Experience with Remote Access Laboratories In Engineering Education

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Abstract: *Early attempts to implement on-line laboratories for remote access have encountered significant problems including complex software that is expensive to maintain, the need for administrative support, and the difficulty of deploying new experiments when needed. Several groups have been developing frameworks for on-line labs that overcome these problems. Most have been motivated by the possibility of providing laboratory experiences for distance learning. This paper describes a framework developed at The University of Western Australia that aims, instead, to increase the participation of on-campus students in lab work, though it could also be used for distance education. The investment required has been less than 10% of the cost of some comparable frameworks that are not yet completed. We now have some evidence that our remote access lab system provides a cost-effective solution that can be sustained within normal operating budgets after the initial investment to build the system has been made. This paper also provides many comparisons with other remote labs reported in the literature.*

Keywords: *remote access laboratory, internet, engineering education, learning effectiveness, mechatronics.*

Introduction

Many remote on-line lab experiments have been reported in the literature recently (for a recent surveys see Faltin and Teichman 2002 and Ertugrul 2000). (Note that there are many reports of "virtual labs" where "virtual" means simulated. It is important to emphasise that this paper is entirely concerned with remote access to real equipment.)

From the first months of operation in 1994, our telerobot (Taylor & Trevelyan 1995) was used from time to time, on request, as a device to help with courses on robotics. One of the earliest examples of a purpose designed lab experiment system on the web was described by Henry (1996a, 1996b). Salzmann *et al* (2000) and Gillet *et al* (2000) describe an internet-accessible DC servo device and how it can be used to help with student learning. Shen *et al* (1999) and del Alamo (2002a,b) describe similar arrangements in which students can remotely test semi-conductor devices in web-enabled experiments. A further similar arrangement has been developed in Norway (Fjeldy and Jeppson 2001). Ferguson (1997), Röhrig and Jocheim (2001) and Lemckert (2001) and many others have worked specifically on distance learning applications of this technology. Qanser (2001) offers commercial software and hardware for web-enabled control system lab experiments, and widespread engineering packages such as MATLAB and LabVIEW have well-developed software tools.

What has been learned from these pioneering efforts? Few of the early pioneering web sites are still in operation, or even show signs of recent developments. In terms of academic papers there was a surge of interest between 1994 and 2001, and the pace of development has slowed since then. The telerobot site is the only one of these to have continuously operated throughout this period. The UTC web lab (Henry (1996a) has operated since 1995 but considerable efforts have been required for maintaining a modest system. Operating and maintenance costs have been significant: special purpose hardware-related software has been a major impediment to the maintenance of several projects. Maintaining software capabilities through significant operating system, computer hardware and user software upgrades has taken significant resources and is cited as an issue of concern by most authors.

High software investment and maintenance cost has not discouraged further development efforts, however. Several new remote labs are under construction at the time of writing, particularly in Western Australia, the USA, Germany and UK (eg Böhne *et al 2002,* Schäfer *et al* 2002). The UWA system is being extended, and the MIT iLab project is being re-implemented in a Microsoft .NET framework. Most current projects have devoted more resources to a remote lab framework: a set of tools that enable many different remote labs to be deployed without large additional investment in software and expertise. At the same time, the ready availability of commercial software has enabled many smaller institutions to set up remote labs on an individual basis (e.g. Senese et al 2000).

The relatively small number of working systems and the slow rate at which this technology is progressing reflect some significant problems with early implementations. The problems appear in the form of high installation, operation and maintenance costs. Some of the underlying causes are:

- Cost of maintaining the system to keep up with hardware, operating system, internet service provider and browser technology changes.
- Complexity of technological components and of integrating a working system.
- Lack of administrative support for large classes.
- Need to deal with unreliable internet connections.
- Need for collaborating users to be able to work together.
- Difficulties with integrating on-line lab experiences into conventional courses.

