THE REMOTE LABORATORY – A NEW COMPLEMENT IN ENGINEERING EDUCATION

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Abstract *¾ An interactive Internet-based remote laboratory called I-lab has been developed. The objective of I-lab is to make advanced current versus voltage and capacitance versus voltage measurement instrumentation available to students via the Internet at low cost. Our approach is based on LabVIEW6i software packages and commercial measurement equipment. We expect I-lab to enhance student learning and we believe that I-lab will motivate students to undertake more advanced data analysis now that less time needs be spent on practical details. Students access the measurement equipment through one of two available client interfaces; a regular web page or a LabVIEW Player application. The remote laboratory that I-lab provides cannot be replaced by simulation software packages. Based on this concept, laboratory courses in many disciplines of engineering and science can be offered to students anywhere in the world.*

Index Terms ¾ distance education, I-lab, Internet laboratory, remote laboratory

INTRODUCTION

Interest in using the Internet in education as a complement to traditional educational methods is an emerging educational trend. Internet-enabled instrumentation is becoming more popular, especially in applications for distance education and remote laboratories. The remote laboratory for transistor characterisation offered by Norwegian University of Science and Technology (and developed in cooperation with Rensselaer Polytechnical Institute) is such example [1]-[3]. MIT also offers a remote laboratory, the WebLab which is part of their I-campus, for device characterisation [4]. Another cooperation program that offers a variety of remote laboratories is the European Retwine program, which involves universities in France, Germany and Spain [5], [6].

The Internet is an ideal medium for remote instruction purposes. Its protocol standards make data communication and graphical user interfaces easy to implement. National Instruments [7], [8] offers software packages that allow us to use the Internet for remote operation of lab instrumentation. Their Internet Developers Toolkit makes virtual instrument front panels viewable from standard web browsers by converting the front panels into images.

The concept of virtual instrumentation is to create a more powerful, flexible and cost-effective instrumentation system built around a computer, using software to control the instrument set-up and to provide an intuitive and user-friendly interface. A virtual instrument can easily export and share its data and information with other applications.

In this paper we report on the development of an introductory course on microelectronic devices offered to second-year undergraduate students where we apply I-lab [9] as a replacement for traditional laboratory exercises. In this course I-lab is used for characterisation of semiconductor diodes.

With an Internet laboratory we can complement and improve traditional ways of teaching at the university and give more flexibility to the students, who can perform measurements at any time during the day.

THE I-LAB SYSTEM

For instrumentation we use a Keithley 236 Source Measure Unit (SMU) for I-V characterisation and a Hewlett-Packard 4284A Precision LCR Meter for C-V characterisation. The system also includes an Agilent E5250A Switch Mainframe with a 10 x 12 Swith Matrix. The switch makes it possible to connect either the SMU or the LCR meter to one of five available diodes. The measurement instruments are connected to each other through a GPIB bus which in turn is connected to an NI GPIB-ENET/100 GPIB Ethernet bridge. A computer connected to our LAN is used for instrumentation control and data aquisition.

I-lab is based on a client-server structure using LabVIEW6i from National Instruments. The client communicates with the server via the Internet, see Fig. 1. The server communicates with the measurement equipment through the instrument GPIB bus via the Ethernet bridge. This structure allows the server computer to be located anywhere in the building. A graphical user interface on the server side allows the administrator to monitor and control the server as well as to modify the configuration of the instrumentation.

Users access the measurement equipment through one of two interfaces, i.e. a regular web page, see Fig. 2, or a LabVIEW Player application, see Fig. 3. The client provides interaction and communication directly with the server. The regular web page is realized as a pop-up window and does not require any files to be downloaded in order to perform the experiments. This is very useful for students performing the laboratory exercise via a slow Internet connection. Using the LabVIEW Player application, it is necessary to download the free-of-charge LabVIEW Player if it or LabVIEW6i is

