Electrical measurements student laboratory – replacing hands-on with remote and virtual experiments

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Abstract This paper discusses the problem of transferring knowledge to students of an undergraduate electrical measurement course, and also describes the design of a Web-based measurement laboratory and experimental setup of Web-based experiments at the Faculty of Electrical Engineering and Computing (FER) in Zagreb, Croatia. The suggested design offers the possibility of teaching or presenting high-precision experiments using expensive or sensitive equipment that is unavailable in sufficient quantities to serve large numbers of students.

Keywords distance learning; teaching; virtual laboratory

In order to meet the basic educational targets required by the development of science and technology, the Faculty of Electrical Engineering and Computing, the University of Zagreb (FER) is regularly updating its electrical engineering curriculum. Today, the undergraduate curriculum is organised as the four-year curriculum FER1, in which students first have to complete a two-year-long sequence of core courses that introduce them to fundamental electrical engineering concepts; then they can choose one of six branches of studies for their final two years of studies: Electrical Power Engineering, Electrical Machines and Control of Electric Devices, Automatics, Industrial Electronics, Radiocommunications and Professional Electronics and Telecommunications and Informatics. Each year the Faculty enrols more than 600 students. The only two-semester long course in the sophomore year of the electrical engineering curriculum is the Measurements in Electrical Engineering. It builds on several previous courses in the freshmen year. The presentation of the course is through a two-hour lecture and three-hour laboratory per week. The lectures are designed to cover the material and give theoretical background for the laboratory experiments. The electrical measurements laboratory supporting the course is the oldest and most comprehensive student laboratory in the Faculty, dating back to 1924. With several decades of history behind it, and with the commitment of continual updating and modernisation of the equipment and experiments, the students are today working on more than 50 experiments in the laboratory covering a wide range of electrical measurement topics: fundamentals of measurement science, analogue and digital instruments, oscilloscopes, measurement amplifiers, bridges, data acquisition fundamentals, different measurement methods for electrical and nonelectrical quantities, sensors and transducers, magnetic measurements, measurement uncertainty, etc . . .

Laboratory work as part of education

Education is not just the gaining of knowledge (accumulating facts and principles). Science has been built up over the centuries through observation, investigation and experimentation. The students must be able to apply the knowledge they learn, to interpret information that is unfamiliar to them, to explain phenomena, and to solve problems. This is especially true in teaching electrical measurement topics, and this kind of experience should be given to the students through laboratory work. Experimentation brings the course theory alive. In this way, students can see how unexpected events can affect measurements in a real world. However, due to expensive equipment, the necessity of repeating the same experiment many times (because of the large number of students) and insufficient number of qualified teaching personnel, measurement laboratories for didactic purposes are difficult to set up. This makes practical education of students and engineers difficult, especially in the fields of quality control, test engineering and metrology.

Hands-on versus remote and virtual laboratory

The classic hands-on laboratory experiment consists of various equipment put together on a bench in a meaningful way so that students can perform the practical work and get first-hand experience of the equipment and various factors that can interfere with the measurement. Thus, the students are receiving the necessary qualities that an engineer must have once he or she graduates. It also offers the students the chance to work collaboratively and to interact with the equipment. Most importantly, the student can learn by trial and error in a real environment. In a real laboratory, students learn that sometimes the instrument is not working, not because there is something wrong with the instrument, but because there is a faulty wire somewhere in the circuit, or the instrument is placed too close to some other instrument that can cause a wrong reading (like a monitor, etc . . .). On the other hand, real laboratories need a huge number of highly educated personnel to administer a lot of students. The time must also be divided up because the laboratory has a limit to the number of students that can attend experiments simultaneously. As there are over 600 students that need to be accommodated in our laboratory, every experiment is placed in three different rooms, and carried out by a maximum of four people simultaneously. This set-up ties up badly needed space, and consumes students' time in menial set-up and tear-down procedures. The equipment is also rapidly changing, which becomes a financial burden to the university.

