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Aspects of Traditional versus Virtual Laboratory for Education in Instrumentation and Measurement

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Abstract – *Nowadays the multimedia tools have an important role in both the management of the lectures and the organization of the course program on instrumentation and measurement. In this new scenario the Virtual Laboratory (VL) represents the environment in which the learning activities are performed. Starting from this observation, in the paper an overview of the state of the art of the VL-based education on instrumentation and measurement is given. The fundamental aspects concerning both the software and the hardware to design the VL are examined. Attention it is also devoted to innovative requirements and interesting open questions arising from the large diffusion of the VLs.*

Keywords - *Virtual Laboratory, Virtual Instrument, Distributed Laboratory, Education.*

I. INTRODUCTION

What is the Virtual Laboratory (VL) and why is used in the education on instrumentation and measurement?

In the past, the traditional teaching activities in the field of the instrumentation and measurement at the Technical Universities were based on (i) the face-to-face lecture, (ii) the laboratory experiences, and (iii) the consulting with the teaching staff.

In order to understand the measurement procedures and measurement system design, it is necessary to repeat many times the same experience involving actual measurements of physical phenomena many times in order to make all learners able to operate the measuring instrumentation [1]-[3]. Some drawbacks make it difficult to provide a complete set of updated workbenches to each learner.

Nowadays, owing to the fast development of the software and the hardware technologies, several solutions are available to overcome these drawbacks, and, consequently, several changes have characterised the teaching activities [4]-[19]. The multimedia tools based on the newest software and hardware technologies play an important role in the management of the lectures and in the organization of the course programs [20]. They permit to introduce new and interesting arguments otherwise difficult to teach and to learn [21].

From the teacher point of view, other advantages, are: (i) to speed up the teaching, (ii) to analyze the problems in more deeply, and (iii) to made the arguments exhaustive.

As a consequence, the lecture lost the traditional organization and it is assuming new distinguishing marks. Moreover, the progress of the multimedia tools and the novelties available on the multimedia market cause the continuous upgrading of (i) the organization, (ii) the topics, (iii) the goals, (iv) the quality, and (v) the effectiveness of the lectures [22]-[26].

From the student point of view, several advantages, including also the pedagogical aspects, can be considered. The student is involved into new learning scenario that differs from the traditional one characterized by well-defined environments: the classroom and the laboratory. Nowadays, the VL represents the environment in which the learning activities can be performed on the basis of the individual requirements. It is assuming the functions of (i) the face-to-face lecture, (ii) the laboratory experiences, and (iii) the teaching staff consulting [27]-[30].

The potentiality of the technology for the remote teaching [31] and, in particular, the use of the internet as a channel to reach the students or workers at their homes was soon recognized [32]-[34]. Therefore, currently a lot of teaching material can be found as (i) web based lectures and seminars, sometimes interactive, provided by hardware or software producers, (ii) web support to university courses, including slides of lectures and exercises [35], [36], (iii) simulation of actual experiments to be executed either remotely or on student's PC [37], [38], and, more rarely, (iv) remotely accessible laboratories, where the learners can access real instrumentation through a web page [39]-[43].

Owing to the increasing importance that the VL is assuming the objectives of the paper are related to the increasing importance that the VL is assuming nowadays: (i) to provide an overview on the state of the art on the VL development, (ii) to discuss its advantages on the education activities, and (iii) to define the contest of new interesting problems to be solved. In particular, the fundamental aspects concerning both the software and hardware criteria to design the VL for education in instrumentation and measurement are examined. Successively, the aspects regarding the education activity in terms of (i) innovation, (ii) quality, and (iii) reality are discussed. At the end, an overview on the open and interesting questions related to such a topic is given. In particular, attention is devoted to (i) the innovative requirements for the VL development, and (ii) the aspects concerning the interoperability of the different VLs.

II. OVERVIEW ON THE VL FOR EDUCATION IN INSTRUMENTATION AND MEASUREMENT

By following the innovation in the software and in the hardware market, the VL has assumed different structures and has increased its complexity and versatility in the years. Initially the VL was based on Virtual Instrument (VI) only. The VI was able to control the single measurement instrument by means, in the most cases, of an IEEE 488 standard interface designed to permit the instrument control from different manufactures to be interfaced in the same way. A Graphical User Interface (GUI) permitted to achieve this aim in friendly way [7].

