

Remote Instrumentation Laboratory for Digital Signal Processors Training

Sergio Gallardo, Federico J. Barrero and Sergio L. Toral
*University of Seville,
Spain*

1. Introduction

The development of computing and networking applications based on Internet has opened a new way to understand control and instrumentation systems. Information and communication technologies make possible the use of telecommunication networks, such as the Internet, to design remote applications applied to different fields, such as, telecontrol, measurement instrumentation, telemedicine, embedded systems, teaching and so on. Furthermore, remote control of measurement instrumentation for real experiments via the Internet is a growing topic of interest for many researchers (Chirico et al. 2005). This is especially noticeable in Digital Signal Processors (DSP) training, where practical training is absolutely essential to assure good knowledge transfer to educate good professionals (Hercog et al., 2007).

A growing interest has been experienced on recent decades in the development of DSP-based devices. DSP technology is commonly employed nowadays in devices such as mobile phones, multimedia computers, video and DVB recorders, CD and MP3 players, hard disc drive controllers, modems, and will soon replace analog circuitry in TV sets, telephones and other circuits (Poornachandra and Sasikala, 2010). In fact, the sales of DSP devices exceed the sale of general-purpose microprocessors by almost 10:1 (Hong et al., 2004).

The architecture of a DSP chip is designed to carry out operations incredibly fast, processing up to tens of millions of samples per second, to provide real-time performance, that is, the ability to process a signal "live" as it is samples and then output the processed signal, for example, to a loud speaker or video display. All the practical applications DSP mentioned earlier, such as disc drives and mobile phones, demand real-time operation and the design of such DSP solutions requires to the professionals a concurrent knowledge of signal processing methods and technology (Poornachandra and Sasikala, 2010). This fact has promoted the inclusion of DSP and DSP devices in the electronic engineering undergraduate curriculum. This tendency also appears in Instrumentation and Measurement courses. High quality DSP based instrumentation equipment has proliferated during the last years. Furthermore, one of the most demanded job profiles in the Information and Communications Technology (ICT) sector is related to the design of DSP applications, as it is claimed in the Career Space initiative (Office for Official Publications of the European Communities, 2001; Toral et al, 2006). The DSP Applications Designer is involved in requirement studies, simulations and performance analysis, and participates in the design and optimization of algorithms for signal modulation, detection

and channel coding/decoding, compression and decompression, and implementation with digital signal processors. For instance, high-quality DSP based equipments have proliferated during the last years. Most of these equipments are based in the popular Texas Instruments TMS320C6711 or TMS320C6713 DSP devices and their starter kits, DSK6711 or DSK6713.

In this context there have been important changes in engineering education, especially in electrical and computer engineering (ECE) education, both in terms of content (curriculum) and what it is taught or how it is taught (delivery of material), (Carley et al., 2000; Felder et al., 1998; Milliken et al., 2002; Roppel, 2002; Taylor et al., 2003; Wilson et al., 2000).

On the one hand, emphasis in the electrical engineering field has shifted significantly to the design of digital systems. On the other hand, technology that is around everything we do, has taken a place in the classroom and hypermedia tools, web-based educational support, simulation environments, and so on, have dramatically increased, (Aedo et al., 2000; Almeida et al., 2003; Bagui, 1998, Conole et al., 2004; Christian et al., 2001; Metzger et al., 2003; Pahl, 2003)

In this context, Telecommunication Engineering Studies at the University of Seville was first organized in 1991. The DSP course is an intermediate undergraduate digital electronic subject based on the design of advanced embedded digital systems and DSPs. The lack of enough lab work in the original organization motivated a change in the studies in 1998, searching for an increment in the practical work. This fact, together with the necessity of improving the teaching methodology in classrooms with more than 300 students per year, was the starting point to develop new teaching methods using computer-based educational tools (Martinez-Torres et al., 2005). The new European Area for Higher Education and ECTS (European Credit Transfer System) will shortly modify the teaching and learning processes, (Communiqué of Higher Education, 2003; Joint declaration, 1999) and the creation of this new area supposes a complete turnabout in the teaching and learning processes. Until now, these processes have been driven by the teaching activity, adapting the learning processes to the lecturer profile. But in the near future, the teaching and learning processes will be focused on the learning activity and on the learner profile. As a consequence, it is necessary to know the learner preferences and the variables with a significant relevance in the learner behaviour.

Learning through computer-mediated environments will contribute to create this new reality and novelty learning methodologies based on the active role of students (Aedo et al., 2000; Bagui, 1998; Pahl, 2003; Schodorf et al., 1996; Taylor et al., 2003; Wilson et al., 2000).

Although these computer-based training solutions are satisfactory to support systems for subjects with a strong theoretical component, face-to-face lab learning methodologies continue playing an important role in subjects with an important experimental load (Bose, 1994; Felder et al., 1998; Milliken et al., 2002; Roppel, 2000). However, the cost in time and money required for planning and implementing scientific laboratories is outside the scope of many institutions. It can be noted that the high number of students enrolled in subjects with a strong practical component or the insufficient economic resources are the main restrictions for face-to-face laboratory training methodologies (Guimarães et al., 2003; Sánchez et al., 2002). This is the case of DSP learning.

Therefore, limitations of a traditional laboratory structure are well-known: - high price of the equipment and devices under test; - small physical space available inside the laboratory rooms, - limiting the number of users at a time; laboratory availability limited to office

hours, and so on (Chirico et al. 2005; Davoli et al., 2006). Remote laboratories allow for much more efficient use of laboratory equipment and give users the opportunity to conduct experiments from the comfort of an Internet browser (Davoli et al., 2006).

Within this context, the idea of a remote and interactive laboratory arises from the necessity of a suitable educational tool capable of supporting a face-to-face laboratory training methodology. It would complement, but not remove, the student access to the traditional lab, with the possibility of being used for distance and asynchronous education. The amount of students' practical work is then increased (students have the possibility of accessing DSP boards and electronic equipments at any timetable and outside the laboratory building), without increasing available resources (lab equipments).

Web-based remote and interactive laboratories to be implemented can be classified into two categories based on the nature of the final equipment (or user access in an experiment): - Remote simulations, based on the possibility of simulating the dynamic behaviour of a system, but non physical hardware under test is used and, - remotely accessed equipment, based on real equipment which can be remotely handled and controlled by a user interface. Remote simulations support a whole gamut of capabilities and offer several advantages, such as low cost of implementation, absence of real equipment, easiness of integration (Spanias, A. et al., 2005). Nevertheless, remote simulations are not adequate when real-system control is required such as embedded systems control (Hercog et al., 2007) and DSP programming. The complexity of DSP internal architecture makes almost impossible the simulation of DSP internal blocks and functionalities.

Although many remote labs and e-learning tools can be found in the literature (Canfora et al., 2004; Casini et al., 2003; Ferrero et al., 2003; Kikuchi et al., 2004), it is worth mentioning the lack of in depth scientific studies devoted to validate this kind of tools. The majority of them are usually limited to one-dimensional post-training perceptions of learners (Abdel-Qader, 2003), for instance, "happy sheets" which ask learners to rate how satisfied they were with their overall learning experience. A remote instrumentation laboratory named eDSPLab has been implemented and recently used (academic years 2004-2005 and 2005-2006). As opposed to these previous approaches, this paper considers eDSPLab as a new technology for users, applying an information system theory called Technology Acceptance Model (TAM) as a novel method to validate its use (Lee et al., 2003). Using TAM, the causal antecedents or external variables which have a significant influence in the use of eDSPLab are identified. The obtained results show the external variables motivating the use of eDSPLab, allowing the inclusion of the remote lab in a wider e-learning tool based on a Learning Management System (LMS) to obtain an improved performance. This new e-learning tool combines a large variety of commercial software packages and Web oriented languages (Shockwave™, Macromedia Director™, HTML –Hypertext Markup Language–, VRML –Virtual Reality Modeling Language–), which improve the detected effectiveness of eDSPLab. All the desirable features of multimedia systems with utility in educational environments have been applied according to the European Higher Education Area (EHEA) and European Credit Transfer System (ECTS), devoting particular attention to the interactive features and their impact in the learning process.

