

CONCEPTUAL ARCHITECTURE FOR A VIRTUAL DISTRIBUTED INTERNET LABORATORY IN ENGINEERING FIELD

Alexandru TRANDABAT¹, Marius PISLARU², Codrin DONCIU³, Stefan HANGANU⁴

"Gh. Asachi" Technical University of Iasi

Bd. Dimitrie Mangeron nr.53, RO-70050 Iasi

¹⁾ *ftranda@ee.tuiasi.ro*, ²⁾ *mpislaru@ee.tuiasi.ro*, ³⁾ *cdonciu@ee.tuiasi.ro*, ⁴⁾ *stefan.hanganu@conexgrup.ro*

Abstract. *This paper presents a conceptual architecture for the virtual instrumentation remote control over the Internet network. It is based on a multiple-layered structure that combines web services with client-server procedures. The system allows a high flexibility with respect to physical devices supported as network procedures but also as development efficiency. Moreover, due to highly modularized structure it can be easily expanded and integrated with commercially available development suites.*

Keywords: *Remote measurement, Internet, Instrumentation, computer networks, virtual laboratory.*

Introduction and motivations

Telecommunication providers are dedicating considerably efforts to the development of computer controlled test and measurement techniques. At physical layer, most networks use clusters of devices variously interconnected that cooperate in order to forward information signals. Such clusters are in practice physical racks, and often one or more slots of a rack can be dedicated to a measurement device. The aim is usually to continuously monitor network performances or the quality of transmitted signals. Nowadays, modern test systems available in the ICT industry as well as in research laboratories are again commonly organized as instrument clusters controlled by a host computer via suitable standardized interfaces. This operating scheme has considerable advantages especially in the organization of repeatable and well-designed test procedures, where for ISO certified factories it is mandatory to develop most of their test procedures in computer-controlled way. A natural, even though not trivial, extension to the computer controlled test system is represented by a remotely controlled test system. In this case the logical structure of a test system can be represented by a set of clusters, each composed by more devices or instruments, connected to

some communication network. An operator can control separately the devices of each remote cluster or more clusters simultaneously by sending commands, and by receiving the corresponding answers. One really interesting case of transport network is constituted by the Internet network. In fact, services can be designed where test applications could coexist with well-known general purpose network services in an integrated way. The final end-user can benefit from many other advantages including, indeed not limited to, the deep diffusion of the network at a reasonably low cost. At the present time well-accepted standards are available at the level of physical and logical neighbourhood between computers and instrumentation or devices, such as the well-known IEEE-488 standard, just to provide a simple example. Moreover, standards are available at the network side at many level of abstraction, from the physical level, up to the definition of rather high-level protocols such as TCP or HTTP. A skilled system designer or integrator can also advantageously exploit well accepted or quickly evolving tools for the delivery of end-user services. One simple example consists in the use of applet techniques associated to web services, even though more promising approaches based on JINI are currently under discussion. Besides, commercial

products originally designed for the control of physical devices and instruments through some computer interface, are now being expanded by manufacturers in order to add network-aware services. Despite the presence of all the previous available resources, still the organization of a complex application where multiple instruments or devices have to be controlled is not a trivial task. The designer has to cope with many different design aspects. For instance, a good design should take into account the possibility that instruments are substituted with the passing of time with more updated versions of themselves, or also that functionally identical devices could be used in a unified way, despite each could require different programming procedures. On the other side, access policies to devices have to be planned in a way that could depend on run-time considerations. Different procedures could simultaneously require the use of the same remote physical device, so that some time-sharing policy has to be assessed.

This paper presents architecture for a rapid prototyping of test and measurement applications in a networked environment. The main goals of the proposed system are its open architecture, the facility of integration with both existing development tools (Java and LabView), the compliance with both interface standards from the device's side, and network protocols at the Internet side. The described approach provides abstraction layers that allow the designer a unified view of devices in terms of easy interchangeable commands, which noticeably simplify programming issues. It also yields a simple yet effective separation between functional services that a networked system should provide. This logical separation considerably lowers the design efforts and hence provides a clearer approach both from the point of view of development and of maintenance of a remote test system. In the next section it is discussed the architecture of the proposed laboratory. Then, some meaningful examples will be considered.

