vary significantly in their prerequisites, abilities, goals for approaching a learning system, pace of learning, way of learning, and the time they are able to spend on learning. Thus, the target group of learners is typically very heterogeneous. A system is ideally able to provide and present content for all (or at least several of) these groups to be suitable, for example, for a student who wants to learn about database concepts or for a company employee who wants to become familiar with company-internal processes and their execution. To fulfill the needs of a flexible system, a learning platform has to meet a number of requirements, including the integration of a variety of materials, the potential deviation from predetermined sequences of actions, personalization, and adaptation, and the verifiability of work and accomplishments [13].

Content consumed by learners and created by authors is commonly handled, stored, and exchanged in units of learning objects (LOs). Basically, LOs are units of study, exercise, or practice that can be consumed in a single session, and they represent reusable granules that can be authored independently of the delivery medium and accessed dynamically, e.g., over the Web [16]. Ideally, LOs can be exchanged between different LMSs and plugged together to build classes that are intended to serve a particular purpose or goal.

LOs can be stored in a relational or an object-relational database and are typically broken down into a collection of attributes, some of which are mandatory and some of which are optional; a more concrete proposal appears in [16]. In a similar way, other information relevant to a learning system (e.g., learner personal data, learner profiles, course maps, LO sequencing or presentation information, and general user data) can be mapped to common database structures. This does not only make interoperability feasible but also allows for a process support inside an e-learning system that can interact with the underlying database appropriately [13]. Indeed, the area of e-learning consists of a multiplicity of complex activities that can be modeled as processes or workflows and can be attributed to and associated with the various components of a learning platform.

By using a workflow management system, for example, one can think of a college degree program that is fully supervised by an electronic system [13]. Currently, in Italy, there are some examples of universities providing college degree programs at distance that have been certified by the Ministry of Education and University, e.g., the "Guglielmo Marconi" University [20].

Much research has been focused on e-learning technologies, and many topics have been presented covering accessibility, interoperability, durability, and reusability of components [21]. A Web service-oriented framework also gives flexibility to the design of an LMS and hides the implementation complexity from programmers, thus speeding up the design process. Applying Web service technologies to a SCORM-compatible LMS simplifies the implementation and maintenance of the LMS and allows service consumers more choices in finding the service they require [21]. A deep review of a wide number of LMSs on the market can be found in [22], where a guide to choosing among their functionalities is also provided.

From the realization point of view, there are many e-learning products that are implemented using different platforms that are not compatible with each other. For example, distributed object systems such as Microsoft COM family and the Common Object Request Broker Architecture (CORBA) standard did not interoperate. Each platform presented numerous security and administration challenges when deployed over the Internet, and neither quite met the scalability expectations created by the Web. Web Services provide a standard means of communication among different software applications running on a variety of platforms and/or frameworks. Web services are designed as a reference architecture to promote interoperability end extensibility among these applications, as well as to allow them to be combined to perform more complex operations. In particular, [23] focuses on how to integrate Web services on the e-learning application domain.

One possible drawback of the virtual learning environments, such as those based on LMSs, is that they could be content centric. Many instructors simply move all their teaching materials to the system. The materials are presented uniformly to all learners regardless of their background, learning styles, and preferences.

Nowadays, the trend in education strategies goes in the direction of learner-centric learning. Learner-centric learning places the learner at its heart. Learners are expected to actively engage in the learning process to construct their own learning. Thus, they have more responsibility for their own learning. Instructors are still responsible for learners' learning, but they play the role of a "facilitator," who guides the learning process instead of being the sole information provider. Learner-centric learning will give learners a deeper and richer learning experience, as there is greater participation and involvement in learning [24].

Collaborative teaching techniques are a typical example of that kind of education strategy. PBL, for example, is a teaching/learning model that involves students in problem-solving tasks, allows students to actively build and manage their own learning, and results in student-built realistic deliverables. This approach is characterized by the following features: a project centered curriculum, largely autonomous students, authentic tasks, active learning, preponderant role of feedback, and development of generic skills. Projects are used as a teaching/learning method. Students work on concrete, close to real-world tasks and produce realistic products. The requirements and the learning outcomes also vary considerably.