In order to prove the benefit of eDSPLab, non-opinion-based assessment of outcomes is also provided and End User Quality of Service, defined as the quality perceived by the end user, is expressed in terms of satisfaction and technical terms. Objective and subjective

measurement parameters, as network performance parameters, user test, listening and interviews are proposed and employed to characterize system performance.

In short, based on these fundamental aspects, a remote measurement laboratory based on LabVIEW has been projected and implemented. It provides the users with access to remote measurement instrumentation and DSP embedded board, delivering different activities related to digital signal processing and measurement experiments. Novelty aspects of the proposed solution are the integration of an embedded system based on a DSP with measurement instrumentation for remote training and both integrates on a Web based environment which provides remote access to control different didactic setups related to DSP devices and their applications is shown. The environment, named eDSLab, allows asynchronous and off-campus learning, and avoids some of the problems caused by the high number of enrolled students and the insufficient economical resources, the advantages of the LMS which integrates workflow and data management and tools for user collaboration and includes the ability to track very detailed information about individual learners, making the system highly beneficial to large online environments and a powerful server monitor to closely monitor the remote measurement laboratory, Fig. 1.

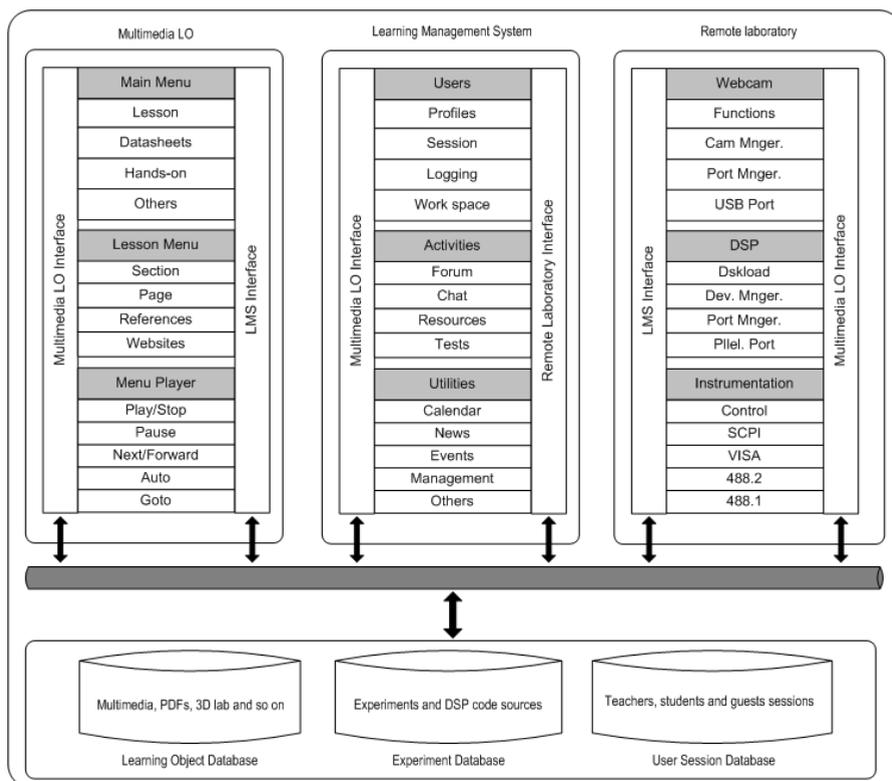


Fig. 1. Projected Web environment: Measurement laboratory based on LabVIEW, Learning Management System based on Moodle and Macromedia Director Learning objects.

2. Laboratory architecture and experimental setup

eDSPLab has been successfully implemented in an Advanced Microprocessor course and in an Instrumentation and Measurement course at the Telecommunication Engineering degree at the Electronic Engineering Department of the University of Seville, Spain, Fig. 2. It has been designed for real lab work using the DSP starter kits without a physical attendance to the real lab. Students interact with the DSK boards using the Web and eDSPLab for debugging real DSP experiences in the physical lab.



Fig. 2. eDSPLab test bench overview.

Both, the Advanced Microprocessor course and the Instrumentation and Measurement course are taught as part of the students' curricula in order to provide some DSP professional skills and measurement instrumentation skills, respectively. In this way, students are trained for eventual industrial work in companies using DSP technologies in their products. The real lab attendance is complemented by offering a distance and asynchronous learning methodology. In groups (2 to 3 students), students must implement predefined DSP exercises started in the real lab and completed using eDSPLab. The evaluation of the practical work (notice that the mark for the practical work has a contribution of 25% on the overall qualification) depends on the accomplishment of specific lab exercises at the end of the academic year.

eDSPLab architecture can be divided into three elements, the measurement instrumentation and embedded DSP board, the server framework, which is the core of the remote laboratory, and the client side, with thin client or fat client possibilities, Fig. 3.

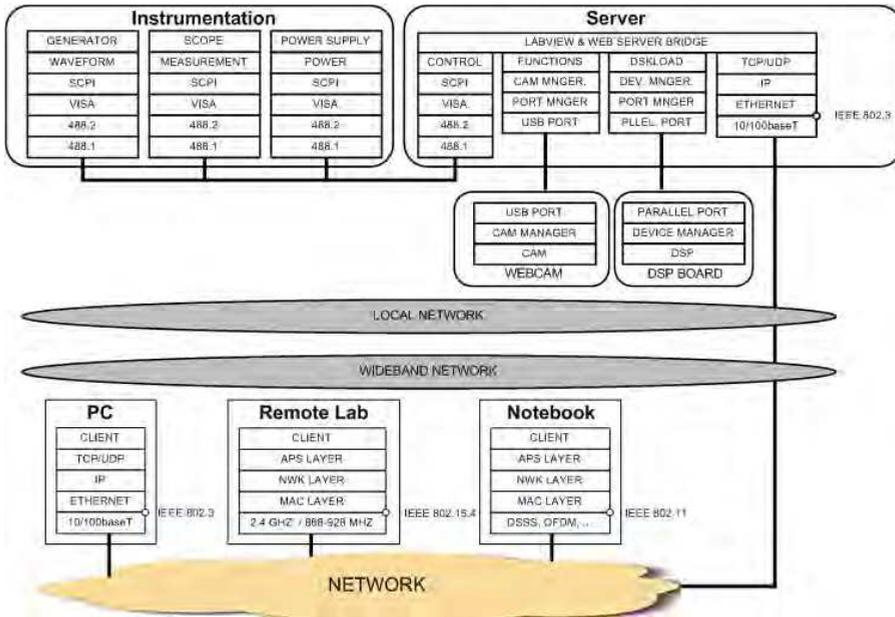


Fig. 3. eDSPlab architecture.

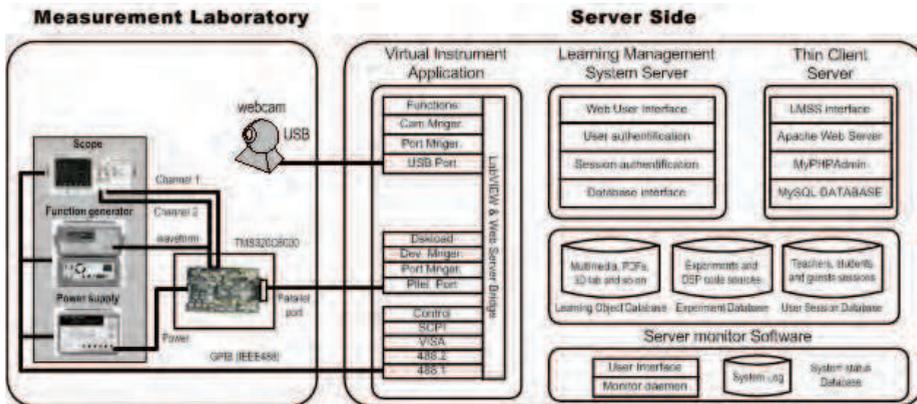


Fig. 4. Server architecture.