Successively, the availability of the local area networks and software innovations made possible to manage a set of measurement instruments [44]. Nowadays, the internet technology permits (i) to implement the VL over wide area networks, and (ii) to use the advantages of the web technology [43]-[48]. Consequently, the VL architecture can be based on (i) stand-alone VIs operating stand-alone as the fundamental components, and (ii) both the VI and the connecting network as components of a Distributed Virtual Laboratory (DVL).

There are basically two ideas to be considered when the VI is taken into account. The first is the possibility of controlling a real measurement instrument by a GUI more friendly. To achieve this aim the IEEE 488, the serial or the VXI interfaces can be used. In this way a set of different measurement instruments, co-operating among them, could be presented like a single, more sophisticated, instrument. In particular, (i) the Fig.1a shows the classical and original architecture of the VI, (ii) the Fig.1b shows the VI architecture to carry out complex measurement by using a number of instruments, and (iii) the Fig1c shows the VI architecture to carry out complex measurement by using a number of instruments and software procedures.

The second idea is to present a program simulating the real instrument's behaviour as a VI. Once again it is possible to use more than one algorithm to simulate complex measurements, and to present the final results as the results obtained from a single powered VI. By taking into consideration both ideas, it is possible to realize mixed systems, more sophisticated and more flexible, that provide two modules (i) one for the simulation of the experiment, and (ii) another to carry out the real measurement process. Another very interesting and important component that is widely used in measurement systems is the Digital Signal Processor (DSP). In accordance with the VI concept, it is possible to include the use of the DSP into the VI.

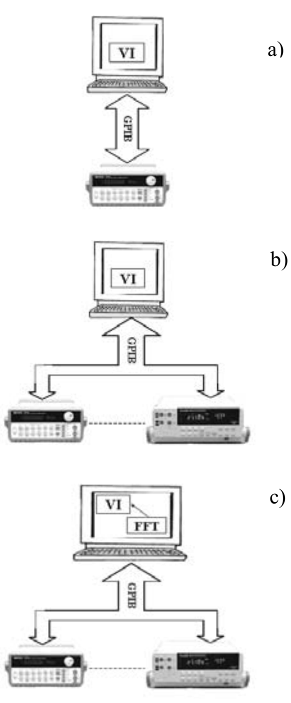

Fig. 1 Virtual instrument constituted by a) single instrument, b) set of instruments, and c) set of instruments and a software procedure.

The general architecture of the DVL is shown in Fig.2, where the student can access the laboratory by means of a remote client through internet.

There are many available networks designed to meet differing requirements of the measurement applications, (i.e. Profibus, DeviceNet, Inter-bus, Ethernet,). The Ethernet technology for restricted areas and internet for geographic area are very attractive and cost-effective

Even if the interaction between the student and the instruments take place through the network, the main idea is still valid: the student is supplied with a graphical interface that makes the instrumentation easier and friendlier. How the real measurement procedure takes place, what kind of instruments and algorithm are used and how the network communication is implemented can be made transparent to the student. Differently, the student can know how the DVL works if necessary from the education point of view.

As a consequence, the general concept and definition of the VL can be related to the presence of (i) the computer to connect the measurement instrument and to process the measurement results, (ii) the software to implement the distributed application and to display the measurement results in an easy manner, and (iii) the network connecting the VI and the users.

III. SOFTWARE ENVIRONMENT FOR VL

Two different approaches to develop the measurement software of the VL can be taken into account: the first one refers to the use of the commercially available integrated development systems, i.e. LabVIEW [49] and related software tools as Measurement Studio. The second approach, also used in the literature, is based on the Object-Oriented Programming (OOP) as using Java and related technologies [50]. By using both the approaches, the main aim of the VL can be achieved, but it is also true that both have advantages and disadvantages that should be considered before the architecture design.

In both these approaches the communication structure is highly important. When a standard communication structure is not used, the reusability and the interoperability of a VI is greatly limited to the specific laboratory application and the expandability of the system is bound from the availability of skilled technicians able in

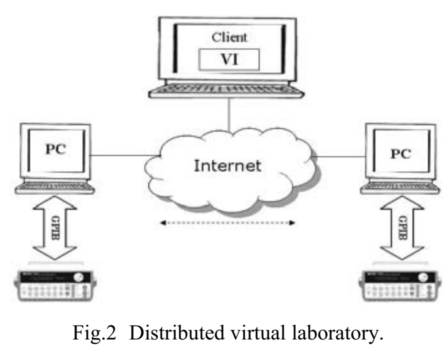

Fig.2 Distributed virtual laboratory.

developing new VIs to be included in the system.