The wide spread of Internet-based facilities has had a great influence on measurement-related tasks and measurement teaching problems. The World Wide Web became a platform that can enable learners to get in touch with measurement resources worldwide by requiring a minimal connection cost, allowing the realisation of numerous flexible and customised measurement experiments. However, student engineers need to be exposed to the physical experiences – and the uncertainties – of real environments, and that can be achieved only in real hands-on laboratories. In virtual environments instruments tend to work a little too perfectly. The best that can be achieved with the use of modern technologies are the remote laboratories where real equipment is accessible through web-based applications. They are similar to virtual laboratories, but unlike simulations, they provide real data and uncertainties of the real world. There are now four main approaches that are followed for the remote teaching of measurement science:

- Web-based lectures and seminars, sometimes interactive, mainly directed to professionals that want to reduce the start-up time for new applications;[1,4]
- Web-based delivery of teaching material for University courses, including slides of the exercises;[5,6]
- Simulation of actual experiments that are to be executed either remotely or on the user's PC;[7,8]
- Remotely accessible laboratories where the students can access the actual instrumentation through a web page. [2,3,9]

In case the distant experiment is unavailable, or in the event of network problems, some remote experiments are suitable to be easily transformed to a virtual laboratory, by providing controlled random data or past measurement data instead of real measurement data, without any loss of the functionality of the experiment or student experience. This is true only in the case of experiments where students' work is based on the extraction of information from acquired data.

The main components of every remote laboratory are: measurement devices (instruments, devices under test, additional equipment), measurement server (controlling and collecting data, connected to the measurement devices) and laboratory server (with remote laboratory hosting software). Measurement and laboratory server can be executed on the same computer. Measurement devices are usually connected to the Measurement server (MS) through standard interfaces such as GPIB, RS232, USB, PCI and others. The experiment software controlling them is usually developed in graphical programming tools like LabVIEW, from National Instruments, or Agilent VEE (HP VEE) from Agilent Technologies, or other specific software that controls them through the above-mentioned interfaces. The simplest case of the remote laboratory is an experiment (a group of real instruments and electrical circuits) that is connected to the computer through a standard interface (DAQ, GPIB, RS232, parallel, etc.) and with the host computer connected to the network. The client side can be any computer connected to the Internet running a simple Web browser. Once connected, the client will be able to see the same front panel as on the local computer hosting the experiment and also will have the same program functionality.

FER Web-based measurement laboratory

As previously explained, some of the experiments have to stay hands-on, while others can be implemented in virtual environments to reduce costs, and also offer students a chance to stay in touch with recent developments in science and technology. Not every remote experiment can be a good substitution for a hands-on experiment, and also not every experiment can be implemented remotely. It was shown that only when presentation and analysis of the measurement data can be computer supported or where experiments tend to be computer-oriented, can remote laboratories be useful. On the contrary, in those experiments where students can learn more by actually connecting the hardware or where there are certain problems in the experimental set-up in real conditions, remote experiments will be a poor replacement. (Typical examples are experiments carried out in the first year of undergraduate studies, where students are facing the basic measurement equipment for the first time.) Having this in mind, the Web-based laboratory platform has been considered. The necessary requirement for the laboratory experiments was that they have to be accessible locally (in the laboratory room), but also over the network. Therefore, it was the first step during the realisation of the FER Web-based measurement laboratory to create a system capable of sharing these experiments over the Internet. LabVIEW is today the most confirmed way to communicate with the instruments, mainly thanks to a powerful graphical user interface and huge number of possibilities in displaying data. LabVIEW is easy to learn, and can be used to teach the functional principles of devices, conducting measurement methods and experiments. Also, LabVIEW has the option of using the Instrument Simulator, which simulates the operation of both a digitising oscilloscope and a digital multimeter (DMM). As such, LabVIEW has been chosen as the platform for experiment controlling software. It also has its own solution to development of a Web-based remote laboratory system – the Remote Panel feature – but the disadvantage is that it requires the client side to have LabVIEW's special Run-Time Environment previously installed. Also, the Remote Panel feature does not provide some kind of advanced user access control and auditing, and also there is no solution for integrating several experiments into one web portal. National Instruments also offers LabVIEW Internet Toolkit that was found to be partially suitable for our purpose. It provides flexibility and easy implementation of serving LabVIEW's VIs images over the network, but for our purposes lacks adequate user access control/auditing, reservation and it cannot integrate several experiment hosting computers into one web-learning portal.