Furthermore, the server architecture can be structured into four components, Fig. 4:

- The Virtual Instrumentation Application (VIA). The VIA manages both, the flow of data between GPIB devices (an oscilloscope, a power supply, and an arbitrary waveform generator), and the DSK (Developer Starter Kit) communication, to load the remote user binary code onto the embedded device or DSK.
- The Thin Client Server (TCS). The TCS manages the thin client-server interaction. The thin client depends primarily on the central server for processing activities, and mainly focuses on conveying input and output between a user and a remote server.

- The Learning Management System Server (LMSS). The LMSS interfaces to users via Web and manage learning interventions. It provides Learner self-service, training workflow, the provision of on-line learning, on-line assessment, management of Continuous Professional Education (CPE), collaborative learning, and so on.
- Server Monitor Software (SMS). The SMS is used to closely monitor the remote measurement laboratory, notify the failures or performance problems and run actions, analyze network protocols, and so on.

2.1 Virtual instrumentation application (VIA)

In the last decade, personal computers evolution has boosted several engineering sectors. Among them is Instrumentation and Measurement discipline. This evolution has promoted the apparition of the term virtual instrumentation, referring to a combination of hardware and software elements whose functionality is beyond the one immediately available with the hardware used. Those instrumentation systems that integrate one or several virtual instruments and have the software as its major component, are presently used both in industrial and laboratorial applications (Geirinhas, 1998).

The instrumentation and measurement hardware which implements virtual instrumentation is practically unlimited, a whole gamut of possibilities can be found in the market to solve our necessities and the customization of a VI, its limitations and its overall performance depend on software framework, including languages and development tools (Geirinhas, 1998).

The VIA has been designed using LabVIEW™, a National Instrument graphical development environment designed for creating flexible and scalable test, measurement and control applications (National Instruments, 2003 & 2005). The VIA manages both, the flow of data between GPIB devices and the DSK communication.

The measurement instrumentation bench is composed by an Agilent E3631A Programmable DC Power Supply with GPIB and RS-232 interfaces to program both voltage and current, an Agilent 33220A function generator which offers 11 standard waveforms plus pulse and arbitrary waveforms, 20 MHz sine and square waveforms, 14-bit, 50 MSa/s, 64 Kpoint arbitrary waveforms, AM, FM, PM, FSK, and PWM modulation types and USB, GPIB and LAN interfaces and a digital scope HP 54603B with two channels, 60 MHz bandwidth and add-on modules to interface for remote control output to RS-232 and HP-IB. The bench is connected to the server via a GPIB board. All the electronic equipment (Agilent 54603B, Agilent E3631A and Agilent 33220A) are GPIB talkers and listeners (send and receive information through the GPIB bus) while the Personal Computer is the GPIB controller (manage the flow of data between the GPIB devices). The embedded board is connected to the server through its parallel port and it is based on the Texas Instruments TMS320C6711 DSP Starter Kit (DSK).

The VIA front panel, that is, the user interface of the VI, can be observed in Fig. 5. Different controls and indicators are implemented, which are the interactive input and output terminals of the VI, respectively. Controls simulate instrument input devices and supply data to the block diagram of the VI. Indicators simulate instrument output devices and display data the block diagram acquires or generates. The user interface of the VI is composed of eight sections: Three consoles which support the user interface of the virtual instruments, two interfaces associated with the DSK and a Web cam to real time monitoring, system status control and restricted-access section.

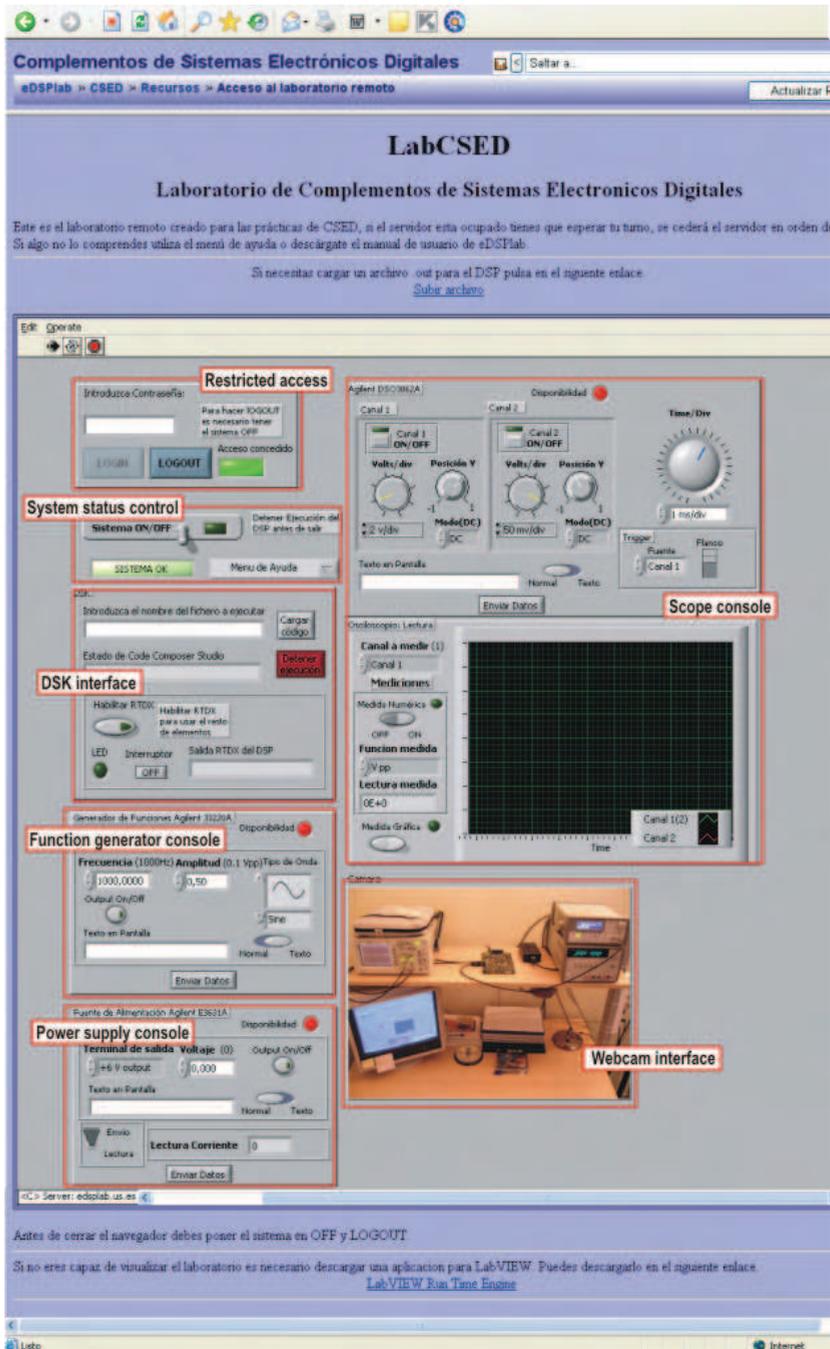


Fig. 5. Virtual Instrumentation Application (VIA) front panel.