Teachers carefully define the content of the project, its objectives, assessment, and support, among other things. The students work in a synchronized way [2].

Another drawback of typical virtual learning environments is the lack of practical experience on actual instrumentation. As e-learning environments have been originally developed for teaching of computer-science-related topics, their concept of PBL is related to software projects. Today, LMSs and LCMSs are widely used to teach every kind of topic; however, their practical experience on instrumentation is still mainly limited to simulations.

III. Remote Laboratories

To understand the measurement procedures and measurement system design, it is necessary to repeat the same experience of actual measurements of physical phenomena many times to make all learners able to operate measuring instrumentation [25]–[27].

Some drawbacks make it difficult to provide a complete set of updated workbenches to every learner. The most relevant are 1) the high cost of measurement equipment and, in general, of experimental laboratories in educational sites and industry; 2) the growing number of students and specialized technicians; 3) the reduced number of laboratory technical staff; and 4) the continuous evolution of involved measurement instrumentation, which makes it difficult and very expensive to keep technical staff up-to-date.

The potentiality of remote teaching for scientific disciplines [28], and in particular the use of the Internet as a channel to reach the students or workers at their homes, was soon recognized [29]–[31]. Therefore, currently, a lot of teaching material can be found as 1) Web-based lectures and seminars that are sometimes interactive, provided by hardware or software producers, and mainly directed to professionals that want to reduce the time to market for a new application [32]; 2) Web support to university courses, including slides of lectures and exercises [33], [34]; 3) simulation of actual experiments to be executed either remotely or on student's PC [35], [36]; and, more rarely, 4) remotely accessible laboratories, where the learners can access real instrumentation through a Web page [9], [10], [37]–[39].

As off-the-shelf LMSs are usually closed proprietary software systems that are often not customizable at all, the research carried out by scientists to provide teaching of electric and electronic measurement including experiments did not take into account the possibility of integrating remote laboratories and LMSs.

The focus of their activity, instead, was the development of the remote laboratory itself, eventually adding scheduling and user account management modules. The theoretical support to the experiences was provided by traditional classroom lectures or lecture notes delivered by Web sites from the realization point of view; the solutions found in the literature, except for [37], require that the software enabling the remote control of the instrumentation (called virtual instrument or VI) is developed almost from scratch in C, C++, and Java languages. When a standard communication structure is not used, the reusability and the interoperability of a VI are greatly limited to the specific laboratory application, and the expandability of the system is bound from the availability of skilled technicians who can develop new VIs to be included in that system. The project [38], following the research trend in [8], [9], and [40], reverses the problem, relying on the use of LabVIEW from National Instruments, which is a standard language for VI development for producing VIs and the software AppletView from Nacimiento for producing Java applets that constitute a remote interface of LabVIEW VIs. In such a way, it is possible to reuse the wide number of already developed VIs for integrating existing instrumentation in a remote laboratory without developing new software. Java applet ensures the compatibility of the laboratory with every operating system and does not oblige the student to download heavy plug-ins from the Internet. Moreover, most of the solutions found in the literature require the development of the accessory software applications enabling the sharing of the laboratory instrumentation, such as scheduling and security policy. The main limit of the new solution is the impossibility of developing learners' own VI.

Following the same approach found in the LMS-oriented research, in the last few years, a new trend started for ensuring the VI interoperability and reusability using eXtensible Markup Language (XML) and Simple Object Addressable Protocol (SOAP). The VIs are realized and could be accessed as Web services [8], [10]. The main advantage of these solutions is that they can be easily integrated in LOs for existing LMSs. However, in these cases, the language used to develop the VIs is C++ or J2EE; thus, the existing LabVIEW VIs cannot be reused.

IV. Integrating the Laboratory and the LMS

This paper proposes a new distance learning environment to teach electric and electronic measurement that integrates an off-the-shelf LMS and a geographically distributed laboratory. The next sections describe the main services provided, focusing on the distributed laboratory accessed through the LMS. In particular, it will describe the distributed system, its architecture and innovative functions, as well as its integration with the LMS.