Virtual laboratory design

To coordinate the different users on the network and connect them to the appropriate measurement hardware, the FER Internet Laboratory uses a central (master) server (MS) and several decentralised experiment control servers (ECS). Experiment control servers are placed in their own intranet for security reasons and are connected to the outside world via a master server which acts as a network proxy server. In addition, a specific module controls the overall laboratory system. A specific scheduling system placed on MS manages the catalogue of available experiments (instrumentation) and redirects user requests to the first available ECS (see Fig. 1). The requestor finally gains control of an experiment that is running in LabVIEW VI (on an ECS) without any need for installing the LabVIEW environment on his or her computer. A MS is the only machine that is directly accessible through the Internet, while other ECSs are not visible directly to the clients. They are accessible only through a web application, which authenticates users, gives them the right to run experiments and monitors every user action. Every ECS is placed in a student measurement laboratory or in some special laboratory and is connected to a set of

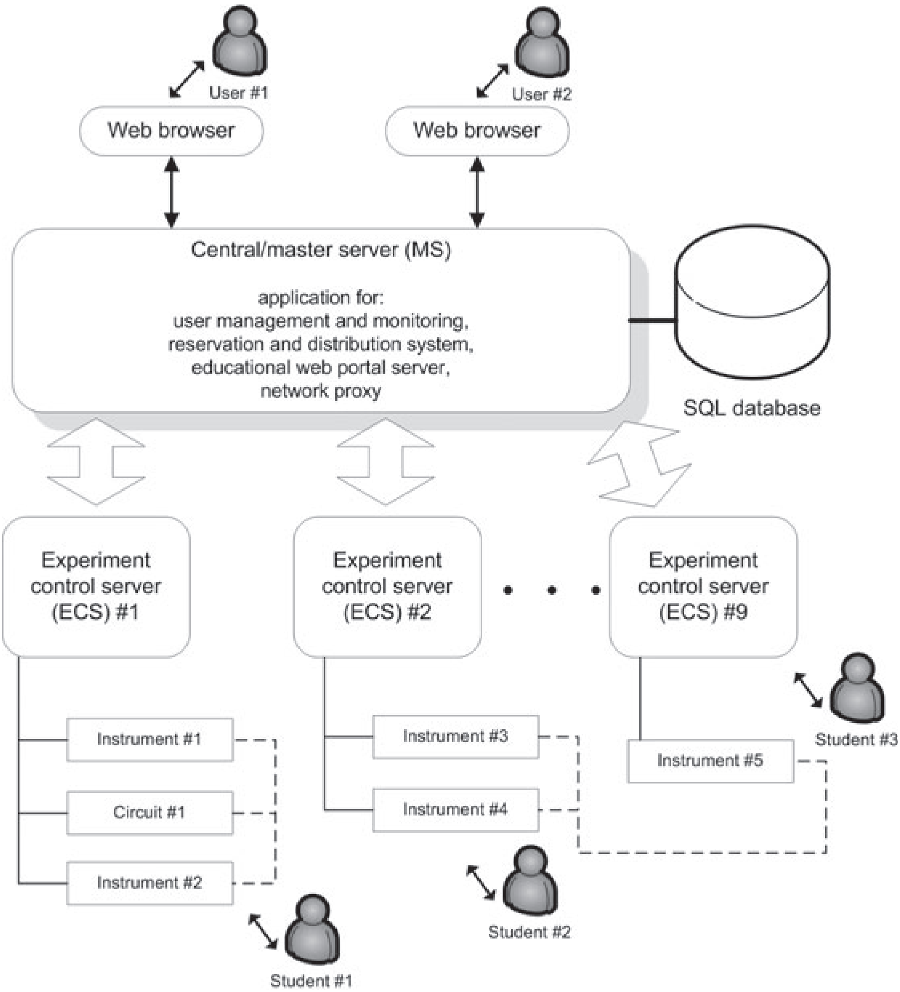

Fig. 1 *Concept of FER web-based laboratory shows data and communication flow between users and measurement hardware.*