The Architecture of the Virtual laboratory

A deep knowledge about computer network programming is required to develop a remote laboratory from scratch. Such prerequisite could be a major constraint to both the teacher and the student, and hence could constitute a serious limit to the development of a number of experiments. To overcome this problem, the authors have firstly tried to define a simple though flexible communication protocol between client and server computers and then have developed a set of programs and libraries that are intended to help other teachers in the organization of a remote experiment; therefore they will no longer be required to tackle with network programming issues. By using these programs that constitute a "service layer", the teacher can concentrate the attention strictly on the organization of the standard computer-controlled laboratory experiment. The topology of the distributed measurement laboratory developed in this work is schematically represented in the Fig.1.

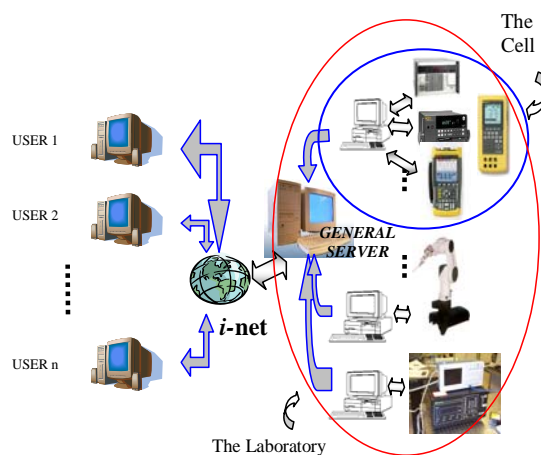


Figure 1. Laboratory

The laboratory (Fig.1) can be composed from any number of "test stations" each controlled by a server computer. The server is connected at one side to a network, and on the other side it interacts with programmable instruments. The instruments are permanently connected to one or more Devices Under Test by means of a switch matrix, not shown in the figure for the sake of clearness. The "client side"(Fig. 2) of the laboratory is composed of several workstations

installed at the same laboratory location. Such workstations are connected to the same computer network of the laboratory and provide the programs used by the students. During a classroom guided exercise, the students use pre-arranged programs that interact with the instrumentation to highlight the lesson topic. The students can freely choose an application and a test station to work with. If more student groups decide to use the same test station, the server programs which control the instruments grant the remote access to the device under control in time-sharing fashion with suitable priority policies. The local computer network of the laboratory can be connected to other computer networks, in particular to the Internet one, by means of an optional firewall computer. In this case, other external workstations may access the instruments and device under control controlled by the laboratory server computers by exchanging information with the General Server. In this way, the students can use the laboratory devices without reaching the university location, for instance from their home.