A. Delivered Services

The developed distance learning environment delivers the typical functionalities of a common LMS described above,

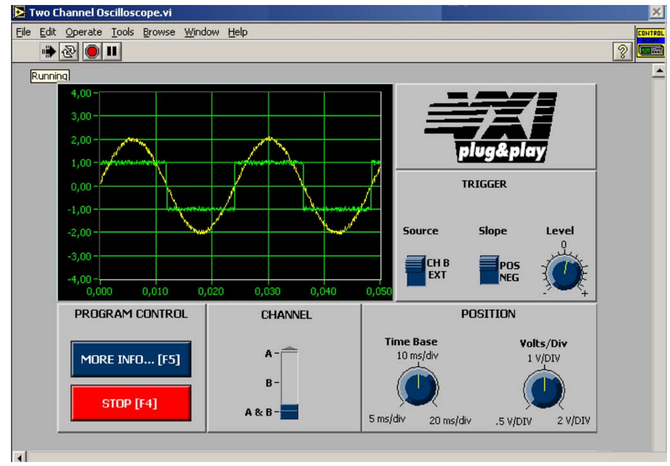

Fig. 1. Synchronous virtual laboratory/experiment visualization.

including user authentication and management and tracking of learning process at the user level. Moreover, it provides several innovative functionalities, encapsulating in specific LOs the remote control of measurement instrumentation. This objective has been achieved by developing an additive module for the LMS Inform@ from Didagroup [41]. The module ensures the integration of VIs written in LabVIEW in the LMS as LOs to enable remote users to get control of a measurement instrument transparently and to display the measurement results within the normal learning activities. Therefore, the students' activities are tracked at the LO level.

The remote laboratory is distributed on a geographical scale since the measurement instruments are located physically in laboratories belonging to different universities. At the moment, two laboratories are involved: One is located at the University of Sannio in Benevento, and the other is located at the "Mediterranea" University of Reggio Calabria. The access requests to the measurement instruments are handled by a scheduling system that connects, through specific policies, the user to a specific physical laboratory in which the required measurement instruments are available.

Different users' profiles are managed by the system: "student," "teacher," and "administrator."

The main services delivered by the remote measurement laboratory module to the student are the following:

1) Synchronous Virtual Laboratory: This service allows the student to follow online a laboratory activity held by the teacher of the course. The student obtains the display on his/her computer of the server desktop used by the teacher to control the measurement instruments involved in the experiment. The experiment is carried out on the front panel of a LabVIEW VI, controlling all the involved instrumentation. In Fig. 1, the control panel of a VXI oscilloscope is connected to the Measurement Server (MS) by means of an MXI-2 interface card.
2) Experiment Visualization: This service allows the student to observe the automatic execution of an experiment and to acquire an accurate knowledge concerning the operations and the possible results (see Fig. 1).

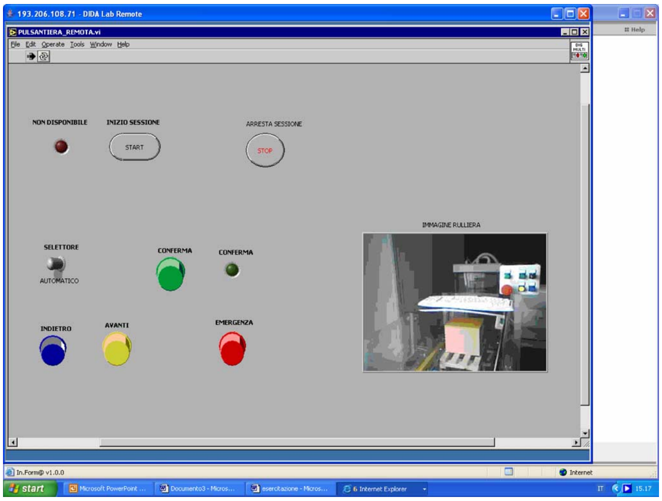

Fig. 2. Experiment control.