The user interface of the VI is composed of three consoles: Function Generator, Power Supply and Scope. The different controls simulate instrument inputs and supply data to the block diagram of the VI. On the other hand, the indicators simulate instrument outputs and display data the block diagram acquires from the GPIB bus.

The DSK interface provides the users with access to the DSP embedded board, delivering different activities related to digital signal processing, Fig. 5. The integration of the LMSS allows controlling source code uploads to the server. The LMSS interfaces to users via Web and manage upload interventions. The source code to be loaded on the DSP embedded board is selected by the user. One time the source code to be executed is loaded, the DSP starts working. A text-based console interface informs the user of downloading and execution process.

eDSPlab also provides a real time monitoring application, based on a low cost 640x480 resolution Web-cam. The Web-cam offers visual real-time feedback of the remote measurement laboratory.

System status control and restricted-access section allows a user to request eDSPlab control. After the login process, it is possible to set a time limit on how long a remote client can control a VI when multiple clients are waiting to control the VI. The server spares a slot of time to this remote user and the eDSPlab control is assigned. The user controls the measurement laboratory during this slot of time, enabling virtual instrument and DSP operation. Instruments control and DSP programming works just the slot time expires: At this moment, the system queries its remote connection-table and extends (or not) the slot time.

2.2 Thin Client Server (TCS)

The TCS manages the thin client-server interaction. A thin client in client-server architecture networks depends primarily on the central server for processing activities, and mainly focuses on conveying input and output between the user and the remote server.

In designing client-server applications, there is a decision to be made as to which parts of the task should be done on the client, and which on the server. This decision can crucially affect the cost of clients and servers, the robustness and security of the application as a whole, and the flexibility of the design for later modification or porting.

One design question is how application-specific the client software should be. Using standardized client software such as a Web browser, remote panel or X11 display can save on development costs, since one does not need to develop a custom client—but one must accept the limitations of the standard client.

A lot of thin clients run only web browsers or remote desktop software, meaning that all significant processing occurs on the server (Andria et al., 2007).

Web applications are popular due to the ubiquity of a client. The ability to update and maintain Web applications without distributing and installing software on potentially thousands of client computers is a key reason for their popularity.

The view and control of a LabVIEW-VI front panel remotely can be made, either from within LabVIEW or from within a Web browser, by connecting to the LabVIEW built-in Web Server. When a front panel is open remotely from a thin client, the Web Server sends the front panel to the client, but the block diagram and all the subVIs remain on the server computer. A user can interact with the front panel in the same way as if the VI were running on the client, except the block diagram executes on the server. Its feature enables to publish entire front panels or to control remote applications safely, easily, and quickly

Thin clients have to use LabVIEW Run-Time Engine to be able to view and control a front panel remotely using a Web browser. The LabVIEW Run-Time Engine includes a LabVIEW browser plug-in package that installs in the browser plug-in directory. Clients install the LabVIEW Run-Time Engine and the user at the server computer creates an HTML file that includes an <OBJECT> and <EMBED> tag that references the VI that clients want to view and control. This tag contains a URL reference to a VI and information that directs the Web browser to pass the VI to the LabVIEW browser plug-in. Clients navigate to the Web Server by entering the Web address of the Web Server in the address or URL field at the top of the Web browser window. The plug-in displays the front panel in the Web browser window and communicates with the Web Server so the client can interact with the remote front panel. Clients request control by selecting Request Control of VI at the bottom of the remote front panel window in their Web browser or by right-clicking anywhere on the front panel and selecting Request Control of VI from the shortcut menu. If no other client is controlling the VI at this moment, a message appears indicating that the user has control of the front panel. If another client is currently controlling the VI, the server queues the request until the other client relinquishes control or until the control time limit times out.

2.3 Learning Management System Server (LMSS)

eDSPLab has been integrated into a more powerful educational environment and several applications currently operate in the server side. The LMSS interfaces to users via Web and manage learning interventions. It provides Learner self-service, training workflow, the provision of on-line learning, on-line assessment, management of Continuous Professional Education (CPE), collaborative learning, and so on. eDSPLab has been integrated into this powerful educational LMS environment, based on Moodle. Moodle has been selected as the LMS because it has been developed as an Open Source Software (OSS) project, with all the advantages of an OSS, such as increased cost effectiveness in the market (reducing the cost of production and avoiding the expensive royalties of commercial software), and the easy resolution of problems within the Open Source Community. The LMSS is able to manage learners, keeping track of their progress and performance across all types of training activities, and learning resources such as content, registration, classroom and instructor availability, instructional material fulfillment, and on-line learning delivery. Students can access the teaching material and they can also download data files containing reference material and class notes in pdf format. Student auto-evaluation tools, FAQ, notice and mark boards, quality survey to provide asynchronous feed back of the teaching process, and chat service to discuss about the concepts of the course are also easily implemented, Fig. 6.

The VI's have been integrated in the Moodle-based LMS, enabling remote users to get control of the measurement instruments. Therefore, the students' activities can be tracked at the Learning Object (LO) level.

Furthermore, students can also access to additional teaching material. Different LO have been designed, including reference material and class notes in .pdf format and multimedia learning tools (Lillo et al., 2005; Toral et al., 2007). The multimedia LOs are made up of a tight coupling of text, tutorials, illustrations, video segments and animations designed with Macromedia Director Software, Fig. 7, and they allow a virtual visit programmed using VRML to the real lab, Fig. 8 (Toral et al., 2007; Lillo et al., 2004; Gallardo et al., 2006; Gallardo et al., 2005).

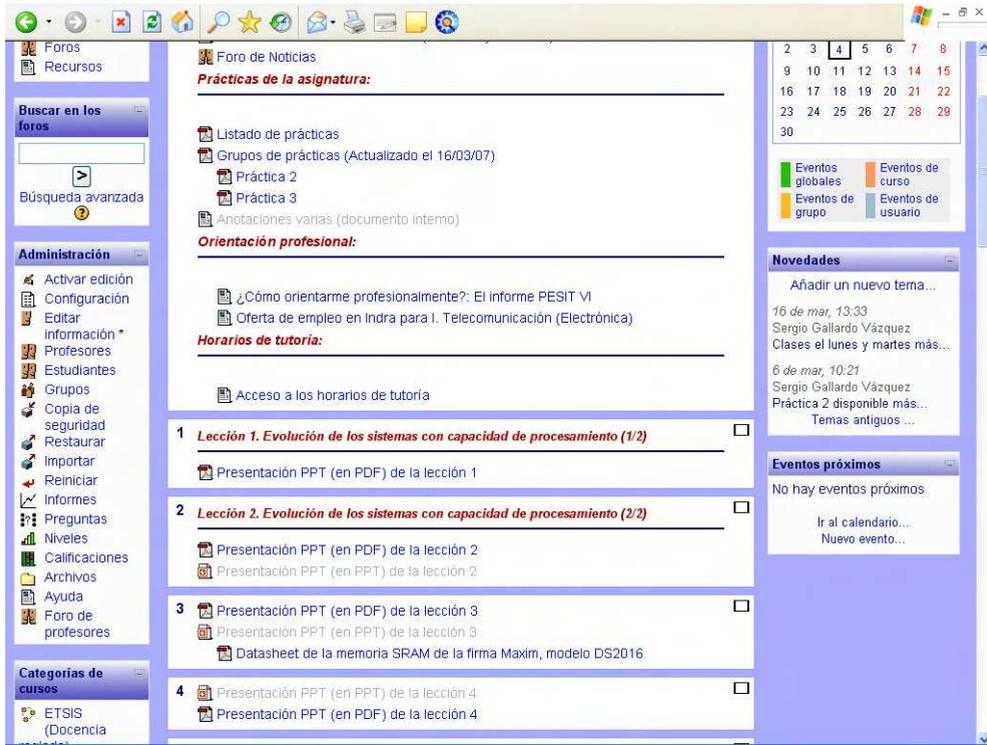


Fig. 6. LMS main menu overview.