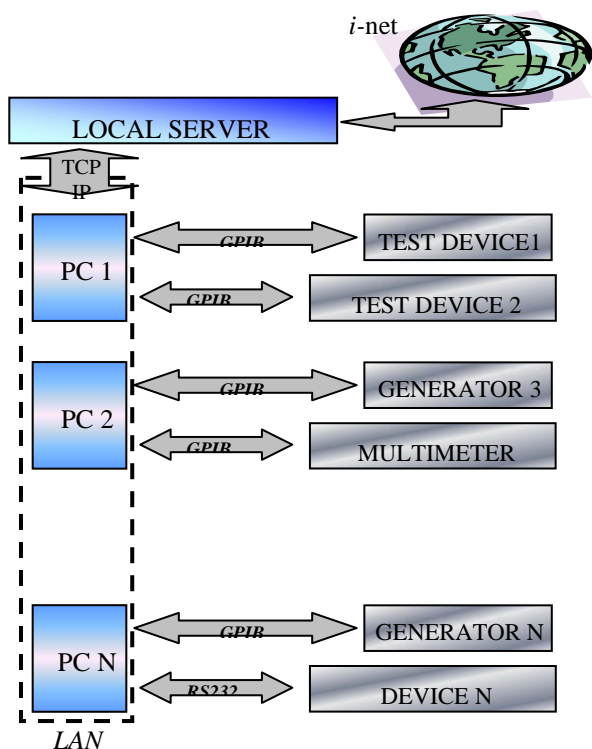


Figure 2. Internal Laboratory Structure

The General Server is responsible for applying proper user authentication procedures and for hiding the IP addresses of SVR and WS computers to the rest of the network. Several advantages are obtained by employing this configuration. First of all valuable and expensive instrumentation can be shared between many users. This allows the development of laboratory experiments even when many students attend the same course, without making overwhelming money investments. The availability of remote test stations that can be used from any far location allows the students to best tailor the number of laboratory hours to their effective needs. The laboratory can be left unattended, or unqualified personnel can be employed for laboratory surveillance. Hence, the teacher can better be involved in discussions with the students concerning the problems they have encountered in the development of the exercises, rather than in trivial supervision activities. The network topology supports a high flexibility in the definition of the number and on the kind of test stations. Moreover, the work computers and the server computers can also host hypertext web pages, which explain better the experiments available by connecting to that computer, and the procedures that they have to follow. This additional documentation can greatly decrease the time required by the students for carrying out the experiments. The system concept is based on user-server paradigm. The purpose is to allow the user to drive a test or an experiment to an instrument through Internet. Grosso modo, the system has four parts: the user interface, the server, the process computer (measurement server) which commands the instruments and the instruments. The users will work on a normal internet explorer where through the virtual instrumentation they can have access to one real instrument resource in order to effectuate a test or they can imagine and develop a process testing and in same time they have the visual information about the process running from a video-camera installed on every process stands.

Client

The user needs a computer with internet connection and a web browser. There are different possibilities in the transport layer: TCP, UDP, DataSocket,... The only application needed for the client is a web browser. To easily develop a client application it is mandatory to have simple tools to communicate through the network and to dialogue with the instruments. This role is accomplished by the Server side of the environment, so the client developer is free to concentrate on the peculiar characteristics of the measurement system she or he wants to prepare. In the Virtual laboratory environment a large number of modules have already been written to speed up the realization of clients. A Virtual Lab. Client has to solve the following tasks:

- it has to provide a suitable graphical interface that can effectively replace the front panels of the physical instruments;
- it has to send commands to the Virtual Laboratory Server (General Server), being careful to maintain sequential order in requests when necessary;
- it has to be able to post-process received data in order to obtain a correct presentation of the results. A client can be written with any programming language that supports TCP communication.

Laboratory server

A general server has to manage the queries from the clients, redirecting them to the correct local laboratory server. Two cases have been foreseen for remote teaching and education. In the first case, a professor can teach in the same time all the students connected to the local server from all partner countries. In order to obtain such a pursuit, the local server has to be set to all users slave mode. This way, the students from their home study points can receive and follow the lessons on a common web page. Due to the web publication, the number of students that can connect to the system at the same time is unlimited.

In the second case, the students should carry out some research activity based on the instruments. In this case, the local server has to be set to all

users master mode. Of course, the number of students that can establish the connection at the same time is less or equal to the number of operational measurement stations within the two distributed laboratories. As each student can perform a connection via modem/provider from his/her home, he/she is able to practice his/her programs on the connected instruments without regarding the source or country where the instruments are located. From the main web page of the local laboratory server, the teacher has the possibility to supervise the student's research activity. By the same approach, a supervisor can survey and/or put together the results consequent to a dedicated research.