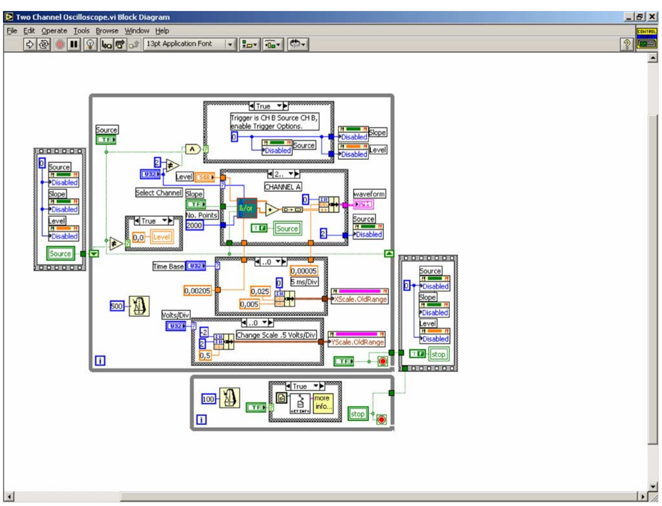

Fig. 3. Experiment creation.

3) Experiment Control: This service allows the student to perform an experiment controlling remotely one or more instruments and observing them by means of a camera. The student can choose a specific experiment in a set of predefined ones, and he can run it only if the required measurement instruments are currently available (see Fig. 2).
4) Experiment Creation: This service allows the student to create remotely an experiment interacting directly with specialized software executed on the servers used to control the measurement instruments. This feature enables the adoption of PBL as a didactic model. Under the supervision of the teacher, the students can develop a specific project producing, in an individual or collaborative manner, a VI to control a set of real instruments (see Fig. 3).

The services delivered to a teacher are related to the remote handling of the available experiments: remote creation, updating, and removal of experiments. Currently, the experiments are created as VIs realized by the teacher or the tutor. The setup of an experiment is the same as if it is carried out locally. The instruments should be connected to the circuit or device under test, and the VI has only to be copied in a specific directory in the PC used as a control unit called MS. Also, if the hardware setup has to be carried out in the laboratory, the VI can be produced in the teacher's workplace and then transferred to the MS by means of the above-quoted services.

Finally, the administrator is responsible for the correct operation of the overall distributed system and for handling the user profiles.

B. *Architecture of the Distributed Laboratory*

To allow a student to access a remote and geographically distributed didactic laboratory, this paper proposes a Web-based multitier distributed architecture centered on the LMS that can be considered as the core component of the overall system.

The module designed to manage the remote laboratory is based on a scheduling system that manages the catalog of available measurement instrumentation and redirects the user request to the measurement laboratory, which is chosen among the partner laboratories, in which is the required instrument is currently available. Moreover, it enables the requestor to gain control of a measurement instrument by the LabVIEW software environment without requiring that it be installed on the client side (Figs. 4 and 5).

The proposed multitier architecture is composed of three tiers.

1) "The presentation tier" manages the Experiment Visualization on the client side. It is based on standard Web browsers, with no need for specific software components (no specific operating system is required). The only software component needed is the Java 2 Runtime Environment, which is used to employ the Java Applet technology for experiment access and control from the client machine.
2) "The middle tier" manages the system logic on the server side. It includes the following components.
   a) The LMS is executed on a central server of the overall e-learning environment, called "Laboratory Portal." The LMS interfaces to the users through a Web Server that is hosted on the same machine.
   b) A Laboratory Server (LS) is used to interface a laboratory with the rest of the distributed architecture. There is an LS for each measurement laboratory of the universities involved in the project. It delivers access and control to the measurement equipment through a service called "Bridge Service." Moreover, the LS is the only machine in a laboratory directly accessible from the Internet, while the other servers are connected in a private local network. For this reason, the LS can also be used for security purposes to monitor access to the measurement laboratory and to protect it against malicious accesses.
   c) An MS is a PC enabling the interaction with one or more instruments. The MS is physically connected to a set of different programmable instruments through an interface card. Currently, the General-Purpose Interface Bus (GPIB) interface is used for all the MSs, while one of them also includes an MXI-2 interface