Remote Access Labs – Design Issues

In 2002 we commissioned a comprehensive internet framework for remote access labs that aims to overcome these problems (Trevelyan 2002). The experience of the telerobot project (Dalton 2001) contributed a reliable system design which became the basis for a new system built in the LabVIEW programming environment.

MIT are currently commissioning another framework with the help of substantial sponsorship from Microsoft (del Alamo 2003). While the design has many similarities to the UWA framework it is based on systems engineered with .NET and links to some other Microsoft developments in campus software. Similar frameworks have also been developed at EPFL (Geoffroy *et al* 2001), the Open University (Schäfer *et al* 2002) and Hannover University (Böhne *et al* 2002). Some of the budgets are large: the Open University and MIT projects will cost around US$2,000,000 each.

There is now enough experience with remote on-line labs to discuss some of the main issues in general terms. The issues include:

- Learning aims: supplement to hands-on labs, distance education, providing for flexible learning styles or sharing expensive equipment resources.
- Institutional aims: single demonstration facility, support for on-campus students, support for selected other institutions, or broad access.
- Lab experience: fast batch experiment with user settings, queued batch experiment with user settings, interactive experiment with on-line user interaction, data acquisition experiment with access to historical data, or programming experiment.
- Telepresence: instrument and chart display readings, still images (low bandwidth), sound, and/or real time video (high bandwidth).
- Access control: single user or collaborating team access, queue management, timetabling and scheduling.
- Administrative support: single task or multiple tasks, course management, student enrolment.
- Software configuration: single or multiple experiments, single or multiple servers, broken connection handling, student data management.
- Investment and expertise needed to extend system.

Simulation or Real Equipment?

One of the most frequently discussed issues is whether a simulation can serve as well as a real experiment, particularly when the experiment is conducted remotely. How can the remote user distinguish real equipment from a simulation, particularly if the user is a student who has little experience with real equipment? In 1995 I demonstrated the telerobot to a class at the University of Toronto and a graduate student asked which computer graphics package we had used to create the blurry still images that were actually obtained from our cameras and transmitted across the internet. He could not accept that there was a real piece of equipment there!

Böhne *et al* (2002) summarise a survey of 19 remote labs: “you often do not get the feeling of being in the lab or of working with real devices. It is hard to tell if the experiment is being performed in reality or just faked by prerecorded pictures and videos generated by simulation”. In reality, one has to rely on the belief by students that the equipment they are controlling is real. It helps if they can see the equipment from time to time as they pass the lab where it is physically located.

The continuing low bandwidth limitations of the internet impose strict limits on the extent to which images and sounds can be faithfully transmitted to a remote user. Real time video of reasonable quality is usually not feasible.

Several telerobot users who have visited the lab after using the robot remotely have remarked that the lab arrangement is somehow different to what they imagined. Because of this, we expect that it is beneficial if students have seen and preferably had the chance to use the equipment in the lab, though we have not yet evaluated this formally. One reason for developing the electric iron experiment is that all students would have an iron at home (though our students never seem to actually use their irons!).

Böhne *et al* (2002) propose that real hardware has limitations that emphasise constraints faced in real life situations. Unlike a simulation, real equipment cannot be reset to an arbitrary starting condition: a simulation application on most computers can be “killed” and restarted almost instantly. It can be difficult to create a simulation: the domestic electric iron described later is very simple in principle but would still be a significant challenge to simulate faithfully (eg see Hites 2002 concluding comments). A further difference is that a real device is imprecisely known, and we cannot vary its characteristics or speed up its response. This means that experimental procedures with a real device are not likely to be the same as explorations with a simulator.

Of course, the advantage of a simulation is that students do not have to wait: they can work with a simulation running on their own computer. However, the fact that students have to queue for a real piece of equipment (if it is being used by someone else) emphasises the reality for them.

Lindsay and Good (2001) reported an unusual experiment in which they compared hands-on lab learning, learning from a simulation and learning from a remote lab. This work has continued but the final results are still to be published. This pilot study was inconclusive, but seems to indicate that when it comes to specific material relevant to a particular lab it is hard to distinguish the results. Hites (2002) concluded from student feedback that remote labs are best used as a supplement for hands-on labs.