A laboratory server is needed in each laboratory. It consists in a computer with a web server, a data base and management applications. The laboratory needs to know the equipment, instruments, setups, users, therefore a resource manager is the main application needed. It checks the measurement servers connected to the laboratory, and gets from them the data about instruments and setups available in each measurement server. The manager needs to know the users authorized to enter the laboratory. All the documentation needed for the laboratory should be available through the web server: instrument manuals, examples or practice guides.

Process computer

The rapid development of new instrumentation, test procedures and software tools implies that a networked test system has to be continuously updated in order to reflect the changes in current technology or in the whole system to be monitored. Furthermore, instrumentation is sometimes rather expensive. Hence some instruments should be shared in order to save and optimize money investments. This means that at a same location various instruments can be placed, all organized in different benches. The benches can be used both in order to perform different measurement tests or also the same test but with different instruments for comparison. Due to the possible large variety of

computer controlled experiments there is needed a method that allows the management of the instruments set-up and software programs. The management procedure should not affect the need of flexibility in the usage of resources, because of the sharing of laboratory instruments. Hereby, the process computer is the computer that joins the instrument with the virtual laboratory. There may be multiple measurement servers. Each measurement server must have information about instruments and setups available for measuring. This information of all the measurement servers will be transmitted to the laboratory server to obtain the virtual laboratory capabilities. Once checked and authorized the user access by the laboratory server, it transfers the user control to the measurement server. Proceeding in this way, the lab server is released so all measurement transactions travel directly from the measurement server to the user. The measurement server provides the users with a graphical interface to control the instruments or the setup for the different measurements. The results can be offered in a graphical or numerical way, so the user can save the results in the desired way. The interface with the instrument will be based on standard drivers and connections. The instrument driver may be Plug&Play or any other, and the interface bus driver can be for instance GPIB, which must comply with VISA or be easily configurable.

Instrument

The first aspect that should be taken into account consists in how to manage the various instruments to obtain an efficient use of both instruments and computers. In fact, in a modern laboratory many instruments can coexist. They can be simply different models in a same family or they can have a completely different structure and functionality. For instance, stand alone traditional instruments such as Digital MultiMeters (DMM's) from different vendors can be used together with rack mounted instrumentation (VXI, PXI, etc.). Moreover, one can prefer the use of Analog to Digital (A/D) or Digital to Analog (D/A) expansion boards

mounted inside a computer. Besides the choice of instruments one should also deal with a number of different and well-standardized options for the connection between instruments and a host computer. The protocols provided by IEEE-488, EIA RS-232, CAMAC, VXI and Ethernet link are just a few well-known examples of such options. These interface standards are similar from a very high-level point of view. In fact, they all offer an end user basic operation such as 'send' and 'receive' of data or commands. Unfortunately, they often implement such operation in a subtly different way so that user-developed software is seldom easily portable from one interface set-up to another one.

The instrument includes the signal routing block. This block is very important in order to provide a single instrument with multiple devices for making measurements. The test signal must be routed to the right device, and the output signal must reach the measuring instrument through the adequate routing.

Examples of laboratory tests

Different programs may be made available to the students, depending on the actual need of courses. Moreover different remote devices can be remotely controlled by means of simple plug-in modules that can be easily added at the server side in run-time. For a theoretical point of view any equipment which can offer an electronic interface toward a computer can be controlled in the above system; it suffices to write down the code for a suitable driver. Such a code fragments are reasonably simple and basically have to translate a function at the server side in the corresponding operating system toward the actual device interface. At the present time the driver for any measurement instruments provided with serial and IEEE-488 standard interfaces are supplied. For the sake of simplicity some case study are presented in the following in order to let the reader understand the capabilities of the whole system. The simplest example is just constituted by client applications which present a replica of the front panel of one or more instruments physically

connected to the test stations. The students can interact with the remote instruments by means of the graphical interface provided by the programs. They can easily change the instrument configuration and observe the corresponding effect. Such programs are designed to prevent the user from using improper set-up conditions, so that the students can quickly learn the correct use of complex instrumentation. Fig.3 shows the front panel of three client programs of this type. Programs 1 is designed to remotely control a Signal Generator,

Program 2 controls a signal acquisition board connected to a suitable demo test circuits and Program 3 is a Function Generator.

