A Signal Processing Laboratory Employing On-Line Teaming for Remote Experiments

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Abstract

The impact of distance learning (DL) is increasing daily. Such an educational delivery mode intends to serve the desire of both students and their instructors for scheduling freedom. Further, engineering education also has a costly component that is not directly time related: the use of sophisticated equipment. A subset of DL efforts is that of web-based laboratory experiments. Most investigators are delivering experiments via the Internet, but targeted to a single on-line user. Presented here is a different approach that stimulates teaming, even when simultaneous remote users are geographically dispersed. Students do not share the same physical location, but rather a virtual one: a multi-user laboratory platform. Within the paper, this philosophical approach and the implementation details (including chat, video, archiving, hardware and software platforms) are explained. One of the main advantages offered by a virtual laboratory is that students from all over the world can use the equipment located in a particular physical laboratory. The particular hardware employed here is organized around a spectrum analyzer.

1. Introduction

Distance learning (DL) is already part of many university programs, and its impact is increasing daily. Such an educational delivery mode intends to serve the desire of both students and their instructors for increased scheduling freedom. Presently there is a technology gap between non-laboratory and laboratory classes, because the lecture-only courses were the first addressed by distance learning (since the conversion is more straightforward). Further, engineering education also has a costly component that is not directly time related: the use of sophisticated (and oftentimes expensive) equipment. A subset of DL efforts is that of web-based laboratory experiments.

This paper first examines the work of others in establishing remote instrumentation-based (versus simulation) experiments. There are many examples of simulation-based remote laboratories, but few cases of using actual hardware. Most investigators are delivering experiments via the Internet, but targeted to a single on-line user. Motivated by perceived shortcomings of present approaches, we propose a different approach that stimulates teaming, even when simultaneous remote users are geographically dispersed. Students do not share the same physical location, but rather a virtual one: a multi-user laboratory platform. In addition, we propose that web-based laboratory experiments can be more economical. Within the paper, this philosophical approach and the implementation details are explained. This approach is accomplished here in a digital signal processing laboratory experiment. The work here targets senior-level undergraduate electrical engineering students.

2. Background

Significant effort has been expended into organizing off-campus delivery of lessons using multimedia tools [1]. Laboratories based on simulation techniques have also been set-up for remote-access.[2] All these facilities intend to serve the need of increased schedule freedom of both students and teaching staff. Engineering education also has a costly component that is not directly time-related: sophisticated (and implicitly expensive) equipment, whose use might be difficult because of insufficient availability. Available equipment needs to be shared among researchers and students enrolled in different programs and with different schedules and knowledge levels. Supposing that the experiments are performed in real laboratories and in real time, usually off-line data processing is necessary. This can be accomplished either in the classroom---which supposes a longer student presence in the laboratory and computer set-up of the experimental platform---or in other locations, which means that experimental data have to be delivered somehow to the off-line processing unit, the preferable solution is the use of the Internet layer.

There are many efforts reported [3, 4, 5, 6, 7, 8, 9, 10, 11, 12] in the field of remote-experimentation, which allows more optimal use of the facilities and time in electrical engineering education. Most investigators are delivering experiments via the Internet, using the philosophy of a single on-line user. A different approach that stimulates the team spirit even when simultaneous users are dispersed and remotely located is presented here. They are not sharing the same real-location, but a virtual one: the laboratory platform.

In the field of remote experiments used for distance learning purposes, one can define two major areas. The first approach uses one or more data acquisition cards as a versatile interface between the physical phenomenon and the digital realm. The experiments are accessed either synchronously or asynchronously by at least one user via different software. Figure 1 shows an example of a client front-panel used for a remote experiment [7] employing a function generator and a data acquisition card located at “Politehnica” University of Bucharest (PUB). In that implementation there is no video module because the equipment operation is not determined by visual interaction with the user.

The second method uses standard digital instruments that can perform either standalone or connected to an external processing unit (usually, a local personal computer). The communication layer allows either serial or parallel data streaming and drastically determines the overall performance of the experiment. The first approach is more suitable for complex experimental set-ups and imposes special requirements in terms of security access.[13] The second method is mostly oriented toward in realizing a more realistic software replica of the equipment itself.[9] In this latter technique, a special concern is the equipment safety. The signal processing domain is very suitable for this second type of remote experiments. Papers [8,14,15,16,17] show the evolution of this approach as applied to spectrum analyzer topics.