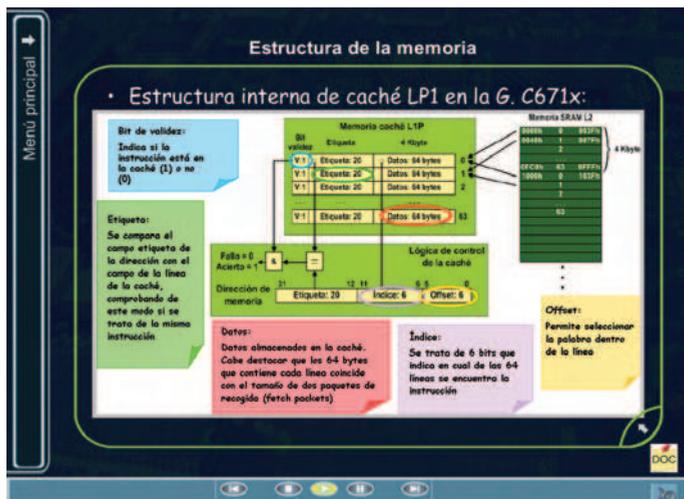


Fig. 7. Learning Object designed with Macromedia Director.

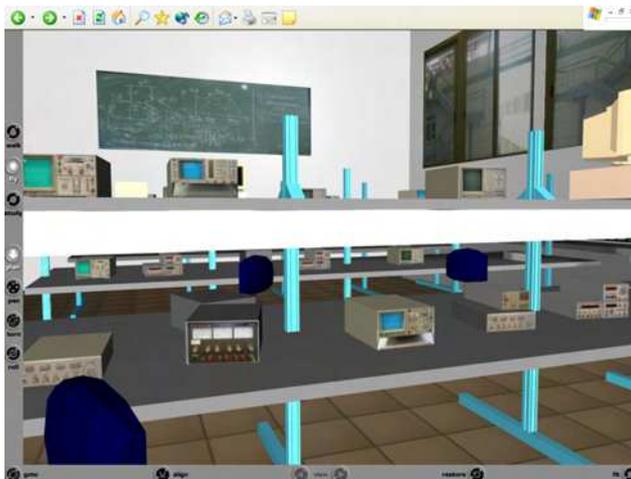


Fig. 8. 3D virtual visit to the real lab based on VRML.

Different users' profiles are managed by the system: "student", "teacher", and "administrator". The "student" profile allows the use of LO including the experiment control service (a complete eDSPLab access for probing specific DSP experiences), the "teacher" profile includes remote handling (creation, updating, removal) of LO, while the "administrator" is responsible for the correct operation of the overall system and for handling user profiles.

2.4 Server Monitor Software (SMS)

The Service Monitor Software (SMS) functionality is related with the capacity to monitor the remote measurement laboratory, notify the failures or performance problems and run actions, analyze network protocols and bandwidth occupation. It has been implemented using different OS tools and commercial applications.

3. Performance analysis

In the fields of packet-switched networks and computer networking, the traffic engineering term Quality of Service, abbreviated QoS, refers to resource reservation control mechanisms. However, the term Quality of Service is sometimes used as a quality measure, with many alternative definitions, rather than referring to the ability to reserve resources. Quality of Service sometimes refers to the level of Quality of service, i.e. the guaranteed service quality. This definition of QoS, used especially in telephony and streaming video, is a metric that reflects or predicts the subjectively experienced quality, for example the "user perceived performance", the "degree of satisfaction of the user", the "number of happy customers", the Mean Opinion Score (MOS) value, or the Quality of Experience (QoE) subjective business concept. In this context, QoS is the cumulative effect on subscriber satisfaction of all imperfections affecting the service. This definition includes the application and the human in the assessment, and demands an appropriate weighting of diverse objective measures such as response time, interrupts, noise, cross-talk, loudness levels, frequency response, noticeable echoes, and so on, and also includes grade of service (ITU-T, Rec E.800 & X.641).

EuQoS (End-user Quality of Service), defined by ITU-T as a collective effect of service performances, which determine the degree of satisfaction of a user of the service, has been measured. EuQoS is the quality perceived by the user, expressed in both, terms of satisfaction or technical terms. It can be viewed from different perspectives. Objective and subjective measurement methods can be employed, as network performance parameters, user test, listening and interviews.

The eDSPlab quality of service measurement and characterization is based on the comparison between both, the proposed thin client model, eDSPlab, and a fat client model. The fat client model is based on the possibility to control a front panel remotely from LabVIEW (installed in both, the client and the server side). In this case, LabVIEW is used as a client to view the remote front panel of the virtual instrument.

A reference experiment has been chosen to compare both proposals. The experiment is related with the implementation of a 4 KHz low-pass FIR (Finite Impulse Response) filter on the DSP embedded board. The integration of the LMSS allows source code uploads to the server. The source code to be loaded on the DSP embedded board is selected by the user (the FIR filter implementation). One time the source code to be executed is loaded, the DSP starts working. A text-based console interface informs the user of downloading and execution process. The remote user generates a sine waveform in the Agilent 33220A function generator, connected to the CODEC input of the DSP. Both, the CODEC output and the CODEC input are connected to scope channels A and B, respectively. The sine waveform input frequency is changed by the remote user between 2 KHz and 6 KHz.

3.1 Objective EuQoS

The SMS monitors the remote measurement laboratory based on the thin client paradigm and the remote measurement laboratory based on the fat client paradigm. Additionally, it will serve as an auxiliary tool for monitoring and troubleshooting.

In order to perform the comparison and to evaluate the performance of the approaches based on the thin client model and the fat client model, the CPU time, CPU usage, I/O Writes, I/O Reads and bandwidth of the involved processes in each approach have been measured, Fig. 9, Fig. 10 and Fig. 11.

“CPU time” parameter represents the amount of time that the processes involved in the remote access use the CPU. On the other hand, “CPU usage” refers to the percentage of time that the processes use the CPU. These parameters, “CPU time” and “CPU usage”, are improved in the thin client approach, that is, thin clients only use the exact amount of CPU resources required by the current task, Fig. 9.

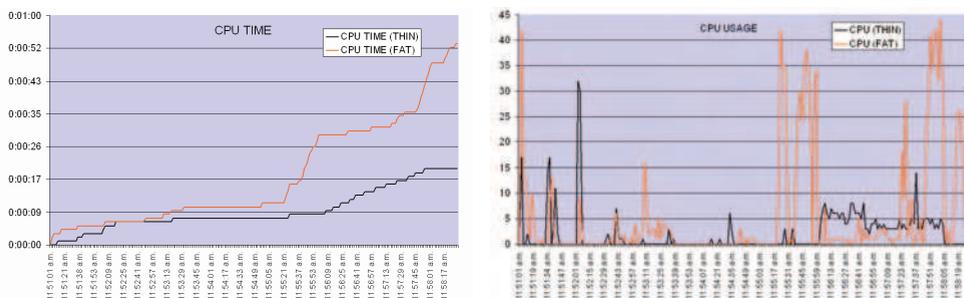


Fig. 9. Measured parameters: CPU time and CPU usage in both, thin client and fat client approaches.