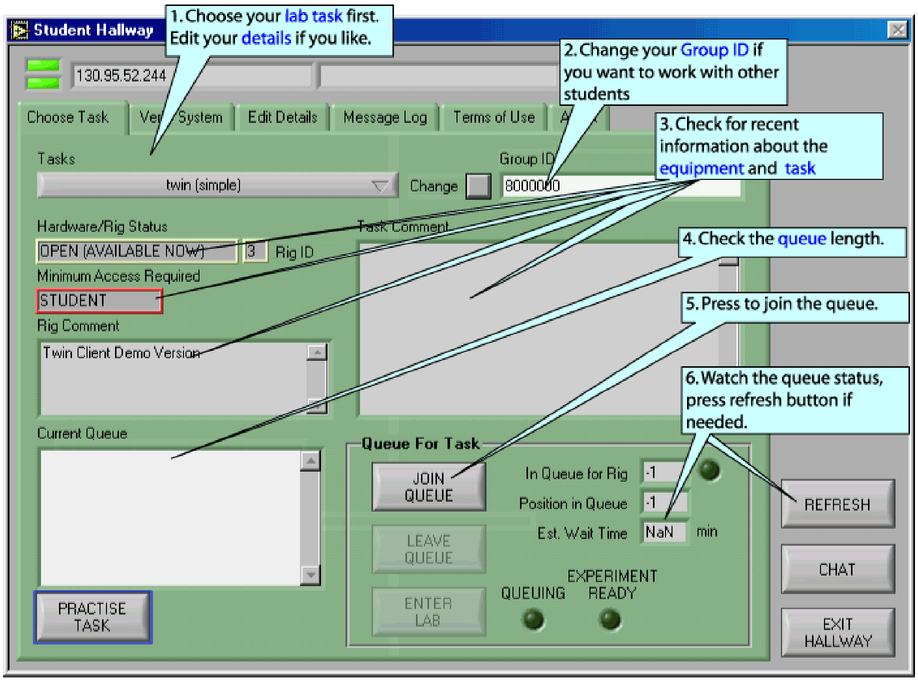
The Lab Experience

Lab exercises present a large range of different experiences. Many require extensive hand manipulation which would be too costly to provide remotely using telerobotics. However, since most engineering measurements can now be recorded electronically, it is possible to offer a wide range of lab experiences remotely.

We can consider the following kinds of remote experiments:

- Queued batch: the user sets parameters and transmits a command to begin the experiment. There is no user interaction during the experiment. Either the experiment happens so quickly that interaction is impractical, or interaction is undesirable, or is simply not provided for in the software.
- Real time interactive: the user can change parameters and observe results in real time. Here there are three limiting factors:
    - The network round trip time: the time taken for a command to be transmitted to the equipment and the initial response to arrive at the user's computer to be displayed – this is typically between 0.1 and 0.9 sec.
    - The network bandwidth may restrict the type of feedback available to the user, and the rate at which it can be displayed.
    - Streaming video or sound may be delayed by several seconds so that it can be displayed correctly at the user's computer.
- Real-time measurement (typically with archives of previously recorded data). In this kind of experiment there is no need for the user to set controls except, perhaps, to select the desired data characteristics. Time delays in transmitting the real-time data do not matter, but may differ between data and video streams.
- Programming experiment. In this kind of experiment, the user is expected to develop code for a programmable device. While working on the code there is no need to access the equipment. When ready, the code needs to be downloaded and then executed, possibly with some kind of user interaction.

The following sections present some current examples of remote experiments to illustrate this classification.