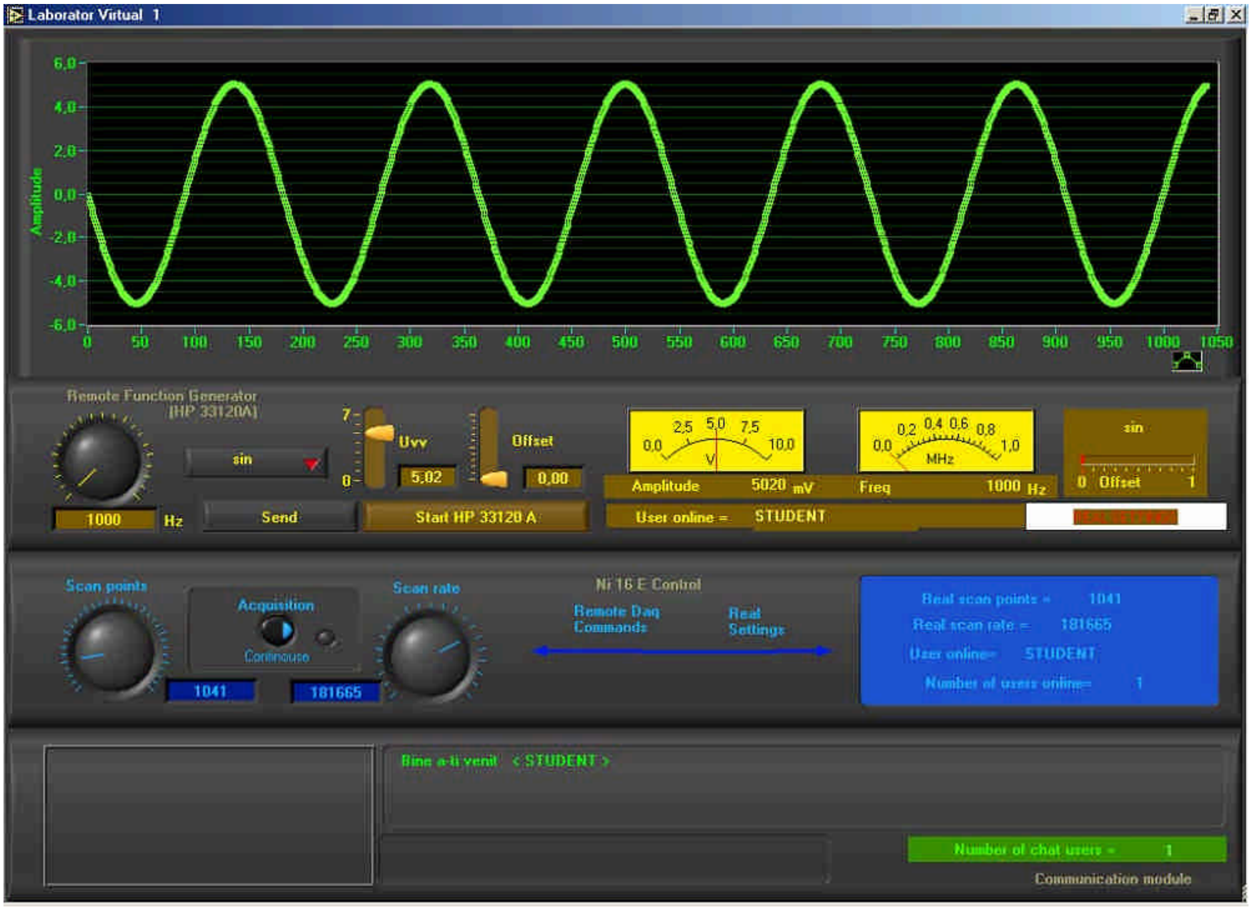

Figure 1. Example of a remote experiment using a signal generator and a data acquisition card.

Most educators have utilized Java platforms for greater portability and easier access via web browsers. There are also projects developed in the LabVIEW™ environment that can be executed on a LabVIEW player freely distributed by National Instruments.

We acknowledge that the dominance of the Internet in the development of information and communication technology has made *Web-based distributed solutions* increasingly attractive. Apart from providing other services, the World Wide Web is being looked upon as an environment for hosting modeling and simulation applications [2,10]. One of the major advantages provided by simulation is its ability to help students develop technical skills. The users manipulate virtual hardware (a simulator) to develop proficiency for operating the corresponding real world system. To preserve the advantage of the Internet, web-based laboratories require a tradeoff between simulation and actual operation of the laboratory equipment.

3. Philosophical Approach

Education has to be at least contemporary, if not in front of the leading technologies of a society. Rapid technological changes make even more difficult the task of shaping the cultural profile of future inhabitants of an interconnected world. More than other learning environments, higher engineering education faces greater demands from the global market - workforce. Moreover, life-long learning is a recognized necessity. Remote experimentation appears to be a valuable training tool for life-long, engineering education.