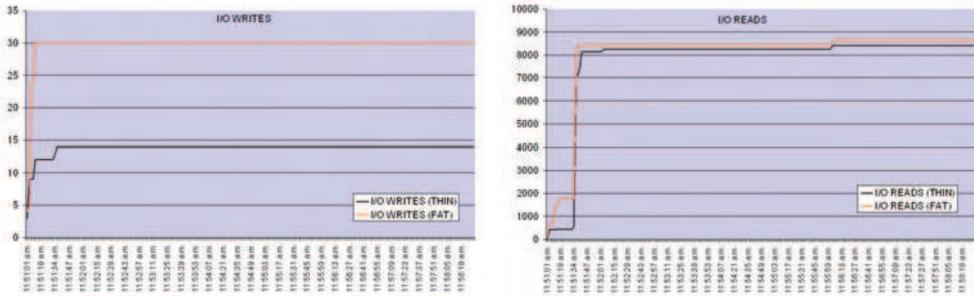


Fig. 10. Measured parameters: I/O Writes and I/O Reads.

Furthermore, “I/O writes” and “I/O reads” parameters are also reduced, Fig. 10. The importance of “I/O writes” lies in it is a statistic value signifying amount of write input/output operations generated by the remote access, including file, network, and device I/Os. Equally, “I/O reads” is the statistical value signifying amount of read input/output operations generated by the remote access (including file, network, and device I/Os). Finally, the bandwidth occupation has been measured in both approaches. A significant bandwidth occupation reduction can be observed in thin client approach.

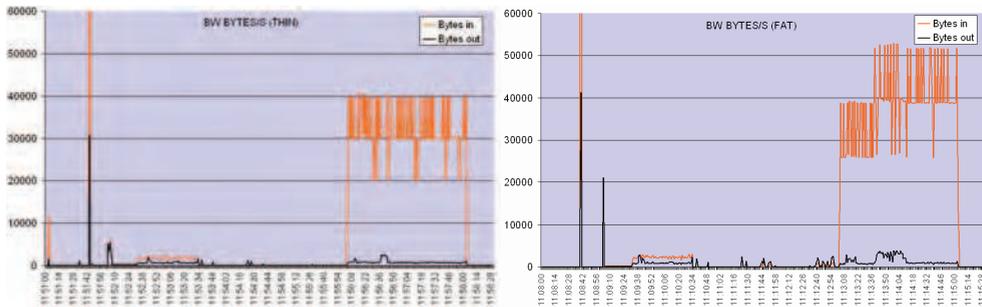


Fig. 11. Bandwidth occupation of both, thin client and fat client approaches.

3.2 Subjective EuQoS

From the subjective EuQoS viewpoint, it is necessary to use a scientific method to ensure the subjective measurements validation. For this reason, to prove the utility and effectiveness of the proposed system from the subjective viewpoint, it has been included as a complementary tool in an undergraduate advanced microprocessor course at the University of Seville during the last course 2004/05. An analysis of the tool has been studied and confirmed using a questionnaire to develop a technological acceptance model (TAM) (Toral et al., 2005). This model has been developed using the information provided by end users for guaranteeing the use of the tool. The obtained result also provides general information about the relationships among the variables involved in the acceptance of the tool and about the indicators used to measure each variable or dimension and guarantee its maximum effectiveness and usefulness, Fig. 12.

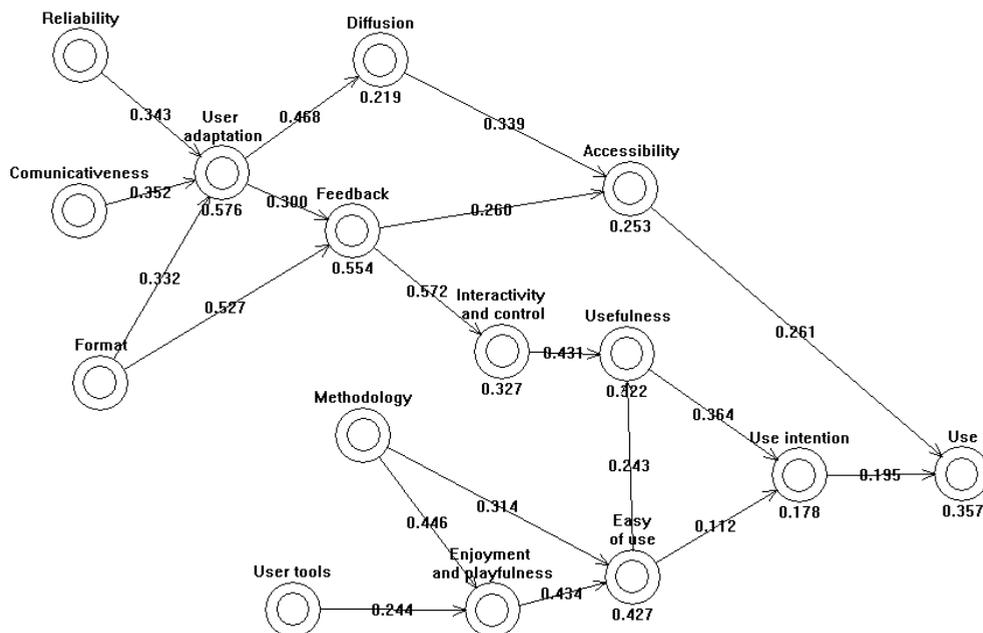


Fig. 12. Final acceptance model.

Learning through computer-mediated environments has dramatically increased. Some researchers state the validity, even the necessity, of these educational tools, but other authors are more sceptical about them. Sometimes, the use of computer simulation has replaced hardware-based laboratory courses. In this cases, students miss what can only be learned in a traditional lab. It seems as if computer-based educational environment has been used without any scientific criteria or, what it is worse, without real necessity. In fact, not much attention has been paid to scientific analysis for improving the teaching process which is normally empirically evaluated and improved.

In order to avoid this lack of scientific criteria in validating educational tools, TAM has been applied to the eDSPLab remote instrumentation laboratory and its LMS platform, to guarantee its maximum effectiveness and usefulness.

A questionnaire was prepared, validated, using the Cronbach's alpha (Toral et al., 2005) and distributed among 47 students of an undergraduate Advanced Microprocessor course to check the use of the tool and identify the external variables with a sensible influence in its use, Table 1. It consisted of 59 statements or indicators using 1-7 Likert type scale (1=strongly disagree, 7=strongly agree). Each dimension can be measured using a set of these statements or indicators which have been previously reported in the literature (Martínez-Torres et al., 2005).

Then, a principal components analysis was applied to reduce the number of variables. Each new generated variable (principal component) is a linear combination of the original indicators of Table 1 with the orthogonal property, so there is no redundant information. Table 2 depicts the results obtained from this analysis: the second column shows the number of principal component while the third one, the variances explained by these components.

Dimension (Reliability)		Item (Correlation item-dimension)
Format (0.7554)	I1	The instructional material is presented in a flexible order (0.3953)
	I2	Ease of readability/understandability of the text (0.5766)
	I3	The information provided by the tool is presented in a useful format (0.5668)
	I4	Clarity of the instructional material (0.6949)
Methodology (0.7601)	I5	The scope and the goals of the tool are clearly defined (0.6706)
	I6	The length of the content blocks are appropriate (0.4696)
	I7	The tool is adapted to the teaching content (0.6403)
Feedback (0.7849)	I8	Useful feedback from the tool (0.5135)
	I9	Receipt of timely feedback from the system (0.7431)
	I10	Feedback from the system stimulates the use of the tool (0.5782)
User adaptation (0.7537)	I11	The tool allows supervising the activity of users (0.4689)
	I12	The users have the possibility of choosing to solve the problems they like (0.4515)
	I13	The tool is adapted to different user profiles (0.5543)
	I14	The tool has different levels of complexity (0.4314)
	I15	The tool allows users to develop their own initiatives (0.5543)
	I16	Ability to control the sequence of instruction (0.4860)
	I17	The e-learning system enables you to learn the content you need (0.3511)
Communicativeness (0.8763)	I18	The e-learning system makes it easy for you to discuss questions with your teachers (0.6845)
	I19	The e-learning system makes it easy for you to discuss questions with other students (0.8117)
	I20	The e-learning system makes it easy for you to share the learned content with other students (0.7964)
Diffusion (0.8562)	I21	Before using the tool, I know all its features (0.7507)
	I22	I know the technical requirements for using the tool (0.7187)
	I23	I know the formative requirements for using the tool (0.7606)
	I24	Lecturers promote the use of the eLearning tool (0.5673)

Table 1. Validation of a questionnaire using Cronbach's alpha. (Part 1 of 3).