In the case that the VL is part of distance learning platform, it is necessary that the GUI is integrated into the Learning Management System (LMS). The objective of the LMS is to manage the 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 fulfilment, and online learning delivery [42].

A. The LabVIEW based approach

LabVIEW is a powerful graphic environment for instrument management. It allows building visually a control procedure just connecting graphical blocks that are made available from the environment. The GUI can be developed visually in a similar straightforward way. LabVIEW generates code for each virtual instrument that is created. The code is not platform independent and can be executed only by the LabVIEW Execution System (ES) for the current platform. The generated code is subdivided into clumps that can be executed in a cooperative mode. When the operating system where the ES runs provides multithreading, the execution of the code can take full advantages of this [51].

There are two inconveniences to be highlighted in this approach. The first, as mentioned above, the generated code is not portable across different platforms (or better any change of platform requires regenerating the code). The second, to be able to execute the VI code the user needs the run-time environment, and therefore run-time license is required. This can be a problem when LabVIEW is used for teaching purposes in the university environment.

LabVIEW provides native network functionality that can be used for remote control of instrumentation. Technologies like DataSocket are also available to made sharing measurements across a network really easy. Although the communication over the network is based on the TCP/IP protocols, its use is completely hidden to the user. The development of intelligent remote measurement nodes and measurement publishing systems is simplified. There is one additional benefit of the DataSocket technology for publishing measurements: the remote users don't need an application development environment installed. Instead, it is possible to create a web interface to receive measurement information from the remote instrumentation, and therefore to use a standard web browser on the user side [52].

LabVIEW makes possible to distribute executable code to several PC nodes to increase the processing power. Therefore, distributing measurements and executable code, it is possible to create measurement systems over large- scale networks.

When real-time constrains are required, the LabVIEW RT can be used [53]. The main idea is to execute the critical code on a dedicated processor, therefore dedicated systems are developed (for instance a data acquisition board with an embedded processor). The LabVIEW RT provides a dedicated kernel with multithreading support and some I/O drivers. The VI that is implemented with LabVIEW RT is executed on the dedicated system, and can be visualized on a different PC node. The communication between those two parts can be achieved using the VI server technology.

Some cross-platform solutions for remotely accessing VIs written in LabVIEW are proposed in [39], [42] and [54]. Basically all of them rely on Java applets reproducing the VI front panel. The use of Java ensures a native portability of the VIs on different client operating systems. Moreover, this kind of solutions does not oblige the student to download heavy plug-ins from internet. By following the same approach the commercial software AppletView, from Nacimiento produces 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. An alternative approach, using the RDP (Remote Desktop Protocol) [55], proposes to grant to the student a limited access to the desktop of the PC connected to the instrumentation where a LabVIEW instance runs. In this manner, the student can even built his/her own VI, given a set of programmable instruments. The architecture of the DVL developed using that approach is reported in Fig.3.

B. The Object-Oriented Programming based approach

The OOP is widely used for measurement system development [56]. The physical instruments, the drivers interfacing the instruments with the communication bus and the graphic components of the front panels can be represented in software as objects. Moreover it is possible to create an extendible hierarchy of instruments based on the inheritance and polymorphism as suggested in [57].

In order to carry out the measurement, some specific steps should be completed. The logic of the measurement procedure can be delegated to a Supervisor object. The implementation of the system is almost straightforward by using any OOP languages like C++, Java or C#.

Although the proposed model is adequate for local measurements, it is easy expandable for remote instrumentation control. Indeed, using the client–server model and the features of the Java programming language, it is possible to provide the mechanism for remote control. The pattern proposed in [58] provides, on the server side, a server for the measurement

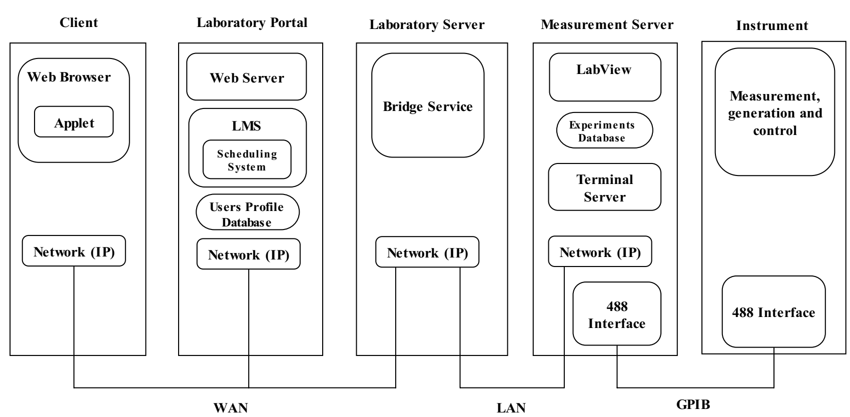

Fig.3. Architecture of the VL accessing the instrumentation by means of RDP [55].