instruments and circuits through one or more interface cards. The GPIB (IEEE 488) interface is used to connect other compatible instruments to the ECS. The software that controls experiments is LabVIEW, with LabVIEW Internet toolkit installed on every ECS. When an ECS in a laboratory is occupied with students working on some experiment, that experiment is not available through the web portal, but the students can work in a virtual environment with simulated data. When the ECS is available, and the LabVIEW environment for hosting that experiment is ready, MS allows some users to access the experiment over the network. In addition, the user may book certain experimental setups in advance. All user data, the reservation data and the hardware device data are stored in a MySQL database. The web portal and content management system was created in PHP scripting language. This concept allows a flexible extension of new devices and experiments. The key advantage of this concept is that the user only needs a web browser without any need for downloading applets and installing run time environments of any kind.

To deal with these problems adequately, it was necessary to create a special web application that is capable of identifying visitors, giving them appropriate rights, reservation of resources and experiments. A brief representation of a realised laboratory control solution is shown in Fig. 1.

Virtual and remote experiments

A few of the hands-on experiments have been selected to be offered to students also as virtual and remote experiments. A hands-on magnetic measurement experiment is shown in Fig. 2, and its virtual equivalent in Fig. 3.

In addition, a new virtual and remote experiment presenting a high accuracy resistance comparison method has been selected as an example, which is impossible to present to large numbers of students in a hands-on laboratory. For comparison of standard resistors ranging from 1 mΩ to 100 MΩ, a method of comparison with the nominal ratio 1 : 1 and 1 : 10 has been developed at FER, using two digital voltmeters (DVM) with $8^1/_2$ digits, (Hewlett Packard model 3458A). Two voltmeters are used, one parallel to each resistor. Each of the DVMs designated as HP1 and HP2

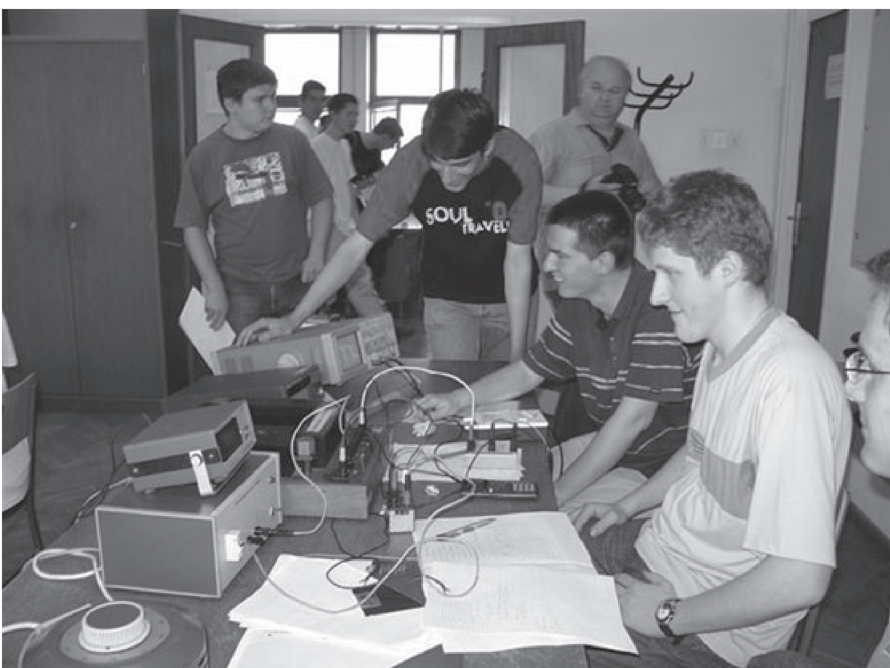

Fig. 2 *Hands-on magnetic measurement experiment.*

Fig. 3 *Virtual magnetic measurement experiment.*

measures voltage drop across one resistor. The measurement process is automated by a personal computer equipped with a GPIB-488 card for operating the voltmeters, and by a specially built PC-controlled apparatus for changing the polarity of the current and changing the position of voltmeters. The DVMs are connected with a GPIB-488 bus to the PC. The automated data acquisition software has been developed using LabVIEW. The realised front panel (Fig. 4) offers the necessary flexibility to the operator, which includes measurement set-up, such as range, number of samples and duration of DVM integration time, builds the calibration database, performs the statistical analysis, and creates a print-ready calibration report with all relevant data.