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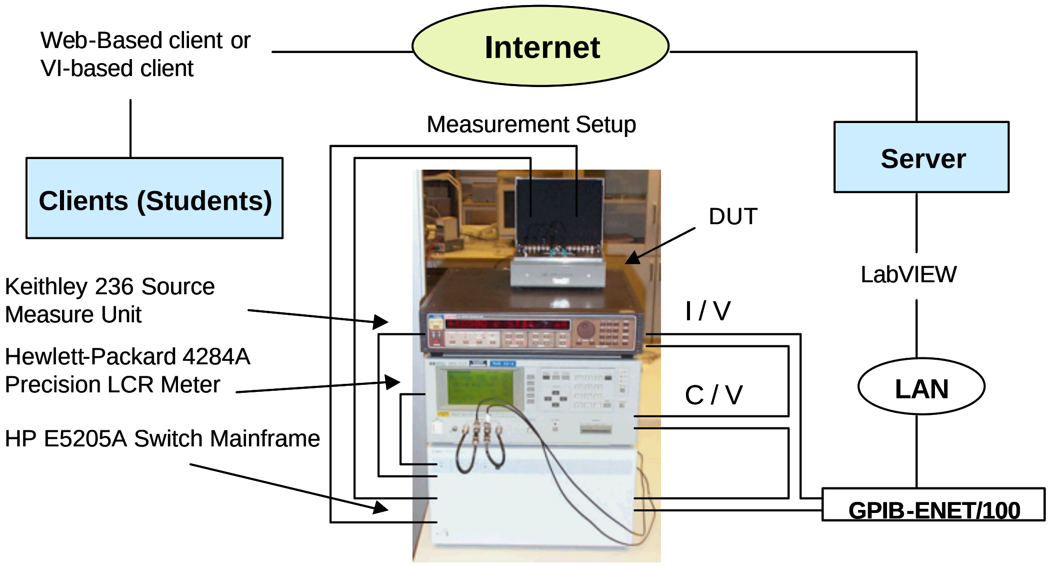


FIGURE 1.
THE I-LAB SYSTEM

not already installed on the local computer. This interface gives more flexibility and graphical details, which may be preferred by some users.

The users access the I-lab web site and by choosing one of the two interfaces the client window becomes available and measurements can be performed. For increasing the feeling of reality and understanding of the laboratory equipment, a photograph and a description of the equipment together with a circuit-diagram are shown on the web page. The user chooses the measurement set-up of interest (I-V or C-V) by entering data into predefined dialogue boxes. The client sends the input parameters to the server via the Internet. The server aquires the experimental results and sends them to the client. The results are then displayed in the client window as a plot and as a table containing the measurement data, see Fig. 4. The users have the option of saving the measurement data on their local computers by simply pressing a button. The data can then be processed in other programs such as MATLAB or Excel.

The input parameters in the client interface have a limited range for preventing such input values that could lead to experiment failure. The user receives an error message if that is the case. If an error should occur that leads to malfunction of the server, and hence affects the communication between the server and the client, the server sends an email to inform the administrator who can then correct whatever has failed.

When more than one person uses the remote laboratory the client measurement requests are queued. The Internet Developers Toolkit available for LabVIEW6i offers such a built-in queue system. When the server has responded the clients request is removed from the queue.

We have tested the system from off-campus using a standard 56 kb/s modem. According to our test, the time needed to access the web site and to start the client window using the regular web page, is about 30 seconds or less. It takes about 20 seconds or less for the system to perform a complete measurement with 10 data points, from sending the request to receiving and plotting the data.

ORGANISATION OF LABORATORY EXERCISE

This spring we used the I-lab in the introductory microelectronic device course with a class of about 350 students. The online-lab could be accessed 24 hours a day from any computer connected to the Internet.

At the same time as we introduced the I-lab system we also changed he organisation of the laboratory exercise. Focus was shifted from practical issues, like how to connect a diode to the instruments, to theoretical issues that could be discussed from analysing the now easily available measurement data. Students were also given the freedom to independently organise their laboratory exercise, and to determine, within some given constraints, which measurements to perform.

In the traditional laboratory set-up used for many years, we had a number of instrumentation set-ups available in the laboratory hall. The students often arrived poorly prepared, trying to figure out what to do during the laboratory session by reading the manual while progressing from task to task by frequently asking questions to the supervisor.