procedures and a web server that exports over internet these procedures. Fig.4 shows the architecture of the VL based on the web service. On the client side it is possible to download the control panel of the VI implemented through C++, Java or C#, relying on a standard browser. The communication between the client and the server can be implemented using Java RMI (Remote Method Invocation) or CORBA (Common Object Request Broker Architecture) standard [59] or Web Services using XML (eXtensible Markup Language) and the SOAP (Simple Object Access Protocol) [60], [61].

The same model can be further extended to develop a DVL. The local measurement system can request/supply services from/to another remote system. The cooperation between subsystems should follow opportune protocols to achieve the common goal. The network communication can be again based on CORBA, RMI or Web Services. It is worth noting that even if the basic mechanism of RMI and CORBA is the same, that is the remote procedure call RMI, the CORBA standard allows the cooperation between pieces of code written in different programming languages, and RMI is limited to full Java environment.

An interesting evolution of this approach was proposed in [62] where the system is implemented using a mobile agent technology. In such a distributed measurement system, the different tasks are carried out in different measurement stations, and the cooperation between them is delegated to the mobile agents. For each mobile agent, an itinerary to be followed and the corresponding subtasks to be performed on each node are specified in order to reach the distributed execution of the task as a whole.

A slightly different distributed architecture was proposed in [63]. The idea is to create a Virtual Instrument Bus (VIB) witch makes a large number of physical buses on a computer network look like a single bus. The VIB software makes all instruments to appear to be located on one single bus, and provides easy code reuse for program generation. The VIB is developed using remote procedure call approach.

The solution based on Web Services over XML and SOAP, instead, allows the creation of dynamic web pages publishing the instrument front panels whichever is the language used for developing them. The main drawback of using such solution is the information overhead needed for abstracting the data source, that slows down the communication. In Fig.4, an example of VL using Web Services for network communication is shown.

The DVL based on the previous considerations have satisfactory performance when no real-time constraint exists for the network communication. Indeed, the communication over the network is based on the non-deterministic TCP/IP protocols. When real–time constrains have to be faced new real-time protocols like ReSerVation Protocol (RSVP) and RTP/RTCP [64] could be implemented in order to guarantee deterministic data delivering and timing.

III.INNOVATION, QUALITY AND REALITY OF VL

Assessed that the software and the hardware technology are ready to realize the VL, the very interesting question is: is the VL feasible? The answer needs (i) to examine the role of the VL in the educational activity innovation, (ii) to compare its functionality to the real laboratory ones, and (iii) to examine the future expansion.

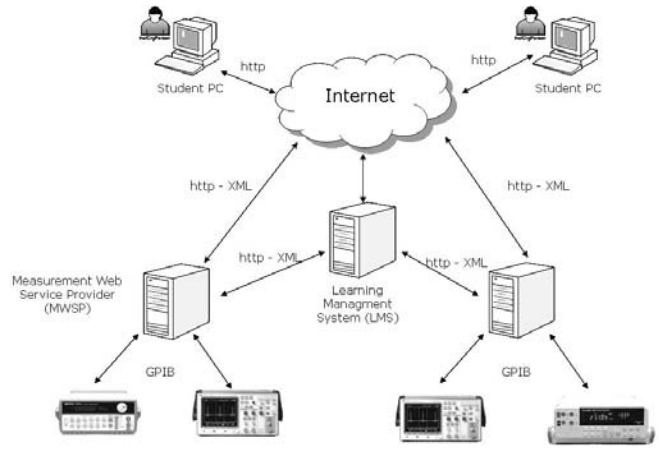

Fig.4 Architecture of the VL based on Web Services.

The education in instrumentation and measurement is characterized by continuing reference to (i) instrument architecture, (ii) measurement procedures, (iii) digital signal processing and (iv) uncertainty evaluation. The VL permits to gain practice on (i) sophisticated instrumentation, (ii) complex measurement procedures, and (iii) digital signal processing by reducing the complexity and the difficulties of the real laboratory. Moreover, the VL permits to overcome the other difficulties arising from the compliance to the safety policy requirements if dangerous apparatus is used. Another interesting aspect is the possibility to make the experimental activity available according to the progress of the theoretical topics.