As the resistance standards are placed in a thermostatted oil bath, they cannot be moved to a student laboratory. Also, as there are only two $8^1/_2$ digit multimeters available, the only possibility to present this high precision method to large numbers of students (over 600 students attend the course 'Electrical Measurements') is through web-based remote laboratory experiment (see Fig. 2).

Virtual and remote experiments – students' and professors' view

While hands-on laboratories offer invaluable experience to the students, the remote laboratory offers new possibilities to both students and their professors, especially in giving the students the possibility of working with equipment which is too

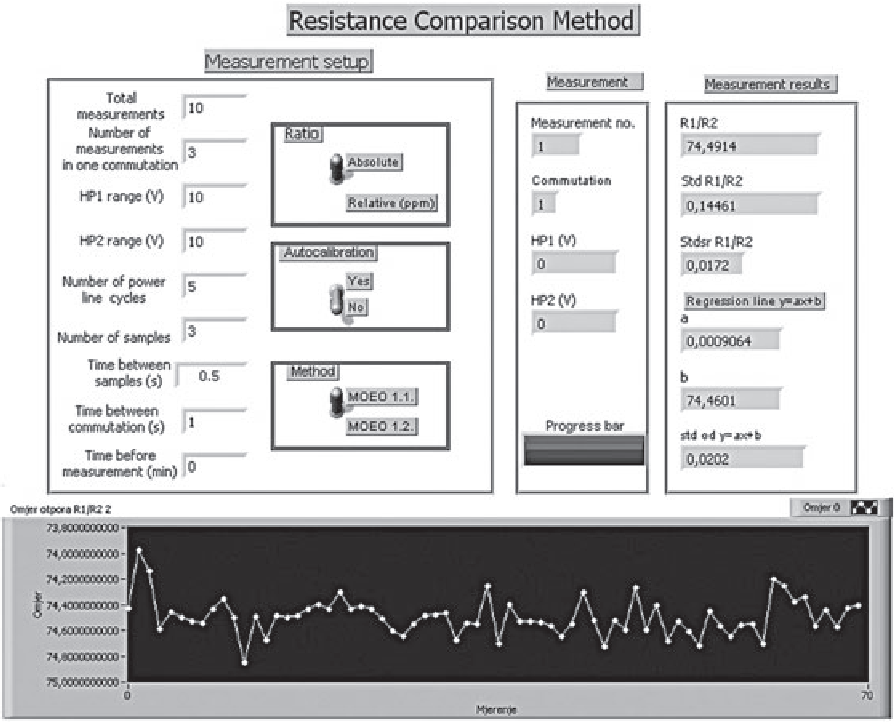

Fig. 4 *Virtual front panel of resistance comparison method.*

expensive to be held in the hands-on laboratory. In the FER electrical measurement laboratory, as four students are working on the experiment simultaneously in the hands-on laboratory, it is estimated that two students are working most of the time with the equipment, while the other two students are passively sitting, or at best are writing down the results. Due to time and space limitations, it is impossible to organise a laboratory for two-person teams in the hands-on laboratory. However, the virtual laboratory is always on, accessible even from the student's home. This way, each student can have a total experience of the experiment, even though he or she will not get in touch with the real equipment. Thus, the virtual laboratory can serve as an addition to the hands-on laboratory, but it must never replace it completely. The students, especially those who are also involved in information and communication technology studies, have shown great enthusiasm about the new remote and virtual experiments, as it will offer them the possibility to get in touch with new technologies.