130.95.52.244

Tasks: twin (simple)

Group ID: 8000000

Hardware/Rig Status: OPEN (AVAILABLE NOW)

Rig ID: 3

Minimum Access Required: STUDENT

Rig Comment: Twin Client Demo Version

In Queue for Rig: -1

Position in Queue: -1

Est. Wait Time: NaN min

1. Choose your lab task first. Edit your details if you like.
2. Change your Group ID if you want to work with other students
3. Check for recent information about the equipment and task
4. Check the queue length.
5. Press to join the queue.
6. Watch the queue status, press refresh button if needed.

Figure 1: Typical hallway interface for students waiting to use the UWA system.

Instrumented Electric Iron

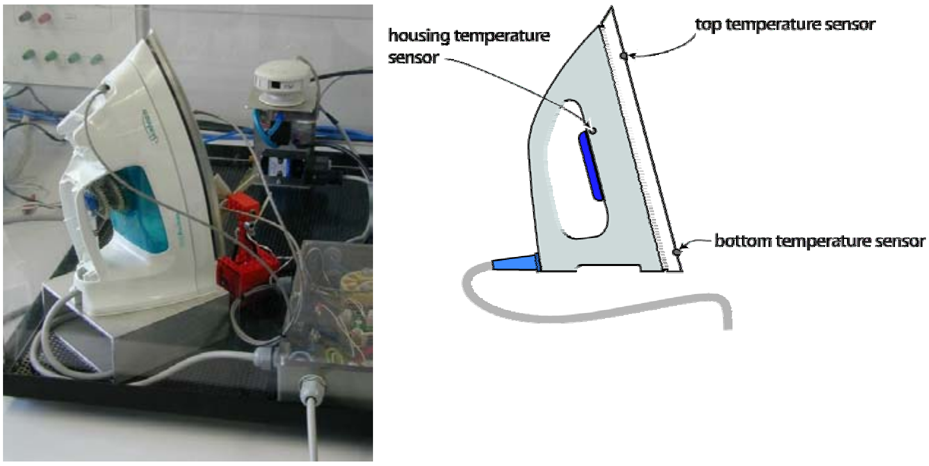


Figure 2: Instrumented remote access electric iron equipment at UWA

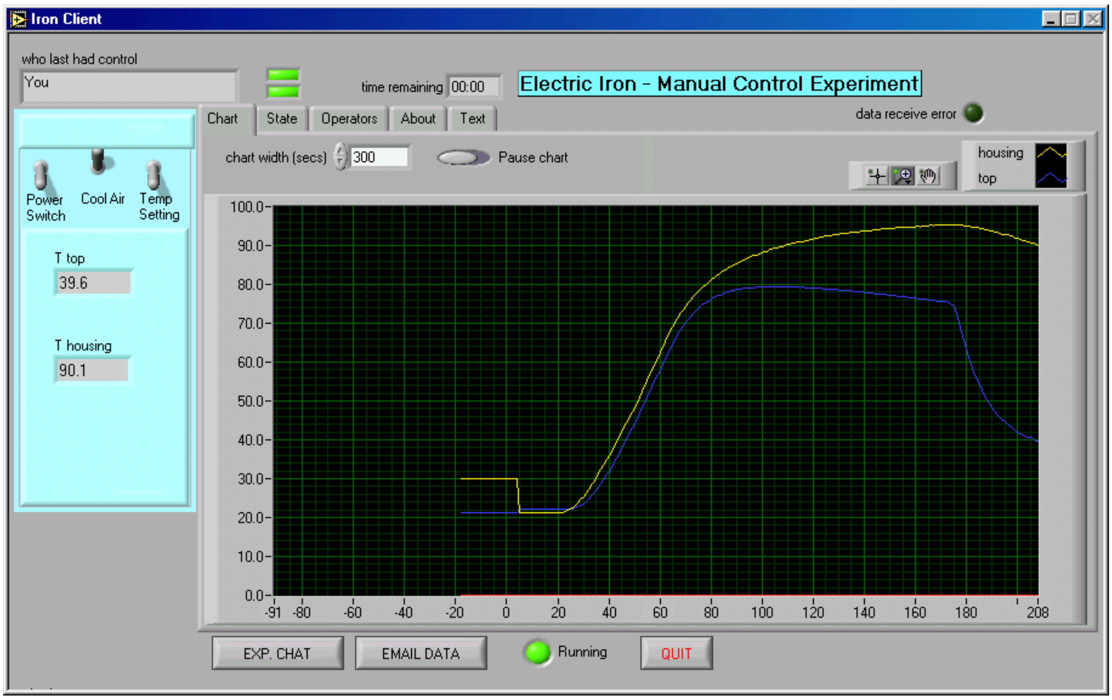
This experiment is offered currently at UWA. A domestic electric iron fitted with temperature sensors and a controllable jet of compressed cooling air, can be operated in several different ways:

- simple manual on-off control,
- pulse width modulated power control,
- feedback control.

The equipment can be used for several lab classes:

- Thermodynamics of a simple domestic appliance, heat transfer by convection and conduction.
- Modelling of a domestic appliance, from simple first order equation representation to finite element thermal modelling.

- Mechatronic discrete control and sensing.
- Control system theory applied to a simple non-linear system.


Iron Client

Electric Iron - Manual Control Experiment

who last had control: You

time remaining: 00:00

chart width (secs): 300

T top: 39.6

T housing: 90.1

Figure 3: Typical introductory task control panel for electric iron experiment

The lab experience requires a student to set certain operating parameters and interact with the equipment for a time of between 5 and 30 minutes depending on the tasks to be performed. Since the appearance of the iron does not significantly change there is little value in providing a real-time image of the iron for the student user.

The equipment is inexpensive. However, the are several aspects of its behaviour that are subtle: these can present a significant challenge to undergraduate students. For example, when using the internal thermostat, the temperature at which the thermostat switches off the heating element decreases significantly aver the first 15 minutes after the iron is first switched on. This is not easy to explain, given that the thermostat is a temperature sensitive switch with well-defined switch on and switch off temperatures.

Torsional Vibrations

A servo motor excites low frequency rotational vibrations of two discs coupled by soft torsion springs. Students need to observe how different amplitudes and frequencies of excitation affect the motion of the discs. Data on disc motion arrives rapidly in real time (data is collected at 30 Hz) but students must observe the discs for several minutes at a time as transient effects last for up to two minutes.

An instrumental and chart display is sufficient to display the disc motion. While it is preferable that students can observe the discs directly using real-time video the data rate required means this is only feasible using broadband or local area networks.

Figure 5: Torsion Vibration remote access equipment at UWA: an example where high rate real-time data needs to be shown to the user.

Some Initial Evaluation Results from UWA

The UWA system has been in use since early 2002. Preliminary results suggest significant cost savings in comparison to other remote lab systems and two important learning advantages. Students can experience more operating time per week than in a conventional lab class. Also, students who are reluctant participants in a normal lab group (up to 40% of the class) can operate remotely without the fear of making an embarrassing mistake in front of their peers. We have also found that prior first-hand experience with the real hardware helps students to understand what they are doing without the need for a real-time video image of the equipment. This means that students can use the system over slow modem connections.

A further advantage is cost. The total investment in the UWA system so far is approximately AU$220,000 which is less than 10% of budgets for comparable projects at the Open University and the MIT i-Lab project.

There are three differences that help to explain why the UWA system cost is much less than the others mentioned.

First, cost-effectiveness has been a desired outcome from the start. For this reason we looked at several different software tools and concluded that LabVIEW was likely to be the most cost-effective. Similar conclusions have been drawn by Vilalta (2001) and Berntzen *et al* (2001) who also report more efficient operation with LabVIEW.

Second, we have worked towards a system in which new additions to the system could be built by undergraduate students in project work with modest supervision. All the equipment on the UWA system has been integrated by students, though some re-engineering by staff has been required to establish high quality templates for later students to follow.