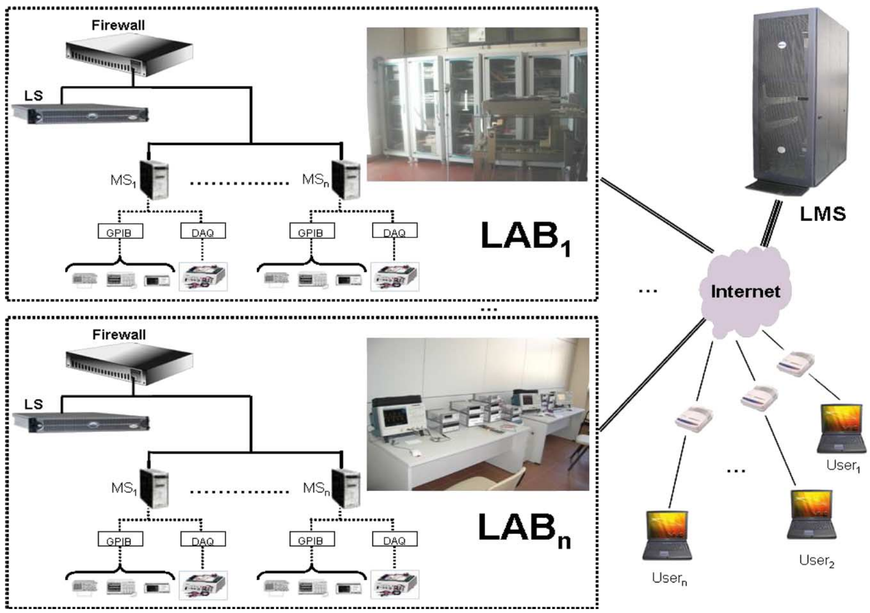

Fig. 4. Hardware components of the proposed architecture.

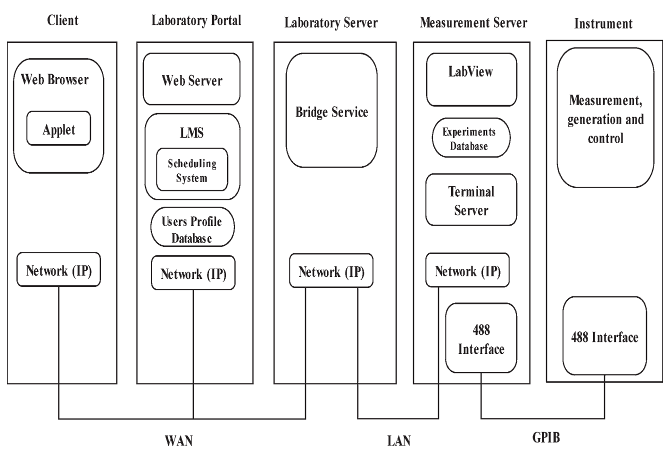

Fig. 5. Software layers of the components of the laboratory architecture.

for connecting VXI instrumentation. The connection with the circuit or the device under test is assured by the instruments or by means of a data acquisition (DAQ) board (see Fig. 4). The used VIs are stored in a database of the MS, where the LabVIEW environment is installed. No adjustment is necessary to include a VI in the virtual learning environment; therefore, the wide number of existing VIs can be reused without requiring additive work.

3) "The storage tier" performs the data management related, for example, to the user profiles and the distributed management of the data related to the available experiments at different measurement laboratories. It is based on a series of geographically distributed databases, managed using the Relational Database Management System (RDBMS).

To overcome the well-known security weakness of Microsoft-based networks, each laboratory is protected by a Linux-based gateway machine that operates firewalling and Network Address Translation (NAT).

C. Remote Access to the VIs

One of the most relevant problems in designing the laboratory subsystem is remote access to the experiment.

The main design objectives taken into account to provide the remote access to the VIs were the following.