Although students have remote access to many “mind-artifacts” (*e.g.*, texts, figurative or non-figurative knowledge representations and inferences) – using either the Internet or their University intranet – they do not yet have open access to the laboratory equipment (the so-called hardware level of learning). Our project aims at developing a virtual platform where different users can share remote experiments using on-line equipment for educational purposes. A new approach, based on an open-access laboratory policy could extend the frontiers of modern engineering teaching tools, among which experimentation is an important component.

Most remote experiments distinguish between monitoring and control functions provided by the client applications at the user location. They are organized into so-called virtual laboratories, although virtual is only the physical presence of the remote-users simultaneously sharing access to the controlled equipment. To avoid confusion, we define the terminology adopted in this paper. Although no consensus has been reached for many of these expressions, we refer to the American National Standard T1.523-2001 Telecom Glossary 2000 [18], Webster’s dictionary, and the work done by specific researchers in this area.

- *virtual instruction*: training that (a) in which usually live instruction is conveyed in real time via telecommunications facilities, (b) that may be accomplished on a point-to-point basis or on a point-to-multipoint basis, and (c) may assume many forms, such as a teleseminar, a teleconference, or an electronic classroom, usually including both audio and video. Synonyms: distance learning, distance training, electronic classroom, teletraining.[18]
- *on-line*: pertaining to the operation of a functional unit when under the direct control of the system with which it is associated.[18]
- *interactive*: pertaining to a communications environment in which more than one party is equipped and ready to participate actively in a session or a protocol. Common usage of the term refers to a session where at least one of the parties is human and another of the parties is a software application.[18]
- *remote control equipment*: devices used to perform monitoring, controlling, and/or supervisory functions, at a distance.[18]
- *remote access*: pertaining to communication with a data processing facility from a remote location or facility through a data link.[18]

- *simulation*: a computer model of a real phenomenon or system. A 3D simulation is described by 3D models in a computer program. Simulations are used in computer games, training programs (flight simulators) and by scientists, who recreate, project into the future and predict real world phenomena.[19]
- *simulate*: to represent certain features of the behavior of a physical or abstract system by the behavior of another system.[18]
- *telepresence*: the experience or impression of being present at a location remote from one's own immediate environment.[20]
- *transparent telepresence*: the experience of being fully present at a live real world location remote from one's own physical location. Someone experiencing transparent telepresence would therefore be able to behave, and receive stimuli, as though at the remote site.[20]
- *virtual reality* (VR): a synthetic, computer generated 3D immersive environment. Immersion can be accomplished by wearing a Head Mounted Display (HMD) and position trackers which allow the computer to modify the output depending on your position. Most of your perception of the real world is blocked out while you are interacting with traditional VR. The terms VR or desktop VR is also sometimes used instead of Web3D or i3d for non-immersive Web3D technology.[19]
- *augmented reality* (AR): an augmented reality system generates a composite view for the user. It is a combination of the real scene viewed by the user and a virtual reality (VR) scene generated by the computer that augments the scene with additional information.[19]
- *laboratory*: (1) a place equipped for experimental study in a science or for testing and analysis; a place providing opportunity for experimentation, observation, or practice in a field of study. (2) an academic period set aside for laboratory work.[21]
- *virtual laboratory*: an interactive environment for creating and conducting simulated experiments: a playground for experimentation. It consists of domain-dependent simulation programs, experimental units called objects that encompass data files, tools that operate on these objects, and a reference book.[22]

We operate with a scientific meaning of *simulation* as "goal-directed experimentation with dynamic models".[23] Also, we denote *virtual laboratory* as being grounded to the first definition of *laboratory* presented above, that is, a place providing opportunity for experimentation. This place becomes a virtual location inside the Web, and has a distributed nature and a dynamic configuration.

Effective instruction of some topics in engineering requires experience with actual equipment, rather than small-scale replicas or simulation. Recently, scheduling flexibility for laboratory classes has become an important issue, since many students have extended commitments, especially part-time students. One solution addressing these issues is to develop web-based laboratories, on an Internet-platform from which real (vs. simulation) experiments can be conducted at anytime, without instructor surveillance or guidance.

Some educators feel that virtual laboratories are not as effective as manipulating the real equipment. For example, it can be argued that students miss the hands-on experience; however, remotely-located hardware is nonetheless superior to simulation in that respect. Often overlooked is the fact that, psychologically speaking, the remote student is shielded against the adverse consequences of misconnecting equipment; still, software protection interlocks prohibiting the student from making such mistakes increases the longevity of the equipment. For this reason, some institutions might consider initially utilizing the remote method to "train" the student before his/her use of the equipment for in-laboratory experiments. Another drawback to simulation is the fact that the student does not enter the actual laboratory, so there is less hardware troubleshooting (*e.g.*, loose wiring or connections) whereas the (non-simulation) approach taken here retains these possibilities but in a restricted form.