Last, we have not attempted to closely integrate the system with the student record system on our campus. Class lists can be imported using spreadsheet text files, and students are permitted a degree of self-enrolment when appropriate.

So far, we have been able to administer the system and maintain the hardware using existing staff resources.

To evaluate the learning effectiveness of this system we offered third year mechanical and mechatronics engineering students an option to repeat part of the experiment they had performed in scheduled lab classes to improve their learning. Software for this particular lab was developed by a final year mechatronics engineering student who was also the teaching assistant supervising the lab classes. (Davies 2002)

These students were invited to use a remote lab task to explore aspects of controller tuning. The task required them to set given proportional, integral and derivative gains for a controller driving a large pointer in the lab, and measure performance parameters such as rise time and overshoot. The task was optional and set in the second last week of semester, so the relatively high number of students who attempted the task was very encouraging. The students were asked to answer an on-line questionnaire, and identified themselves by student number so that we could relate their responses to log file records.

67 students responded to the questionnaire, of which 62 of the students used the system. 57 students managed to operate the remote lab for more than 5 minutes. This attrition was due partly to inability to install or operate the software well enough to connect to the server.

Of the 57 students who used the system for significant lengths of time, the average total operating time was 21 minutes. Most users achieved operating times between 10 and 30 minutes, though these were often in short sessions. The maximum time that a student was permitted to reserve was 15 minutes. Most sessions were less than 15 minutes in duration. For early users, a fault in the system limited sessions to 5 minutes and this affected about two thirds of the class. This fault also caused some problems for users which limited the number of successful connections to the system.

Operating time reported by students	Number of students
Watched, did not operate	28
<10 minutes	8
10 – 20 minutes	14
20 – 30 minutes	5
30 – 60 minutes	6
> 60 minutes	5

Table 1: Operating times in scheduled lab class from survey

This result contrasts with the scheduled lab classes. 10 classes were scheduled for a total enrolment of about 112 students over a 4 week period. Attendance at the early classes was typically 6 – 7 students, and up to 15 students for the later classes. Although there was a booking system to limit attendance, in practice students forgot to attend earlier classes and so later classes were overcrowded.

Table 1 reports the responses by students to the on-line questionnaire. One of the questions they were asked was to recall how long they operated the equipment during the scheduled lab classes.

These results demonstrate that the remote lab has significantly extended the lab experience for most of the students in the class. Only 16 students (about 25%) operated the equipment for 20 minutes or more in the scheduled lab class. However, all except 14 students managed at least 10 minutes using the remote lab, and most managed more than this. Nearly all the students managed to complete the assigned task using the remote lab.

Other questions explored student preferences. We found that a significant number of students had difficulty installing the software in our computer labs, and at home. Installation CDs were made available but few students used them. A simple download and install procedure is needed. However, with more labs on the system, students would learn how to do this better. Most of the students said they preferred to use the real equipment if was available. When asked why they did not operate the equipment in the lab, most said this was because others were operating, or there was not enough time for their turn in the lab class. Some said they did not know what to do (10), or were afraid they would make a mistake in front of other students (6).

In another class, an on-line lab was made available for second year mechatronics engineering students to develop a simulation model of an electric iron. This exercise was conducted in the last week of semester. The students did not have to use the on-line lab because data from the lab was provided independently to the class, but extra marks were awarded for a simulation model that would work in cases other than the one supplied. Out of 50 students in the class, 21 students elected to use the on-line lab for an average time of 53 minutes (cumulative). Average session time was 16 minutes: the maximum possible reserved time was 15 minutes, but many students were able to achieve longer session times because they used the equipment at periods of low demand. Peak usage time corresponded to attendance at the University – 12 noon till 6 pm.

Unlike the position control experiment, most of the students had never operated the equipment before. Most had seen the equipment in the lab during other class activities.