Testing the effectiveness of an experiment and students' reaction to it is a very complex and demanding task because things like understanding of essence, a feeling for a certain measurement and the response to coincidental influencing factors can hardly be measured. Some authors[10] suggest testing of students' understanding of experimental concepts (laboratory and test results) as the measure of cognition. This approach could be used in cases where the goal of the experiment is to give to the student strictly defined and testable knowledge or understanding. Testing of other, less self-defining, but no less important, experiences and understanding can however be done only through the exercise of practical work whose results may be much more difficult, or even impossible, to quantify.

A group of 70 students was tested through the 'Magnetic measurements' experiment as one in a series of 15 hands-on experiments. Results from the remote laboratory were compared with results from the hands-on laboratory. Their lab reports and gained knowledge were tested and they were asked to compare certain aspects of remote and hands-on laboratories. One of the main questions for the students was to rate the effectiveness of the remote laboratory compared to the hands-on one. Figure 5 clearly shows that 84.1% of students of the second group consider the remote laboratory to be the same or more effective than the hands-on one. A pilot group that was tested before showed similar results (72%), and both results are comparable to the results found in other papers. The difference of 12% can be explained by the fact that the pilot group had not done 15 experiments of this type, and they gave very high ratings for the possibility of manually connecting the experiment and to cope with hands-on measurement (they were mainly computer oriented engineers). The main group on the other hand rated remote experiments unusually highly, and it was shown that this was mainly due to the saturation with the other 15 experiments (high set up time, poor user interfaces and necessity of manually computing the data and drawing the graphs). Thus, most of them found the remote laboratory very interesting (87.3%) and were also very curious about the whole idea (93.6%). The rest of the results can be found in Table 1. For both type of experiments, the highest rating was given for the importance of preparatory instructions (96.8%) and teacher presence (87.3%). On the other hand, the biggest problem students had with the remote experiment was the fact that they did not read preparatory instructions carefully enough.

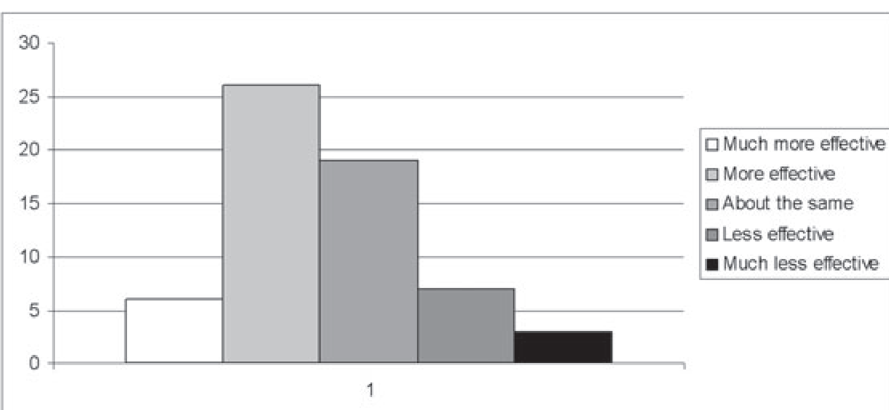

Fig. 5 *Effectiveness of remote laboratory compared to hands-on.*

TABLE 1 *Rating of certain aspects of remote compared to hands-on laboratories (on a scale 1–5 where 1 = hands-on is better and 5 = remote is better)*

Remote vs. hands-on	Mean	Std. dev.
Showing real conditions and problems	2.9	1.08
Enabling me to apply knowledge	3.3	0.93
Providing wider insight in a difficult field	3.4	0.96
Providing opportunity to gain knowledge	3.4	0.92
Providing opportunity to gain experience	3.4	1.18
Total time required	4.2	1.21

It was shown also that those students who spent more time studying theory and preparatory instructions had a much better score. Good theoretical background and interest in the field are the most important issues for any experiment, so every remote laboratory should include an entry test. Online help was not available in real time, and this was found to be a very important issue or even a problem since they were facing this kind of experiment for the first time. There were a lot of problems with PC security issues and most people spent too much time getting familiar with the whole system (e-learning platform). These problems would diminish if they executed more experiments this way. Also, the feeling of immersion was not rated as high as expected (av. grade 3.3, with 76% of people considering it to be more-or-less acceptable). This was mainly due to the lack of either a camera in the lab, or a video of the experimental set-up procedure (video is unacceptable for dial-up connections). As expected, convenience of access, scheduling time and reliability of setup of the remote experiment were all highly rated.