Most investigators are delivering experiments via the Internet, using the philosophy of a single on-line user. This is mainly the approach of commercial experiment providers, as they first became available at the beginning of 2003.[12] A different approach that stimulates *teaming*, is that of allowing simultaneous, remote users to share a virtual, multi-user laboratory platform. Implementation options include chat, video, archiving, hardware and software platforms organized in a multi-user approach. The sense of teaming is exploited by networked games, and this similarity with Internet gaming can be seen as an attractive feature to today's students, but also can induce a lower level of responsibility toward the experiment itself.

One idea behind virtual laboratories hosting remote experimentation is the versatile use of the equipment. Not only are there truly remote users accessing the equipment, but also there are local university students who utilize the laboratory hardware at the same time. In our approach, we restrict the local students' manipulation of the equipment to software access (vs. allowing them to physically manipulate the hardware). This leads to two different access modes, depending on the users' profile: (1) the local users who are present in the laboratory during the actual experiment, and (2) the remote users who attend the laboratory and access the equipment via the Internet. Both implementations require a multi-user, client-server architecture of the applications and allow complete data management [6]. However, major differences appear when considering the communication speed, the limitation in Internet bandwidth and, more critical, the multiple computing platforms.

A diagram of a general client-server application in the case of remote experimentation is shown in Figure 2. Guidelines for establishing a remote experiment inside a virtual laboratory were presented in [24]. Splitting the server into modules corresponding to optional features provides an increased modularity of the software portion of the experiment. One can implement different server applications for chat sessions, for video broadcasting, for user authentication, and for on-line help. These servers may be operating on different machines connected to various web nodes.

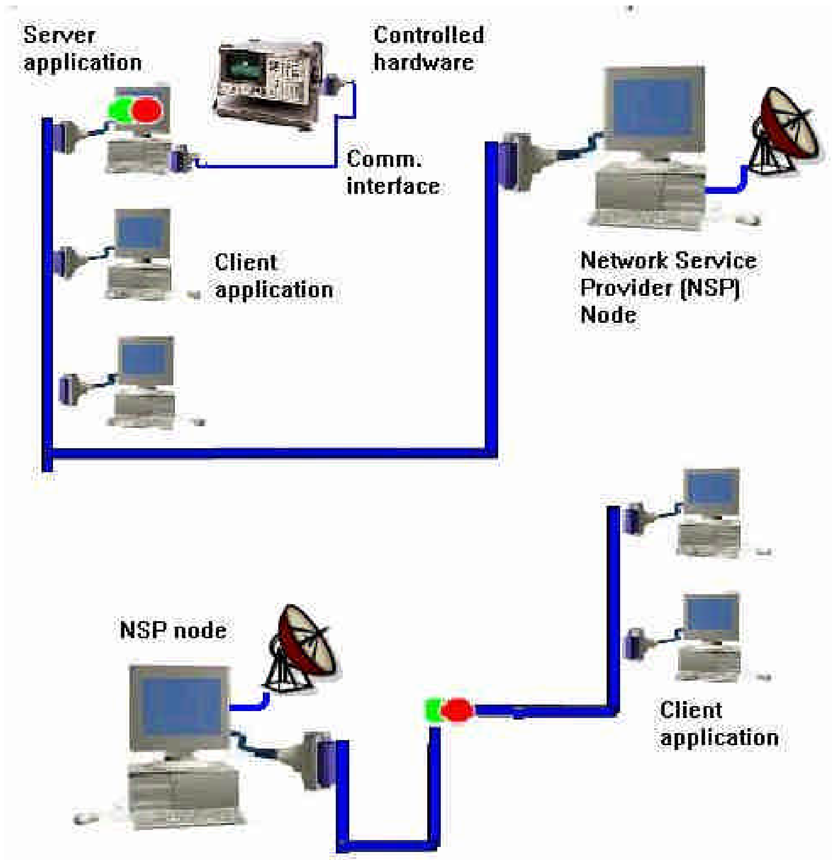

Figure 2. General diagram of a client-server architecture.

Additionally, institutional collaboration can be achieved through the virtual exchange of equipment, which can be accomplished in a "web-ring". Each institution provides specific experiment(s), for which laboratory equipment is shared together with experimental data and protocols. The bandwidth and number of users from each institution is "paid" in proportion to their contribution in terms of equipment and accessibility time. This is very good for overseas cooperation since the time differential favors extended use during periods when the home institution students are otherwise asleep. The diversity of electrical engineering topics taught and practically performed can be extended in this way.

4. Application

In this section an experiment designed for students enrolled in electrical engineering is presented. The particular hardware employed here is organized around a spectrum analyzer. Ultimately, this on-line laboratory seeks to present fundamental signal processing topics (such as frequency and amplitude modulation, signal separation techniques, and noise measurements). The application is also intended to serve as on-line course support for the in-class lectures on basic signal processing topics.