1) Portability: The visualization environment has to be portable on different hardware platforms and operating systems.
2) Usability and accessibility: The visualization and management of an experiment have to be easy to understand and to perform, even for users that are not expert information technologists, and the system features have to be accessed easily and homogeneously by students operating at university laboratories or at home.
3) Maintenance: The maintenance costs should be reduced to the minimum. This can be made through a client–server approach that eliminates the need for installing and upgrading application code and data on client computers.
4) Client-side common technologies: Students have access to the system using their desktop computers based on common hardware and software technologies, with no need for powerful processors or high memory capacity, and connecting to the Internet through low-speed dial-up connections.
5) Security: The remote access of the students through the Internet must preserve the integrity of recorded and transmitted data and of the system as a whole.
6) Scalability: System performance must not degrade with the growing number of connected users.

To achieve these objectives, the thin-client model, instead of the classic client–server one, has been chosen. The student obtains on his/her computer the display of the application executed on the MS and used to control the instrumentation for the requested experiment. Moreover, it has been chosen to use the Web and Java technologies. These technologies, in fact, can be opportunely used to allow a student, using exclusively a common Web browser with a Java Virtual Machine, the remote visualization and control of an experiment, ensuring high system portability and usability and the fulfillment of the other objectives described above.

A "thin-client model" is based on a distributed computing paradigm in which the network separates the presentation of the user interface from the application logic. It is a client–server architecture in which the application execution and data management is performed on the server, called "Terminal Server." The user interacts with a lightweight client, called "Presentation Client," that is generally responsible only for handling user input and output, such as sending user input back to the server and receiving screen display updates over a network connection. As a result, the client generally does not need many resources and can have a simple configuration, reducing support and maintenance costs. By using thin-client technologies, students are also able to use limited hardware devices: the so-called "thin-client devices" [43] equipped only with a processor and a Flash memory (no hard disk or other storage units) such as personal data assistant (PDAs), handheld devices, and mobile phones. This solution extends the class of possible learners to mobile users, owning a smart phone, a PDA, or a notebook with a modem or a wireless LAN adapter.

The thin-client paradigm allows the platform to visualize and control a remote device through the interaction flow among the distributed system components described in the following.

1) The student executes the authentication phase on the LMS using a login and a password, interacting with the Web Server used by the LMS.
2) The student chooses a service (i.e., Synchronous Virtual Laboratory, Experiment Visualization, Experiment Control, or Experiment Creation).
3) The student visualizes on his/her desktop the VI front panel on the MS to which he/she is connected.

If the chosen service is the Synchronous Virtual Laboratory

1) the student is connected to the LS where the teacher is performing the experiment;
2) the Bridge Service of the LS finds the MS that is currently used by the teacher and allows the student to connect to the related Terminal Server to visualize the experiment on his/her own computer.

If the chosen service is the Experiment Visualization, Experiment Control, or Experiment Creation

1) the student chooses an experiment among a list of available ones;
2) on the basis of the required experiment, the student is connected to an LS of a partner university, which is equipped with the required measurement instrumentation available for the deployment of the experiment, chosen by the scheduling system of the LMS;
3) the Bridge Service of the LS finds the MS that is connected to the required measurement instruments and allows the student to connect themselves to the related Terminal Server to visualize, manage, or develop a new VI from his/her own computer.

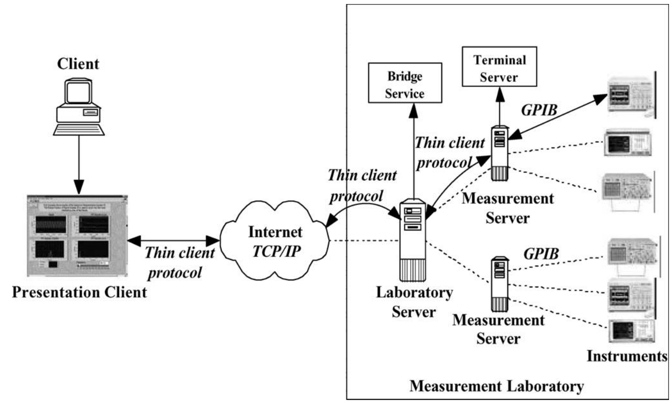

Fig. 6. Remote visualization interactions.