It is also important to remind that the execution speed of the client application is comparable with that of a direct interaction with the instrumentation, provided that the physical network is sufficiently fast. Besides, the development of a Laboratory Client requires more or less the same time required to build an application for a direct dialogue with the instrumentation through a computer interface.

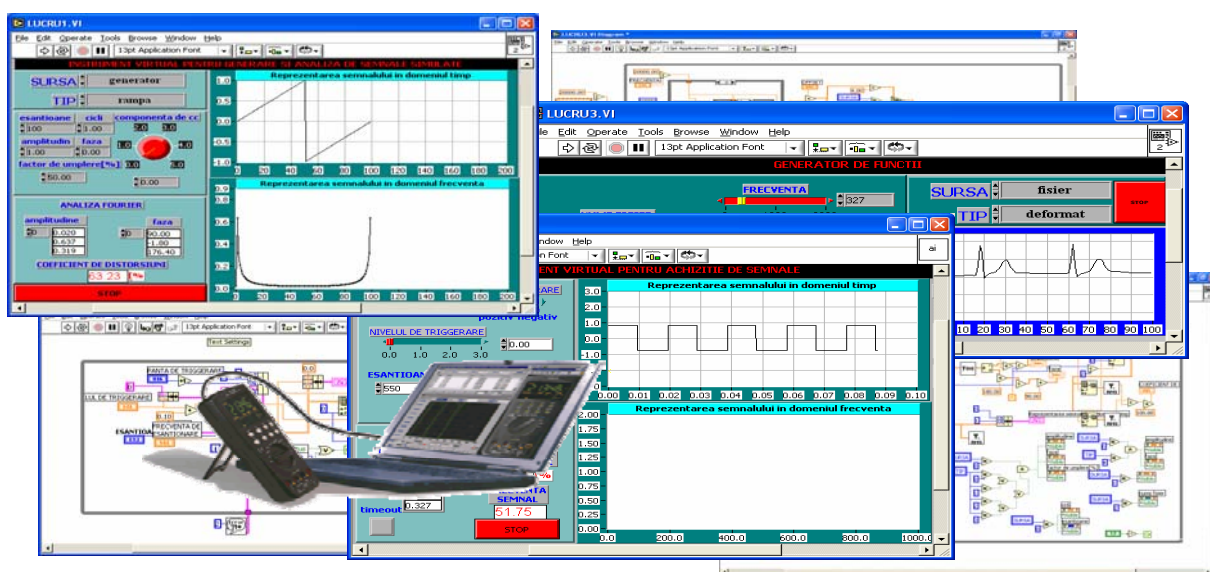


Figure 3. Instrument Front Panel

Educational laboratory and project survey, by use of proposed environment and virtual instrumentation

The low-cost availability of new communication tools based on Internet is opening more and more horizons to remote teaching. Interactive on-line tutorials based on World Wide Web (WWW) sites now can be followed directly on the job sites.

The recent wide diffusion of (i) easy-to-use software tools for the implementation of Graphical User Interfaces (GUIs); and (ii) communication-oriented instrumentation, often provided with Ethernet interface, in addition to the more traditional GPIB and RS-232 ones, can be particularly exploited in the field of control

and management teaching. It is well known, in fact, that for a better understanding of the teaching issues in such an interdisciplinary field, the students have to practice with real instrumentation. Hence, the computer-based simulations are often inadequate to assure a good experience in that direction.

The tools mentioned above give the possibility of accessing real measurement instrumentation from a remote location, such as the students' homes. Moreover, it could be possible to repeat the same experience many times in order to make all students able to operate the measuring instrumentation without devoting expert technicians to such activity for many days, or to work subsequent to different parts of a distributed project.