Many principles of the algorithms in this field are best illustrated by the operation of signal analyzers.[25,26,27] Due to its unique features in both amplitude and time/frequency domains, a spectrum analyzer is a sophisticated equipment seldom available in a undergraduate laboratory. Even when it is operated by students, they are mostly working in teams of 3 to 5 students. Selecting the proper functions and appropriate parameters for controlling such an instrument is highly dependent on, perhaps essential to, visual feedback from the analyzer display to the user. Particularly, the necessity for continuous access to the analyzer output screen makes multi-user operation difficult in the physical laboratory. This is in contrast to operate experiments that employ function generators and oscilloscopes. In those cases, the students know in advance the signal characteristics and measurements can be conducted after minimal adjustments. Spectrum analyzer requires a permanent control, highly interactive, with the user, who actually does not know the signal characteristics.

This virtual laboratory (VLAB) utilizes equipment and software distributed between two universities from which remotely-located students can perform experiments. The software solution is a multi-user, client-server architecture developed in the LabVIEW® environment. The server application is unique to the communication interface and protocol (*e.g*., serial–RS, USB or wireless; parallel–GPIB or Centronics-based) between the computer and the specific laboratory hardware.

Utilized here is an Advantest Spectrum Analyzer R3131, with a frequency range of 9 kHz to 3 GHz. It is a suitable instrument for illustrating basic signal analyses for teaching purposes. Its communication with an external processing unit can be either serial (RS232) or parallel (GPIB). Though slower, we choose to use serial communication between the analyzer and the server application host, since the client-server communication speed is the limiting factor.

Figure 3 shows the particular architecture of VLAB. One of its nodes, VLAB PUB, hosts a total of eight PC stations, and a network server, interconnected via a fiber-optic link with the main node of the Romanian Academic RoEduNet wide area network. Each remotely-accessed device is connected to a PC running a specific server application. Then the user is operating the equipment via a client application that can be formed by multiple client modules. For instance, the application shown in Figure 1 uses a client for chat module, another client for signal generator module, and a third client for controlling the data acquisition card. The servers corresponding to those applications are running on PCs located in VLAB PUB. Another server application enabling user authentication for each experiment is running on another machine in VLAB PUB. Because the spectrum analyzer is located at ASU, both server applications for controlling the instrument and for video broadcasting are running on the same machine at VLAB ASU. It is not necessary for both server applications to be housed on the same machine; in fact, the bandwidth availability can be improved if the video server is on a separate computer.

Figure 4 shows the server front panel, which is on the computer directly connected to the spectrum analyzer. The server alone controls the communication parameters between the server host and the spectrum analyzer. Changing certain features of the Advantest is restricted to the server administrator.