The number of indicators was reduced considering the minimum number of components which could explain, at least, a 70% of the variance of each dimension. Using the data of Table 2, the correlations between these principal components and the use of the eDSPlab environment can be evaluated, to show those ones that have a significant influence in it. These correlations were used to hypothesize the relationships among dimensions. To validate this hypothesis, PLS (Partial Least Squares) technique was used (Chin, 1998). A partial least squares regression is an extension of the multiple linear regression models. In its simplest form, a linear model specifies the (linear) relationship between a dependent variable (the use of the tool), and a set of predictor variables (external variables previously

obtained). The objective in PLS is to maximize the explanation variance R^2 . Thus, R^2 and the significance of relationships among dimensions or constructs are measures indicative of how well a model is performing. The conceptual core of PLS is an iterative combination of principal component analysis relating indicators to dimensions, and path analysis allowing the construction of a model. The hypothesizing of relationships between indicators and dimensions, and dimensions and other dimensions is guided by the results of the obtained correlations. The estimation of the parameters representing the measurement and path relationships is accomplished using Ordinary Least Squares (OLS) techniques.

Accessibility (0.7980)	I25	Accessibility of the eLearning tool (0.6379)
	I26	The communication channel is appropriate for accessing the tool (0.6319)
	I27	The communication channel for accessing the tool is easy to use (0.6519)
Interactivity and control (0.8244)	I28	Ability to use a variety of methods (menu, button,2) to interact with the system (0.2490)
	I29	Extent to which the system enables the subjects to actively interact with it (0.6742)
	I30	Ability to control the pace of instruction (0.7968)
	I31	Ability to control the sequence of instruction (0.7333)
	I32	Ability to select components or modules of instruction needed to acquire the various concepts (0.7251)
Enjoyment and playfulness (0.8661)	I33	Using the eLearning tool is pleasant (0.6580)
	I34	I have fun using the eLearning tool (0.7010)
	I35	The content of the tool is showed in an amusing way (0.7540)
	I36	The graphic design is attractive to users (0.6085)
	I37	Using the eLearning tool excites my curiosity (0.6922)
	I38	Using the eLearning tool arouses my imagination (0.5579)
Reliability (0.8361)	I39	The tool is robust and works properly (0.6310)
	I40	The tool is reliable (0.6114)
	I41	Whenever I use the tool, it works properly (0.7482)
	I42	I am confident about the security of the tool (0.6789)
User's tool (0.6178)	I43	The tool includes a search tool (0.4228)
	I44	The tool shows the different events of my learning process (0.4731)
	I45	The tool includes forums and chats (0.3691)
Easy to use (0.9081)	I46	I find it easy to get the eLearning tool to do what I want it to do (0.8029)
	I47	My interaction with the eLearning tool is clear and understandable (0.8246)
	I48	I find the eLearning tool easy to use (0.8905)
	I49	Interacting with the eLearning tool will not require a lot of my mental effort (0.6683)

Table 2. Validation of a questionnaire using Cronbach's alpha. (Part 2 of 3).

Utility (0.9366)	I50	Using the eLearning tool would improve my performance in this course (0.7983)
	I51	Using the eLearning tool would increase my productivity in this course (0.8915)
	I52	Using the eLearning tool would enhance my effectiveness in this course (0.8243)
	I53	I find the eLearning tool would be useful in this course (0.7731)
	I54	Using the eLearning tool in my job would enable me to accomplish tasks more quickly (0.7705)
	I55	Using the eLearning tool would make it easier to do my task (0.8085)
Use intention (0.8248)	I56	I intend to review some concepts using the eLearning tool frequently (0.7018)
	I57	I intend to compare some theoretical and practical concepts explained in classes with the point of view of the eLearning tool (0.7018)
Use (0.8008)	I58	How many times per week have you used the eLearning tool? (Average value) (0.6678)
	I59	How many hours per week have you used the eLearning tool? (Average value) (0.6678)

Table 3. Validation of a questionnaire using Cronbach's alpha. (Part 3 of 3).

Dimension	Principal components	Explained variance
Format (FOR)	3	0.7797
Methodology (MET)	3	0.8582
Feedback (FED)	3	0.8716
User adaptation (UA)	5	0.7372
Communicativeness (COM)	2	0.8588
Diffusion (DIF)	3	0.8967
Accessibility (AC)	1	0.7223
Interactivity and control (IC)	3	0.8189
Enjoyment and Playfulness (EP)	3	0.7227
Reliability (R)	2	0.8162
User tool (UT)	3	0.8854
Easy of use (EOU)	2	0.8378
Usefulness (U)	1	0.7599
Use intention (UI)	1	0.8523
Use (US)	1	0.8710

Table 4. Reduction of items or questions using principal components analysis.

Figure 12 shows the final model obtained using PLS. The bottom right side of the figure is based on the typical dimensions of TAM (use, use intention, easy of use, and usefulness), while external variables of the model are placed on the top left side. Several combinations have been analyzed, using different relative positions for the external dimensions and according to the correlations of the principal components of Table 2.

The model shows the important role of variables such as accessibility, user adaptation, feedback, interactivity and control, and enjoyment and playfulness. All of them have a direct or indirect incidence in the four major variables of the classical acceptance model. In turn, they are affected by the five independent variables of the model: reliability, communicativeness, format, methodology, and user tools. These independent variables can be considered as design variables but they must take into account the incidence in other variables. For instance, the format of the e-learning tool should take into account its positive incidence over feedback and user adaptation. That means that the designer should provide a format adapted to different user profiles and complexity levels, stimulating the use of the tool with an appropriated feedback to users.

3.3 Academic results

Additionally, and from an academical point of view, some important conclusions have been obtained from the numerical analysis of the course results evolution.

eDSPLab, has been designed to improve the students' practical work taking into account the traditional limited economic resources of educational institutions, which usually entails one of the main problems in real lab training: the low number of laboratory working places in relation to the high number of enrolled students. The practical work has a contribution of a 25% on the overall qualification in the analyzed subject. Therefore, a comparison with academic years previous to its use has been performed to estimate the improvement that the new teaching tool provides. The abandoned and failed rate of the course was reduced from 20% to 16% after the introduction of the eDSPLab, Fig. 13. This fact is more evident during the second year after the introduction of this novel learning tool. Also, Fig. 14 shows how the students' mark distribution was improved. To obtain the rated student mark, a range from -1 to 4 has been used, with -1 being "a student who has abandoned the course", 0 being "a student who has not passed the course", and 4 being "a student who has exceptionally passed the course". The numbers in between refer to intermediate scores. Note that this scoring penalizes for abandonment of the course. The obtained result is prorated using the number of students during the academic year.