The researcher's orientation nowadays is to develop the remote measurement systems by using Java language, due to the main advantages of such an approach, which are: (i) the operating system independence of the resulting software, (ii) the easy distribution of instrument GUIs through Internet browsers without heavy band requirements. The main drawback remains, nevertheless, the necessity of developing the software without using ready libraries or virtual instrumentation, in order to obtain rapid oriented environments. In other words, time consumption still remains a disadvantage. A less flexible, but much more rapid solution consists in setting up the remote laboratory system by using a development tool oriented to the virtual instrumentation design with a built-in remote communication mechanism. The National Instruments LabVIEW could be used for this purpose, as it is a powerful graphic environment for instrument management towards driving real and virtual instruments. In fact, a Virtual Instrument, such as a Graphical User Interface (GUI) for a IEEE 488 can be easily built just connecting graphical blocks that are made available from the environment.

Complementarily, a user-friendly GUI to the instruments can be developed visually in a straightforward way. As quoted above, the proposed virtual laboratory - educational system is composed by communication sets of distributed groups of two stations. The first one is based on several measurement instruments, such as signal generators and digital oscilloscopes as shown in Figure 4. Each couple of instruments is controlled via the GPIB by nine computers (PC1...PC9), while a local server interfaces the system to the Internet. All the measurement stations are linked to the local server by means of an Ethernet LAN.

The second station is focused e.g. on environmental measurement. In this case, the computers are connected via data acquisition boards to several environmental distributed sensors or via GPIB to dedicated environmental measurement instruments. By this way, the students are able to perform the evaluation of air, water and soil parameters such as humidity, temperature, air pollution (CO, CO₂, NO₂

NO₃), pH, dissolved oxygen, salinity, ion selective (Ca, Mg, Na, Cl, SO, K, F) and electric conductivity.

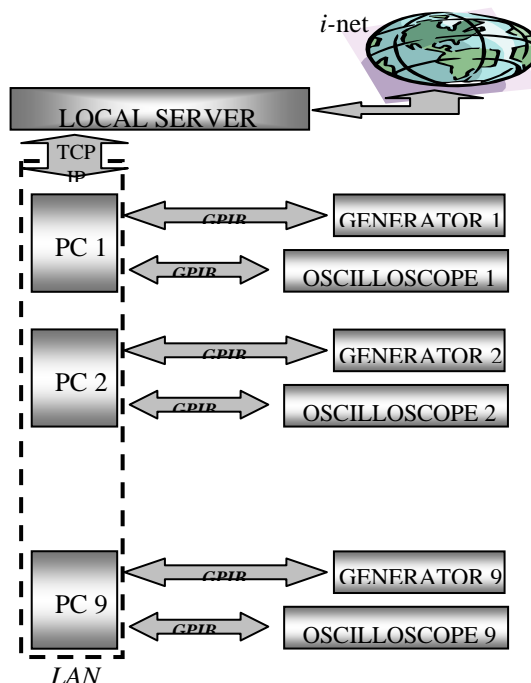


Figure 4. First station architecture

A general server has to manage the queries from the clients, redirecting them to the correct local laboratory server. Two cases have been foreseen for remote teaching and education. In the first case, a professor can teach in the same time all the students connected to the local server from all partner countries. In order to obtain such a pursuit, the local server has to be set to all users slave mode. By this way, the students from their home study points can receive and follow the lessons, see Figure 5, on a common web page.

Thanking to the web publication, the number of students that can connect to the system at the same time is unlimited.

In the second case, the students should carry out some research activity based on the instruments. In this case, the local server has to be set to all users master mode. Of course, the numbers of students that can establish the connection at the same time is less or equal to the number of operational measurement stations within the two distributed laboratories. As each student can perform a connection via modem/provider from his/her home, he/she is able to practice his/her programs on the connected instruments without

regarding the source or country where the instruments are located. From the main web page of the local laboratory server, the teacher has the possibility to supervise the student's research activity. By the same approach, a supervisor can survey and/or put together the results consequent to a dedicated research. An example of the front panel of a remote application is briefly presented in Figure 6.