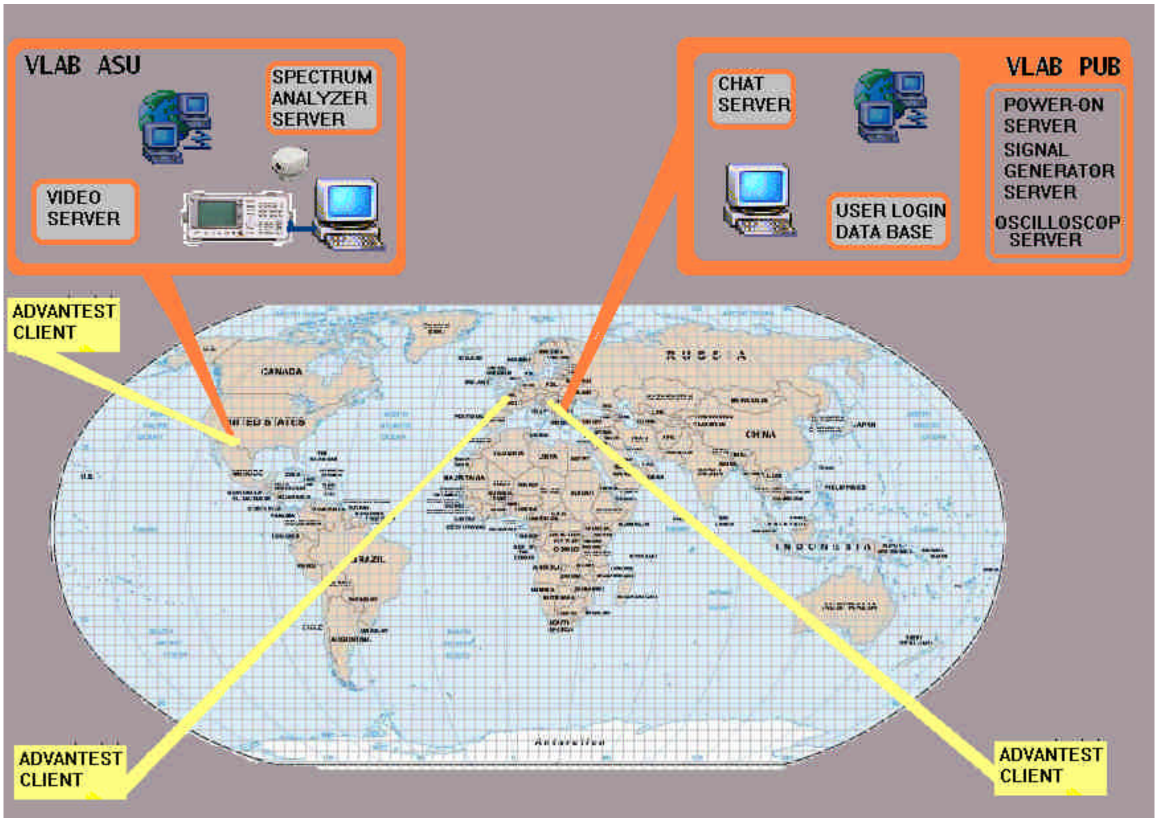

Figure 3. Diagram of specific client-server architecture employed in this project (PUB is "Politehnica" University of Bucharest, and ASU is Arizona State University).

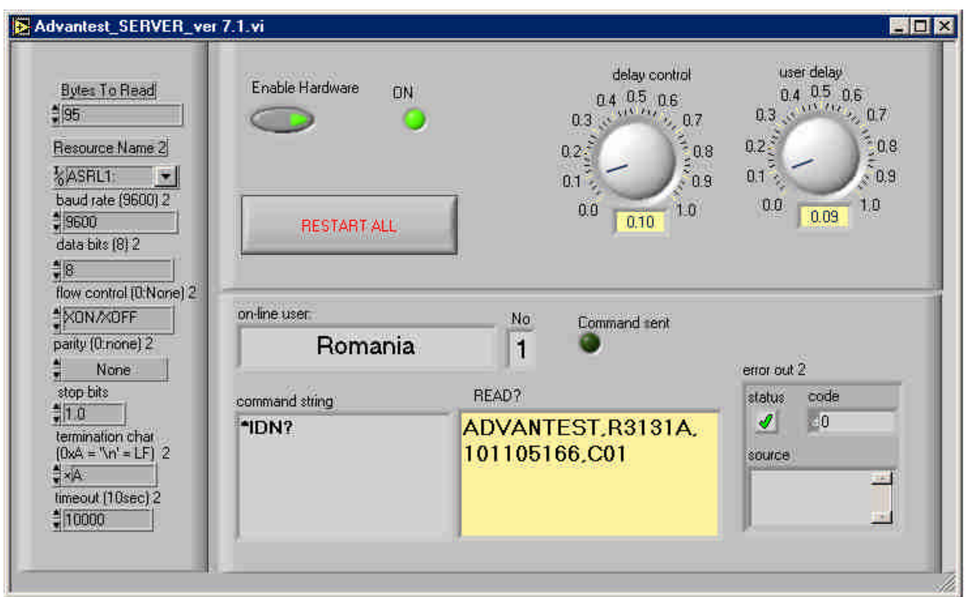

Figure 4. Spectrum analyzer server front panel employing serial communication.

Figure 5 shows the typical front panel on the remote master user's computer when the chat module is selected. We have chosen to design a generic, functionality-based graphic interface versus an exact replica of the actual instrument. This allows us to use same client interface for other spectrum analyzers. This allows easy upgrading of the software when new hardware is purchased or added. Moreover, this implementation provided an opportunity to re-organize the function buttons in a more straightforward, logically-structured arrangement.