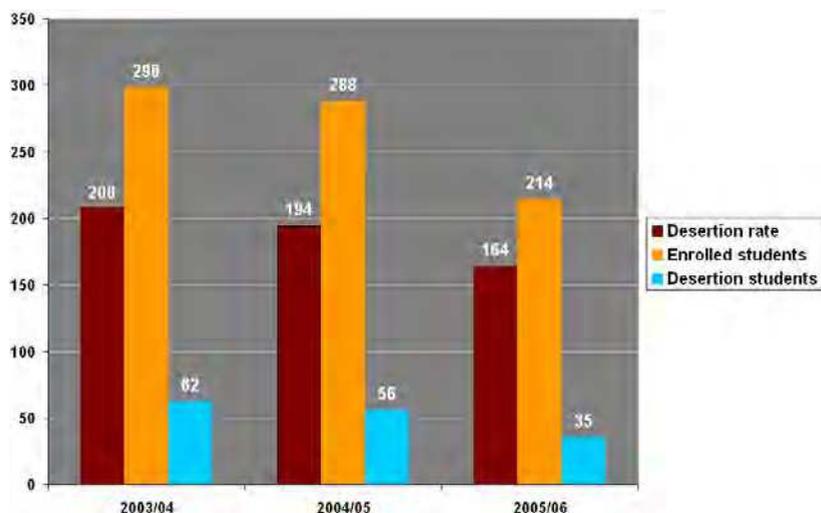


Fig. 13. Desertion plus failed rate showed in %.

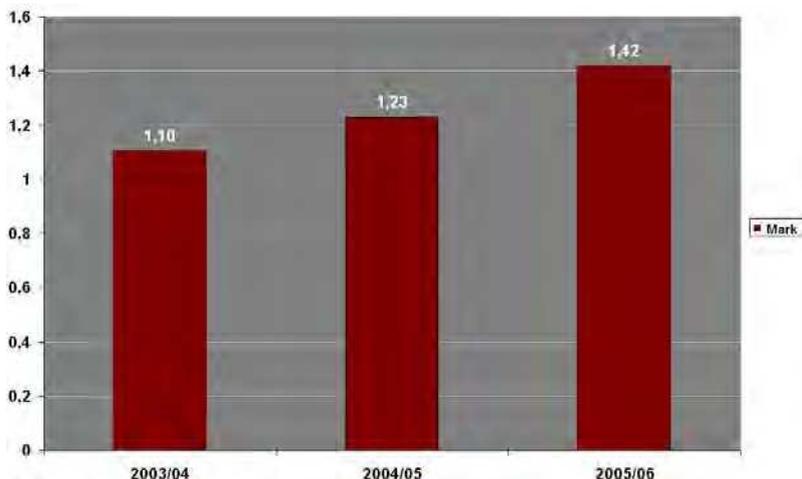


Fig. 14. Prorated students' mark distribution during the last academic years.

The first version of eDSPLab was introduced during academic year 2004-2005, and the final version, which was improved using the TAM results, was applied during the last academic year (2005-2006). It can be observed (Fig. 13) that the abandon and failed rate in the course before the introduction of eDSPLab was about 21%. Figure 13 also shows that the abandon rate during academic year 2004-2005 was about 19%. The use of the first version of eDSPLab poorly improved the abandon rate or, at least, improved the abandon rate less than expected. However, the abandon rate was reduced during the academic year 2005-2006 about a 20%, from 19 or 20% to 16%, after the evaluation of the tool using TAM. This fact corroborates that the efficiency of an e-learning tool like eDSPLab must be assured to validate its educational use. Notice that the students' lab work has increased using eDSPLab although the real lab attendance has decreased, which is confirmed by the increasing value of the students' mark measurement, Fig. 14.

Academic Course	Enrolled Students	Desertion (-1) (Lowest Mark)	Passed	Remarkable	Excellent	Distinction (4) (Highest Mark)
2003/04	298	62	127	78	16	15
2004/05	288	56	82	126	20	4
2005/06	214	35	53	98	22	6

Table 5. Distribution of student marks since academic course 2003/04 to 2005/06.

Finally, an additional and important magnitude to be considered is the percentage of students that take the exam at first time and they pass it. This magnitude has been increased from 91,76 % to the 99.4 % during the course 2005/2006, that is, there is a significant improvement in the continuous assessment and, therefore, in the teaching-learning process.

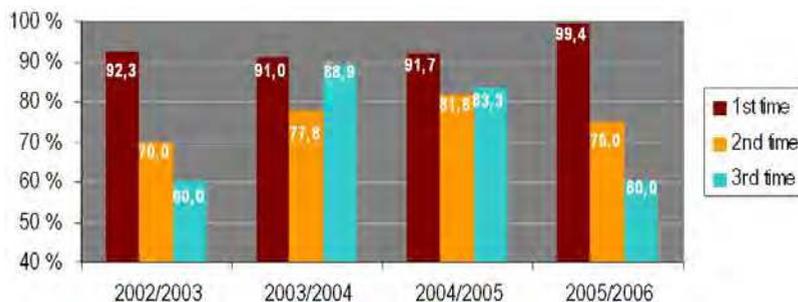


Fig. 15. Percentage of students that take the exam at first time, second time and third time and they pass it.

4. Conclusions

This paper concerns a Web-based measurement laboratory which provides access to remote control of DSPs and measurement instrumentation. eDSPLab, designed using LabVIEW™ and integrated on an LMS, has been presented. The educational tool which provides access for remote control of different didactic setups related to DSP has been used as a practical training tool in Undergraduate courses regarding advanced microprocessors architectures and their applications. Using eDSPLab students can work with the real lab equipment to test DSP applications without being physically present in the lab.

In order to optimize the remote access architecture, the thin client paradigm is used, contributing to improve speed, bandwidth and processor overload parameters of the system.

End-user Quality of Service has been measured and expressed in both, terms of satisfaction or technical terms. The technical measurement and characterization is based on the comparison between, the proposed thin client model, eDSPLab, and a fat client model, Fig. 9, Fig. 10 and Fig. 11. The results highlight improvements in terms of CPU time, CPU usage and I/O read/write operations.

As opposed to frequently reported e-learning tools, the eDSPLab has been evaluated in accordance with typical variables included in technological acceptance model. A questionnaire that measures the different variables or dimensions involved has been developed, and its reliability has been computed using Cronbach's alpha index. Using this questionnaire, a structural and measurement model for the use of the proposed tool has been deduced using PLS. Several results have been obtained. The current use of eDSPLab and the scores of the variables with a direct influence over its use, prove the effectiveness of eDSPLab as a teaching tool. Nevertheless, the derived model have shown the causal relationship among all the variables considered and have also guided some improvements of eDSPLab to increase its use. Particularly, the necessity of integrating eDSPLab into a more complex learning site has been deduced. User tools have been demonstrated to be an antecedent of easy of use and, as a consequence, the remote lab must be accomplished by new tools covering other theoretical and practical content of the subject.

The validity of the improved version of eDSPLab, modified taking into account the TAM analysis, has been also verified by non-opinion-based assessment data which compares the outcomes of the course with the previous years. The results show that the use of eDSPLab encourages students, reducing the abandonment rate registered during the last academic year, and improving academics results. Academic statistics have been carried out, Fig. 14 and Fig. 15, which highlights an abandoned and failed rate of the course reduction,

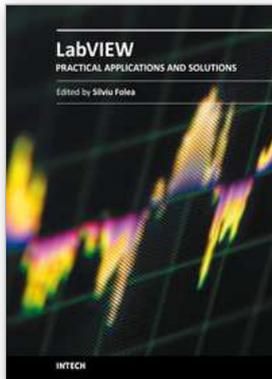
students' mark distribution improvement and a significant improvement in the continuous assessment and, therefore, in the teaching-learning process.

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The book consists of 21 chapters which present interesting applications implemented using the LabVIEW environment, belonging to several distinct fields such as engineering, fault diagnosis, medicine, remote access laboratory, internet communications, chemistry, physics, etc. The virtual instruments designed and implemented in LabVIEW provide the advantages of being more intuitive, of reducing the implementation time and of being portable. The audience for this book includes PhD students, researchers, engineers and professionals who are interested in finding out new tools developed using LabVIEW. Some chapters present interesting ideas and very detailed solutions which offer the immediate possibility of making fast innovations and of generating better products for the market. The effort made by all the scientists who contributed to editing this book was significant and as a result new and viable applications were presented.

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