It is worth noting that in the Experiment Creation phase, once a project has been assigned to a student, the involved instrumentation is already known. The main difference between the Experiment Control and the Experiment Creation is that the student only has access to a VI front panel or to the whole LabVIEW development environment on the MS.

To allow a client to access the system without the need of preinstalled software, a Remote Desktop Protocol (RDP) client has been used, allowing the MS desktop to be visualized on the client side using a standard Web browser. In particular, on the client side, the Terminal Server Advanced Client (TSAC) released by Microsoft, which is a Win32-based ActiveX control, can be used to run Terminal Services sessions within Microsoft Internet Explorer.

However, the fulfillment of the main goals of the experimental section of the LMS for measurement teaching required the design and implementation of a specific client compliant with Microsoft RDP. A specific important goal is that the student, after the authentication phase on the LMS platform, has to obtain the remote visualization and control of the required experiment executed in the LabVIEW environment on the appropriate MS through the Bridge Service component of the respective LS (see Fig. 6). Moreover, to avoid malicious attacks on the system, the student has to obtain the remote visualization of the VI front panel without the privilege of a full user account on the MS, which is, instead, necessary to exploit the functionalities of the Terminal Server executed on that machine.

This result has been achieved through the insertion, made by means of the Bridge Service component, of a valid username and password in the connection request made by the RDP client.

Because of the legacy nature of the TSAC, it is not suited to modify at runtime the RDP connection request to insert the valid username and password. A specific RDP client that uses the Java Applet technology has been developed for this reason. In this way, it is possible to exploit all the advantages of the Java language that are particularly suitable for programming in distributed and heterogeneous computing environments. In particular, its direct support to many programming aspects such as multithreading, code mobility, and security has been considered very useful.

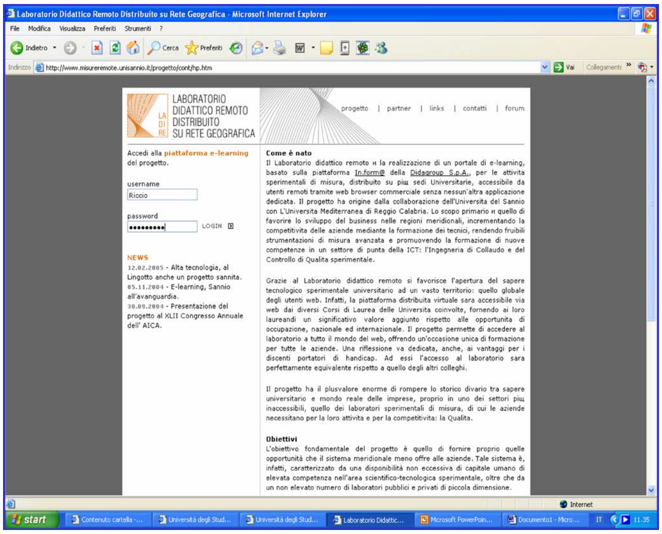

Fig. 7. Web portal realized to enable the authoring of didactic content from other universities.

The applet permits the connection and the automatic authentication on the Terminal Server of the chosen MS. Some of the features of the developed RDP client, called Laboratory Applet, are

- "compression" of transmitted data to minimize the network traffic;
- choice of the "cache dimension" on the client side (not available for TSAC client that limits the cache dimension to 10 MB);
- choice of "load-balancing" option: the possibility to use a load-balancing solution for Terminal Server based on server farms so that the client can be connected to the least loaded available server, in terms of bandwidth occupation, number of opened sessions, CPU load, and memory occupation.

V. First Results

The proposed learning environment, called LADIRE [43], has been realized in its software components and is currently being deployed at the Laboratory of Signal Processing and Measurement Information (LESIM), University of Sannio [35]. Referring to the architecture described in Section IV-B, LADIRE has been realized with one LS, one firewall/NAT, ten MSs, and 40 measurement instruments going from simple Agilent 6.5 digit multimeters to the most up-to date Tektronix TDS 7704 oscilloscope and LeCroy SDA 6000 serial data analyzer, including spectrum analyzers, impedance meters, power meters, signal generators, and power supplies. The enhanced LMS has also been installed on a Dell PowerEdge server, located in the same LESIM, and a Web portal [42] (see Fig. 7) has been realized to enable the authoring of didactic contents from other universities.