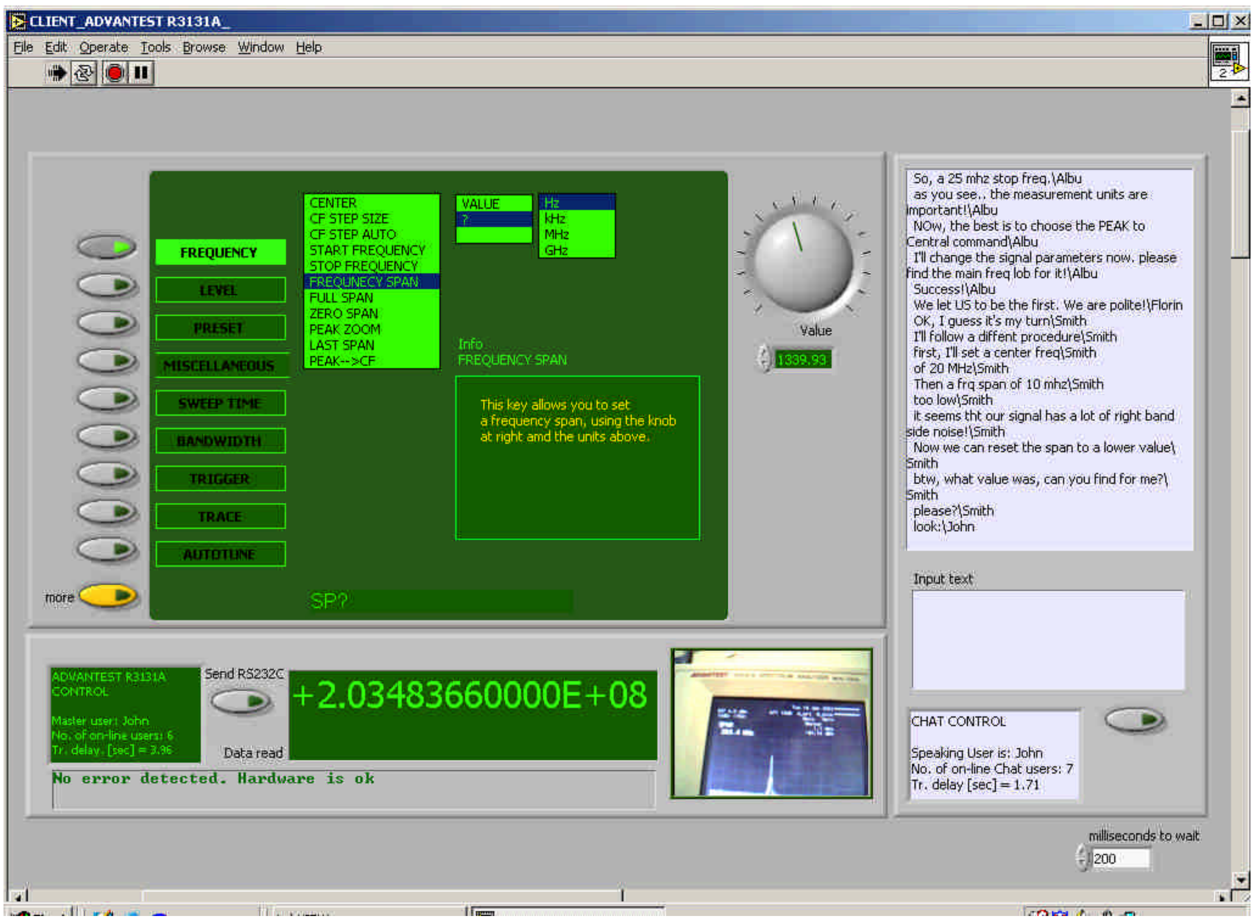

Figure 5. Advantest spectrum analyzer client application front panel. Master user (John) querying analyzer for the frequency span.

The bottom left portion of the front panel provides information on the number of on-line users and the (master) user who is presently controlling the experiment. Even in the on-line team environment, control of the equipment must be conferred to a single master user. In the main (upper part) window of the front panel, a software replica of the spectrum analyzer buttons is supplied together with an information box on the highlighted function. The information box contains Advantest technical data. After selecting a specific function and its parameter(s), the command string is shown in the bottom part of this window. To send this command to the spectrum analyzer, the student clicks the *Send RS232C* button. If the command string ends with a question mark, the Advantest will respond with an answer string, which is displayed in the window to the right of the *Send RS232C* button. In the bottom right corner, the video output from a camera monitoring the Advantest display screen is shown.

Figure 6 shows an example of the same client application, except that the front panel corresponds to a non-master user. The user's status, non-master versus master, is easily identified because the button in Figure 6 is labeled *Connect* instead of *Send RS232C* as in Figure 5, respectively. The previous *Speaking User* was Florin according to the *Chat Control* information window in the bottom right corner of the panel. The present chat user is Smith, who is announcing his intention of requesting a self-test of the spectrum analyzer. The master user is Mihai. Smith selects **Self Test** suboption of the **Miscellaneous** menu, before taking control by pressing the *Connect* button.