Conclusion

Training on real measurement equipment is very helpful to test students' theoretical understanding of measuring electrical quantities. The question is how to incorporate new technologies that offer new possibilities for designing virtual and remote laboratories with the required hands-on laboratory, if we want to give students the practical experience they will need once they leave university. The best way is to use the new remote and virtual laboratories whenever possible, but also to give students enough practical work with real equipment. Results of testing showed that more than 72% of the tested students considered the remote experiment the same or more effective than the hands-on one. Some correlation has shown that highly interested students are more interested in the hands-on experiment because of showing real conditions and problems more effectively. Control of the learning process of the students and the obtained examination results was analysed and it was shown that no significant correlation could be found in knowledge acquisition and the type of experiment, when this knowledge is strictly defined and well presented through the experiment's interface.

In this paper a web-based measurement laboratory for remote instrumentation management and distance training in electric measurement course at FER has been presented. In future other solutions will be tried and more experiments will be added to the laboratory. The internet laboratory and virtual instruments cannot replace real measurements, but it can prepare students and technicians to make reliable measurements close to real life.

References

1 G. Canfora, P. Daponte and S. Rapuano, 'Remotely accessible laboratory for electronic measurement teaching', *Computer Standards & Interfaces*, **26** (2004), 489–499.

2 P. Arapia, A. Baccigalupi, F. Cennamo and P. Daponte, 'A distributed measurement laboratory on geographic network', in *Proc. 8th IMEKO International Symposium on New Measurements and Calibration Methods of Electrical Quantities and Instruments, Budapest, Hungary, 1996* (IMEKO, 1996), pp. 294–297.

3 P. Arapia, A. Baccigalupi, F. Cennamo and P. Daponte, 'A measurement laboratory on a geographic network for remote test experiments', *IEEE Trans. Instrum. Meas.*, **49**(5) (2000), 992–957.

4 AppletVIEW, www.naciemiento.com.

5 S. Rapuano and F. Zoino, 'A Learning Management System Including Laboratory Experiments on Measurement Instrumentation', in *Proc. IMTC 2005 – Instrumentation and Measurement Technology Conference, Ottawa, Canada, 16–19 May 2005* (IEEE, 2005), pp. 1227–1232.

6 J. O. Strandman, R. Berntzen, T. A. Fjeldly, T. Ytterdal and M. S. Shur, 'Lab-on-Web: performing device characterization via Internet using modern web technology', in *Proc. 4th IEEE Intl Caracas Conf. on Dances, Circuits and Systems, 2002* (IEEE, 2002), pp. 1022-1–1022-6.

7 A. Bacciagalupi and M. Savastano, 'Computer-aided electrical measurements experiments', in *Proc. 5th IMEKO International Symposium on Intelligent Measurements, Jena, Germany*, vol. 2 (IMEKO, 1986), pp. 218–220.

8 M. Bertocco, F. Feraris, C. Offelli and M. Parvis, 'Training of programmable instrumentation: a student laboratory', in *Proc. 14th IMEKO World Congress, Tampere, Finland*, vol. 2 (IMEKO, 1997), pp. 13–17.

9 J. M. Thiriet, M. Robert, M. J. Martins and M. Hoffmann, 'Pedagogical resources reachable via Internet for teaching intelligent instruments: developments within a European thematic network', in *Proc. IEEE IMTC 2002, Anchorage, AK, USA*, 2002, pp. 1475–1479.

10 J. E. Corter, J. V. Nickerson, S. K. Esche and C. Chassapis, 'Remote vs. hands-on labs: a comparative study' in Proc. 34th *ASEE/IEEE Frontiers in Education Conference, Savannah, Georgia, USA, October 20–23, 2004*, pp. 17–21.