Around 75% of all access to the system was from on-campus computer labs and 60% of these sessions were from our own computer labs where the software had been pre-installed. Interestingly, even though students could use the equipment from adjacent computers for much of the day when the lab was open, almost no students chose to do so. Had the system been used for larger classes with tighter deadlines, we could more students would have used the system from off-campus locations. Some students complained about having to download the initial installation files (12 Mbytes, mainly for the LabVIEW Runtime Environment), though this was also made available on CD-ROM. However, once the initial installation has been accomplished, each new lab client only requires a 1.5 Mbyte download. The electric iron experiment involved quite long operating times because it takes time to collect the required data. Students could happily work on other assignments while watching the temperature chart.

Even though they were free to do so, none of the students chose to operate with other students at the same time. We did not draw the attention of students to this facility. On at least one occasion a server fault enabled two students to operate the equipment at the same time accidentally. The students reported that “someone was hacking into the system”.

Conclusions

The total investment in the UWA telelabs system was approximately Au$220,000 including integration of the equipment described in the preceding sections. The cash outlay included computer and interfacing equipment for the equipment mentioned above, the core server software development contract and assistance with commissioning, student scholarships and some engineering supervision for designing some of the equipment. Staff time, university workshop time and student projects that are part of the teaching curriculum are not included in the cash budget. A minimum of one LabVIEW professional development system licence is sufficient for developing and operating the system at a cost of Au$3800 (approx): our investment included a full faculty licence at a cost of about Au$30,000 as LabVIEW has become popular in several engineering departments.

Most of the on-labs presented so far in the literature have been single demonstrations of the technical possibilities. Few have been systematically evaluated in terms of student learning effectiveness, and fewer still in terms of cost effectiveness. The enormous effort on software development has been justified in terms of the potential of this technology to broaden the educational experience. Some evaluation has been, and is being done currently, but it will still be some time before we can see whether there are real long term cost benefits.

Although it has taken three years to develop our on-line lab framework at UWA we are very happy with the results and it will become a standard part of our learning environment for students. While we yet to demonstrate overall cost-effectiveness gains, the initial investment has been much less than reported for similar efforts in other universities.

References

Note: copies of web-based references are available from the author.

Berntzen, R., Strandman, J. O., Fjeldly, T., and Shur, M. (2001) Advanced solutions for performing real experiments over the internet. International Conference on Engineering Education, August 6-10, Oslo, Norway.

Böhne, A., Faltin, N. and Wagner, B. (2002) Self-directed learning and tutorial assistance in a remote laboratory. Proceedings of Interactive Computer Aided Learning Conference, September 25-27, Villach, Austria.

Dalton, B. (2001) Techniques for Web Telerobotics, PhD Thesis, The University of Western Australia.

Davies, T. (2002) “Software system for controlling web-based laboratory”, BE Thesis, School of Mechanical Engineering, The University of Western Australia, 2002.

del Alamo, J., Hardison, J., Mishuris, G., Brooks, L., McLean, C., Chan, V., and Hui, L. (2002b) Educational experiments with an online microelectronics characterization laboratory, Proceedings of International Conference on Engineering Education, Manchester.

del Alamo, J.,Brooks, L., McClean, C.,Hardison, J., Mishuris, G.,Chang, V., and Hui, L. (2002a) A web-enabled remote laboratory for microelectronic device characterization, Proceedings of 2002 Network Learning Conference (NL2002), Berlin, May 2002 (on CD-ROM). Also see http://weblab.mit.edu/.

del Alamo, J. (2003) Personal communication.

Ertugrul, N. (2000) Towards virtual laboratories: a survey of LabView-based teaching/learning tools and future trends. Int. Journal of Engineering Education, 16:3.

Faltin, N. and Teichman, T. (2002) Übersicht über Fernlabore (Survey of remote laboratories), reference: http://www.learninglab.de/.

Ferguson, C. (1997) Remote access to computer-controlled manufacturing facilities for engineering students, World Manufacturing Congress, Auckland, New Zealand. On-going project at: http://www.et.deakin.edu.au/research/Eng_Education/internet.htm.