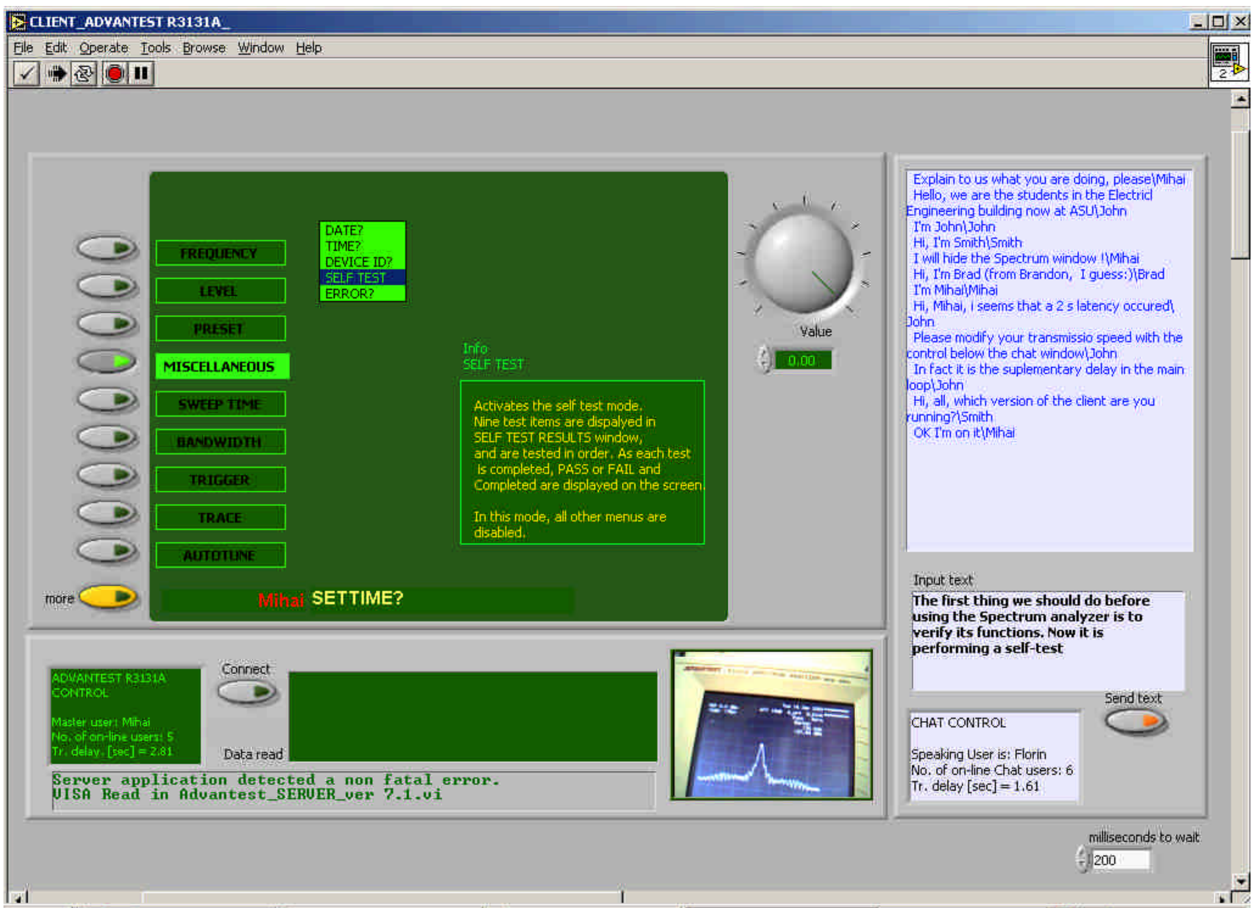

Figure 6. Advantest spectrum analyzer client application front panel. New user (Smith) preparing analyzer for self test prior to taking control from the present master user (Mihai).

In the present solution the students obtain access to the client application after entering their user name and password. This login validated by a server application that looks in a database maintained by the administrator. The authentication application and database are located on different computers to enhance security.

In the classical laboratory environment students can carry out experiments either chaotically or courteously. In the chaotic setting, students jostle for the right to operate the equipment; in the courteous atmosphere, students share the responsibility for controlling the measurement system. Similar possibilities exist for an on-line, multi-user laboratory. In the on-line environment, the chaotic situation would occur when multiple users send competing command strings. To avoid this, we have chosen to utilize the structure of a master user whose position alternates among the student users. Presently, a student user can assume the role of master user by sending the appropriate request string. To eliminate the possibility of users fighting for the master status, a scheduling procedure is to be implemented.

The portability of this application is limited only by LabVIEW, which requires different coding for Windows PC versus Macintosh platforms. The transferability is restricted to equipment that uses the Standard Commands for Programmable Instrumentation (SCPI) driver.

5. Conclusions

Designing such a multiple-access experimentation platform is especially effective for teaching purposes. Students can also practice utilizing the devices in a tutorial mode, before they actually perform the experiment. Software agents might enhance information availability by searching into related resources in order to guide the users of such a laboratory.[28] Such an agent system is under development on a Java platform, while the equipment remote-control is realized as a LabVIEW library. A communication layer between the two platforms has to be designed. Also planned is student assessment of the VLAB experience.

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