The collaboration of electric and electronic measurement professors coming from about 20 Italian universities and the Italian Association of Electric and Electronic Measurement Researchers (AGMEE) is providing the didactic contents as well as several measurement experiments. Some others are currently being developed at the LESIM.

To evaluate the performance of the proposed approach for the remote control of the instrumentation, its capability of providing access to the remote laboratories by means of a common 56-kb/s dial-up connection has been asserted. Therefore, the RDP clients based on ActiveX and Java Applet technology have been used, measuring the bandwidth occupation of the client–server interactions during the remote execution of an experiment. Because thin-client platforms are designed and used very differently from traditional desktop systems, quantifying and measuring their performance effectively is a very difficult task [43]. Many determining factors, in fact, can influence a performance comparison. Some of these are the use of optional mechanisms of the thin-client protocol (such as persistent caching and compression for the RDP protocol), the application executed on the server, the network bandwidth, and the kind of traffic that shares the bandwidth segment, etc.

To carry out the performance evaluations for the project, a reference experiment has been used, i.e., the Spectrum Measurement VI provided as a LabVIEW example from National Instruments. It does not control any instrument; thus, the bandwidth measurement is independent from the programmer's efficiency and from the GIPB communication latencies.

The server configuration on which the Terminal Server is executed is one of the MSs already set up in the laboratory in Benevento; its characteristics are CPU Pentium IV at 2.80 GHz, 512 MB of RAM, and a Windows 2003 server. Its network bandwidth toward the Internet is currently about 768 kb/s. The client was located at the site of Didagroup in San Giorgio del Sannio: a town near Benevento. The configuration of the client is a CPU Pentium IV at 2.0 GHz, 256 MB of RAM, and Windows XP Professional. Its bandwidth toward the Internet is 56 kb/s.

Using the ActiveX-based client during the time interval in which the user performs some operations on the VI, the bandwidth is nearly entirely occupied. Outside these time intervals, due to the use of the compression and persistent caching mechanisms of the RDP protocol, the bandwidth occupation decreases up to about 5.6 kb/s. Using the developed Java RDP client, a similar performance has been achieved. This is made possible mainly by using the same persistent caching mechanism of the RDP and by opportunely changing the cache dimension on the client side. In particular, during the time intervals in which the user performs some actions on the VI, the bandwidth occupation is included between 32 and 56 kb/s. The other time, the bandwidth occupation decreases to about 5.2 kb/s. Relying on such bandwidth occupation, the hardware requirements on the client side are limited to a 56-kb/s modem. On the laboratory side, 768 kb/s is enough to manage ten different experiments that are contemporarily active in the Experiment Control or Experiment Creation modes. As the LMS already supports multicast communication, the laboratory bandwidth is not a problem in the Experiment Visualization mode.

Ongoing activities focus on the experimental assertion of the robustness of the scheduling system when many VIs are being executed contemporarily, and a long request queue should be managed. Moreover, a deep analysis of the security of the proposed thin-client model is being carried out.

VI. Conclusion

This paper presented a distance learning system to teach electric and electronic measurement. The theoretical parts of the courses are provided by a standard LMS, enabling 1) account management, 2) security protection, 3) collaborative learning, 4) student activity tracking, and 5) feedback collection. The experiments on actual instrumentation are supported by a distributed laboratory system including remotely accessible instrumentation. The experiments are managed by the students at home using just a Web browser. The remote visualization of the experiments is going to be improved by means of video cameras and low-bandwidth video streaming technologies. The project, started in 2003, is going on with the collaboration of several Italian universities to be certified by the Italian Ministry of Education and University.

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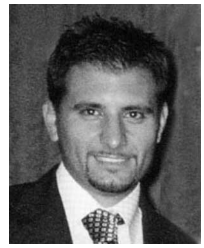

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