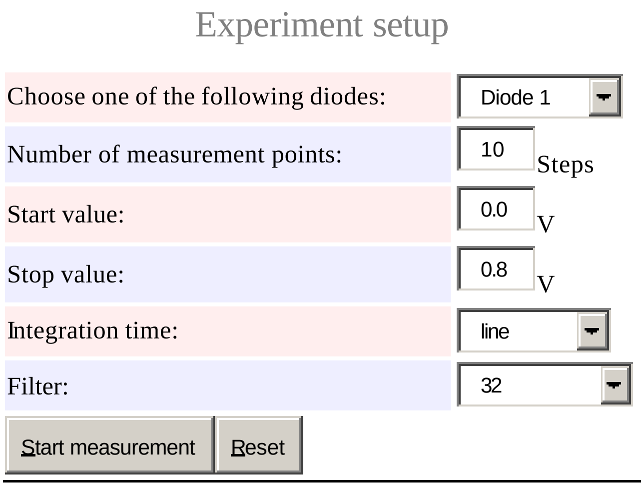


FIGURE 2.
REGULAR WEB PAGE TO PERFORM AN I-V MEASUREMENT

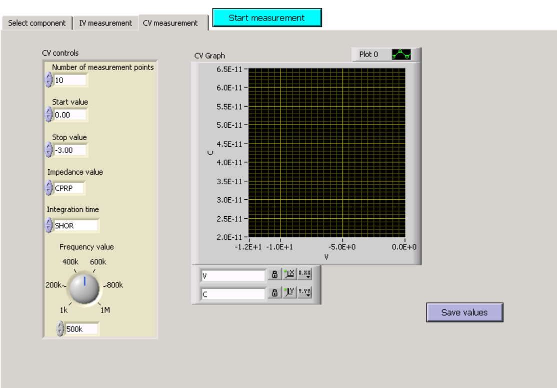


FIGURE 3.
VIRTUAL FRONT PANEL TO PERFORM A C-V MEASUREMENT

In its new form the laboratory exercise was formulated as an open task, where we simply wanted the students to figure out a number of parameters that are important for characterising a semiconductor diode. They were then asked to tell us how these parameters could be determined through measurements and to actually determine all or some of these parameters for a randomly assigned diode by using the I-lab system.

In the new form of the laboratory exercise the students were given about two weeks to perform the task - each student having a partner so that they were working in groups of two. After the two weeks they were given 10-12 minutes to present their findings to a teacher and to four other groups. The tight time schedule required the students to come well prepared with their data and findings properly presented on up to four or five transparencies. The laboratory presentations were concentrated to two days with four presentation sessions run in parallel. Each session was chaired by a professor or lecturer who determined which presentations were to be regarded as excellent (as by some predefined well specified guidelines available to the students). Each teacher thereby assessed ninety students.

Since this was a first time experience we did not know what to expect from the student presentations. We had some fears of complaints since the system had gone down a number of times, up to 24 hours during the first weekend without our notice. This is further described in the Technical Problems section. However, none of the potential student frustration was visible during the presentation sessions. On the contrary, most students were very relaxed and to their best - making a very self-confident impression and mostly showing great pride in what they had achieved during the laboratory exercise. Compared to the sometimes reluctant impression that students gave during the old form of laboratory organisation, this was a positive experience and definitely to be preferred. Of the student presentations from the sessions that one of the authors to this paper chaired, only one presentation was below the standards - the others were very good presentations. About 20 per cent of the presentations were excellent and were accredited with bonus points.

The extremely positive experience from the student presentations were partly supported by the other three supervising seniors. Of course, such impressions are very subjective and different teachers might look for and appreciate different features.

After completion of the course we received written review forms by the students and the result of the evaluation is presented in the next section.

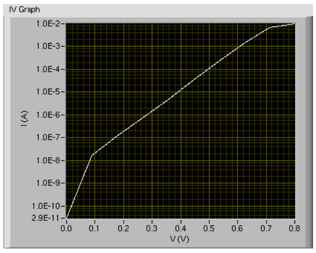
EVALUATION

During the last two terms two different student groups have used I-lab. First a small group of final-year students was given an assignment to solve using the remote laboratory. Our purpose was to get useful feedback for further improvements of I-lab before introducing it to the large class of 350 second-year students. The group gave us positive feedback and valuable suggestions that were used to improve the remote laboratory.

The students could choose whether they wanted to use the LabVIEW Player or the regular web page as an interface to access the measurement equipment. 85 per cent of the students preferred the easy access offered by the web page interface. A reason for that could be that a majority of the students used their private computers from home having only a slow connection to perform measurements. Therefore, they did not consider it worthwhile to download the LabVIEW Player application of 16 Mb, when an easier access alternative was offered. Another reason was that LabVIEW Player is not available for UNIX or LINUX. UNIX is the Operating System used by the school. 90 per cent of the students performed the measurements after school hours in the evening. None of the final-year students had to wait more than two minutes for the measurement results, which was most appreciated. The students also appreciated the possibility of being able to redo the measurement if they noticed that some values were incorrect or questionable.

I-lab was also used in the introductory microelectronic device course for second-year students as mentioned above. Unlike final-year students the second-year students have not yet adopted a research-oriented attitude toward learning and almost everyone of the students felt that the task attached to the remote laboratory was more demanding than ordinary laboratories, but they also felt that the task was more instructive. Here a minority of the students performed the measurements from home, but still 70 per cent performed it after school hours in the evening. Around half of the second year students had to wait more than five minutes, because of problems with the server to be described in the next section, but the rest of the students were very pleased with the time it took to perform a measurement.