Fjeldy, T., and Jeppson, K. (2001) Internet technology in laboratory modules for distance learning. See http://www.unik.no/~torfj/remotelab.htm.

Geoffroy, F., Gillet, D., and Zeramdini, K. (2001) Component-based Design of a Flexible Environment Dedicated to Web-based Experimentation. Swiss Federal Institute of Technology in Lausanne (EPFL). http://lithwww.epfl.ch/~geoffroy/015-its2002.pdf

Gillet, D. and Fakas, G., "eMersion: a New Paradigm for Web-based Training in Engineering Education", International Conference on Engineering Education, ICEE 2001, Oslo/Bergen, Norway, August 6-10, 2001.

Henry, J. (1996a) Controls laboratory teaching via the World Wide Web. ASEE Annual Conference, Session 3513, available from National Instruments Academic Resources CD-ROM 2001 Edition. See also http:// http://chem.engr.utc.edu/.

Henry, J. (1996b) Running laboratory experiments via the World Wide Web. ASEE Annual Conference, Session 3513, available from National Instruments Academic Resources CD-ROM 2001 Edition.

Hites, M. (2002) Creating and running undergraduate experiments controlled through the internet. American Society for Engineering Education Conference, Illinois Institute of Technology, Chicago, April 12, 2002.

Lemckert, C., Fergusen, C. (2001) Remotely operated laboratory experiments in engineering for distance education students. On-going project at: http://www.et.deakin.edu.au/research/Eng_Education/flow.htm.

Lindsay, E. and Good, M. (2001) Remote, proximal and simulated access to laboratory hardware – a pilot study. International Conference on Engineering Education, August 6-10, Oslo, Norway.

Quanser (2001). Company web site at http://www.quanser.com/.

Röhrig, C. and Jocheim, A. (2001) Java-based framework for remote access to laboratory experiments. Department of Electrical Engineering, University of Hagen, Germany. (http://prt.fernuni-hagen.de/virtlab/ace2k/html/)

Salzmann, Ch., Gillet, D., and Huguenin, P. (2000) Introduction to real-time control using LabView with an application to distance learning. Int. Journal of Engineering Education, 16:3. See also http://iawww.epfl.ch/Staff/Christophe.Salzmann/MS_HTML/ChMS.html.

Schäfer, T., Seigneur, J-M., Donnelly, A. (2002) PEARL: A generic architecture for live experiments in a remote laboratory. Distributed Systems Group, Trinity College, Dublin. (Paper for ICSEE2003 conference, available from http://kmi.open.ac.uk/projects/pearl.

Senese, F., Bender, C., and Kile, J. (2000) The Internet Chemistry Set: Web-based Remote Laboratories for Distance Education in Chemistry, Interactive Multimedia Electronic Journal of Computer-Enhanced Learning, Wake Forest University, Issue 2, http://imej.wfu.edu/articles/2000/2/index.asp

Shen, H., Xu, Z., Dalager, B., Kristiansen, V., Strøm, Ø., Shur, M., Fjeldly, T., Lü J.-Q, Ytterdal, T. (1999) Conducting laboratory experiments over the internet, IEEE Trans. on Education, August, 1999. See http://nina.ecse.rpi.edu/shur/remote/.

Taylor, K. and Trevelyan, J. P. (1995) Australia's telerobot on the web. 26th Symposium on Industrial Robotics, Singapore, October 1995, pp 39-44. See http://telerobot.mech.uwa.edu.au/.

Trevelyan, J. P. (2002) Towards Cost Effective On-Line Laboratories. Proceedings of 2002 Network Learning Conference (NL2002), Berlin, May 2002 (on CD-ROM).

Vilalta, X., D. Gillet and Ch. Salzmann, (2001) Contribution to the Definition of Best Practices for the Implementation of Remote Experimentation Solutions", IFAC Workshop on Internet Based Control, IFAC Workshop on Internet Based Control Education, IBCE'01, Madrid, Spain, December 12-14, 2001.

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