Numerous are the realizations of the VLs in order to satisfy particular requirements in different fields [1]-[3], [6]-[15], [17]-[18]. Common advantages of all these VLs are the following:

- the exercises can be customized for each student;
- the result validation quality of result validation can be automatically performed and its quality significantly improved;
- the laboratory resources are better exploited. Students can access to the laboratory from anywhere and at any time;
- the level of reality is clearly higher than in simulation. Even if the access to the laboratory environment is virtual, the target development system and the attached devices exist physically.
- the time consumption and the building efforts re optimised and the difficulties in assimilating the material are minimized.

Nevertheless, the only one disadvantage of the VLs is:

On the disadvantage side, there is no direct help and suggestions that could be given by a tutor in presence of the students. Partial solution is the online help system and tutoring.

Among the others there are two fundamental aspects concerning the VLs that must be taken into account: (i) the quality of the education by VL, and (ii) the reality of the environment created by the VL.

The quality assessment of the VL involves several factors and it can be considered an index of its effectiveness as education tool. To this aim in the design phase it is necessary to specify a set of requirements and factors to be taken into account in the design phase to achieve the desired quality level. In particular, the interest is usually devoted to: (i) the graphical environment, (ii) the software supervisor in order to point out operating errors, (iii) the comparison of the results with the correct ones obtained in the same operating conditions, and (iv) the accessibility to the higher skill levels on the basis of expertise acquired at the lower ones. Also the reality of the environment is important aspect. It is possible to create the virtual environment similar to a real measurement laboratory. To this aim, the software environments must able (i) to permit to the student to develop and to easily integrate new parts (software and hardware) of the measurement station easily, (ii) to show the information coming from the instruments with the real information concerning the experiment.

IV.DESIGN CRITERIA OF DVL

The main design objectives to envelop the DVL are:

1. *portability*: the visualization environment has to be portable on different hardware platforms and operating systems;
2. *usability* and *accessibility*: the visualization and the management of an experiment have to be easy to understand and to perform, even for users that are not expert of information technologies, 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 and the procedure simplified. This can be made possible through a client-server approach that eliminates the need for installing and upgrading code application and data on client computers;
4. *client-side common technologies*: students have to access to the system using their desktop computers based on common hardware and software technologies, with no need of very powerful processors or high main or secondary memory capacity. The access to the laboratory should be granted through dialup connections with a common 56 kbps modems, without a performance decrease in comparison with broad band 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;
6. *privacy assurance*: the students' data should be protected against unauthorized access;
7. *scalability*: the system performance has not to degrade with the growth of the connected users.

V. OPEN QUESTIONS RELATED TO THE VL

The wide diffusion of the VL in different fields of the technical education makes interesting to consider the following aspects: (i) interchangeability among the software parts of the different VLs realized from different peoples, and (ii) interconnectivity among different VLs to permit the contemporaneous use from different physical laboratories. The previous are some of the open, innovative and interesting questions to solve.

The interchangeability among the software parts gives a freedom to integrate new software parts of the system easily. In this manner each VL can added by using part of another VL. The attainable advantages are:

- reduced time to develop new parts of the VL if already available and tested parts are used. The efforts can devoted to integrate the VL with innovative tools;
- the modernization of the VL is very easy and fast;
- the VL can include all the interesting software parts avoiding to the user to visit different VLs;
- high system scalability.

Indeed the number of development kits can be easily increased depending on expected usage. It can be noted that the interchangeability among the software parts requires that the software architecture must respect particular conditions.

The interconnectivity among different VLs permits to reduce the server capability. However it increases the software development complexity.

These questions can be topics to be discussed in the framework of the specialised working group. On the basis of this demand, it was organised the Working Group (WG) "e-tools for Education in Instrumentation & Measurement" (etEI&M), operating into the IEEE Instrumentation and Measurement Society, Technical Committee TC-23 Education in Instrumentation and Measurement. The web site of the WG is:

http://www.deis.unical.it/deis1.0/portale/ricerca/leim/wg/

IV. CONCLUSIONS

The overview on both the software and hardware realizations of the VLs has shown the innovation aspects introduced in the education in instrumentation and measurement. Nevertheless, it has been shown that new and interesting aspects must to be examined, also. These are: (i) the quality of the VL for education purposes, (ii) the reality of the virtual environment respect to the real laboratory, (iii) the interchangeability among the software parts of different VLs, and (iv) the interconnectivity among different VLs. These aspects are typical topics to discuss in the framework of the specialist-working group.

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