IV measurement results

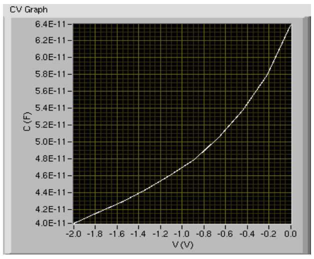


Press button to save data

Save

V	I
0.000	29.590E-12
0.089	17.606E-9
0.178	119.450E -9
0.267	726.460E -9
0.356	4.714E-6
0.444	33.830E-6
0.533	235.050E -6
0.622	1.434E-3
0.711	6.772E-3
0.800	10.000E-3

CV measurement results



Press button to save data

Save

V	C
-2.000	3.681E-12
-1.778	3.697E-12
-1.556	3.710E-12
-1.333	3.729E-12
-1.111	3.755E-12
-0.889	3.783E-12
-0.667	3.830E-12
-0.444	3.886E-12
-0.222	3.983E-12
0.000	4.201E-12

FIGURE 4.
THE FIGURE SHOWS EXPERIMENTAL RESULTS SENT FROM THE SERVER WHEN I-V AND C-V MEASUREMENTS ARE PERFORMED WITH THE WEB PAGE SOLUTION.

Afterwards a majority of the students in both groups were pleased with the remote laboratory and felt that it had more advantages than disadvantages. Advantages were that they could access the laboratory anytime, it was comfortable to be able to perform the measurements from home and they could redo the measurements if they noticed some incorrect values.

We discovered that one of the disadvantages of performing the lab via the Internet was that most of the students in both groups missed having an instructor to consult. About half of the students missed not having hands-on contact with the measurement equipment. The other half said that it usually takes a long time to figure out how the equipment works and that it is better to concentrate on the data analysis instead.

TECHNICAL PROBLEMS

With a small group of students, around 15, there were no problems for the LabVIEW server to hold that number of people (clients) in queue, but for a larger group, around 350 students, it became a problem. The server went down a number of times and needed to be restarted. A temporary solution was added to I-lab so that the LabVIEW server was automatically restarted after a server crash.

We do not know yet why the system goes down. The queue system can easily handle 300 requests. However, the queue can grow much larger when a client experiences no immediate response and therefore sends multiple requests. The queue then grows rapidly since a request is only deleted from the queue after being properly processed by the server. A client can thus have several identical requests queued. We are now investigating these problems and how they can be solved permanently.

DISCUSSION

I-lab provides real laboratory experiments via the Internet which cannot be replaced by simulation software packages without losing important features. When replaced by simulation software the “real stuff feeling” vanishes and a new problem appears to convince students that the simulation models correctly model the real devices. Also, fitting a simple model to a detailed model is not the same thing as fitting a simple model to measured data. The course evaluation form also revealed that measurements cannot be replaced by simulated data according to student opinion. Other universities or companies can also use the remote laboratory for characterisation of their own devices sent to us and then simulation software is not an alternative.

In the evaluation we noticed that it is important to make a well-structured laboratory experiment manual for the students who perform the experiment without an instructor. Otherwise students can easily get frustrated. It is also important to have an instructor available for questions during daytime and that a supervisor be available to the students during laboratory discussion sessions so that they are not left to themselves with a feeling of being deprived of the traditional guided hands-on experience.

We have compared the web-based client to the LabVIEW based client and noticed that there were both advantages and disadvantages with the two interfaces.

Advantages of the web-based client are that it is easier to use and that no source code can be read on the client machines. There is wide platform support available and no special software needs to be installed, except for the requirement that remote users need a web browser. A disadvantage is that anyone with a web browser can access the system unless passwords are requested.

An advantage of the LabVIEW based system is that remote control is much easier to implement, since both server and client are programmed in LabVIEW. It has more flexibility and graphical detail, and security is higher since only users with access to the client VIs can use the system. The administrator can choose via the server interface which users should be allowed to access the system. A disadvantage is that it requires remote users to have the current version of LabVIEW Player installed or else they need to download the software. Also remote users may have access to parts of the source code.

CONCLUSIONS

We have noticed that I-lab enhances student learning and motivates students to undertake more advanced data analysis since less time needs to be spent on practical details.

As more people are given the possibility of sharing the same measurement equipment and controlling it remotely from their offices or even from their homes, expensive equipment will become more cost effective. Inter-university co-operation also leads to increased availability of advanced measurement instrumentation. Also, advanced university instrumentation can be made available to external organisations and companies can make advanced technology available to students.

Based on this concept, laboratory courses in many disciplines of engineering and science can be offered to students anywhere in the world.

I-lab has been received positively in the introductory microelectronic device course and we are planning to expand I-lab and to use it in other courses.

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