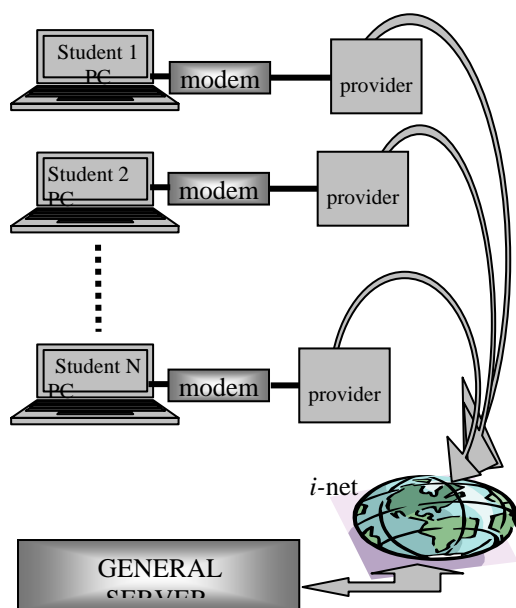


Figure 5. User connections

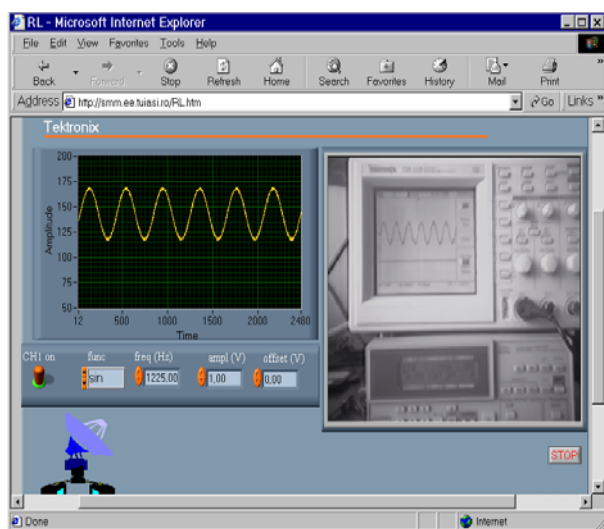


Figure 6. Example of application under Internet Explorer

Conclusion

The usage of internet-based tools as a support to traditional laboratory experiences can significantly improve the learning curve of students. Moreover an internet based distributed laboratory considerably lower the costs since expensive equipment can be more efficiently shared between more courses for teaching purposes.

References

- [1] P. Arpaia, A. Baccigalupi, F. Cennamo, P. Daponte, "A distributed measurement laboratory on geographic network", Proc. of 8th IMEKO Int. Symp. on New Measurement and Calibration Methods of Electrical Quantities and Instruments, Budapest, Hungary, Sept. 1996, pp. 294-297
- [2] P. Arpaia, F. Cennamo, P. Daponte, M. Savastano, "A distributed laboratory based on object-oriented systems", Measurement, vol. 19, No. 3/4, Nov.-Dec. 1996, pp. 207-215.
- [3] M. Bertocco, M. Parvis, "Platform independent architecture for distributed measurement systems", Proc. of IEEE IMTC 2000, Baltimore, USA, May, 2000, vol. 2, pp. 648-651
- [4] Hesselink, L, Rizal, D, Bjornson, E, "CyberLab, A New Paradigm in Distance Learning", Stanford University, 2000
- [5] Carlson, L, "Using LabVIEW to Reform Engineering Education", National Instruments Corporation, 1996
- [6] Gillet, D, Salzmann, C, Gorrochategui, E, "Remote Manipulation with LabVIEW for Educational Purposes" Swiss Federal Institute of Technology - Lausanne (EPFL), Switzerland, 2000