Infrastructure for Remotely Accessible Laboratories at the University of Southern Queensland

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***Abstract**: Technological developments during the last two decades have made it possible for educational institutions to establish systems for the remote access of hardware and software resources. Teaching staff have come to recognise the benefits of laboratories that can be remotely accessed. Remote access of hardware and software resources is of particular interest to the Faculty of Engineering and Surveying at the University of Southern Queensland (USQ) because of its high proportion of distance mode students. Work towards setting up remotely accessible laboratories at USQ started in 2007. This paper reports on the University's remote laboratory communication infrastructure and the reasoning behind its configuration. It also provides details of the various techniques that are being used for interfacing with laboratory hardware. The paper includes a discussion on the initial experience of staff and students using the remote access system and what is being done to improve user experience.*

Introduction

Remote access of laboratory resources has a number of potential benefits (Moulton et al, 2004). It gives students better control over their learning. Compared to traditional laboratory classes, access times per student to laboratory resources can be significantly increased. Students have more choice about when they wish to do their laboratory work. Practical work for students can be made less prescriptive allowing them to investigate a range of 'what-if ?' scenarios of their choice. Students can be given the opportunity do at least part of their laboratory work at a time when they feel they will benefit the most from that work.

Difficulties arise when there is a need to schedule students to be physically present in a laboratory to work on particular pieces of teaching equipment. In many instances the teaching institution can only afford a limited number of duplicates of such equipment. The laboratory may be open only during certain hours and those hours may have to be shared with other classes. Students are then forced to work in groups that are much bigger than ideal and the time they spend using laboratory equipment is often inadequate. The same problems arise if students need to access a software resource for which the number of allowable simultaneous users is limited by license conditions. Remote access provides a way to alleviate those problems.

At the University of Southern Queensland laboratory classes have traditionally been run in two modes. While the educational content and objectives of laboratory work are the same for all students, practical classes are run separately for those studying on-campus and those studying by distance. Those studying on-campus do their laboratory work during normal teaching weeks and those who study in external mode do so during a residential school over a period of one week during the mid-semester break. Currently students enrolled in a four-year full-time equivalent program do four weeks of residential school in total. In addition to difficulties and problems that are mentioned above, there are problems that are faced specifically by those studying by distance (Lemkert and Florance, 2002). The main ones are:

a) the need to obtain leave from work;
b) residential school expenses including cost of travel and accommodation and lost of income in cases where leave taken from work is unpaid;
c) separation from families; and
d) the need to perform practical work at a time that may not be optimal compared to when relevant theory was covered.

Remotely accessible laboratories can at least partially solve the problems mentioned above. The intention is not to completely eliminate “hands-on” laboratory work, but to use remotely accessible facilities to enhance the student’s laboratory experience. There are many approaches to the design of internet based laboratories (Viedma et al, 2005). However, the benefits of remote access can only be realised if the communication infrastructure and data acquisition and control system that allow the remote client to use laboratory resources are carefully designed and maintained. This communication infrastructure forms a backbone which is used by all clients irrespective of the laboratory resources they are accessing. The next section of this paper is a review of the factors that led to the configuration that has been adopted for the communication infrastructure. This is followed by comparison of the different techniques of data acquisition and control that are being used for remote access. Finally, the paper reports on the initial experiences of teaching staff and students who are using the system.

Communication Infrastructure

A conceptual representation of the communication infrastructure is shown in Figure 1. A key component is the remote access software. In simple terms the remote control software allows the client to assume control over the laboratory host computer. Operation of the client (student) side keyboard and mouse has the same effect as using the mouse and keyboard of the laboratory host computer. Also the remote control software displays, in a window on the client’s side, the desktop of the laboratory host computer. Commercially available remote control software includes Microsoft’s Windows Remote Desktop, VNC, PcAnywhere and Sun Microsystem’s Sun Secure Global Desktop (SGD). The main criteria that led to the choice of SGD as the remote access software for the Faculty was ease of use from the client’s point of view, in-built security, availability of support and cost effectiveness. Students access the Faculty’s remote laboratories via their web browser. Assuming their web browser is java enabled, students click on a link that is provided to them to connect to the SGD server. Upon successful authentication, the SGD server displays the “webtop” on the student’s desktop. The webtop is a webpage containing links to remote experiments that are available to the student. When the student clicks on the link corresponding to the experiment they wish to perform, remote access software is automatically launched and they gain control over the host computer. If necessary, the first time SGD is used on a remote computer, the client’s web browser is automatically updated to permit java use. Input from the client is limited to a few mouse clicks.

An important requirement for the communication infrastructure is security of connection that meets standards specified by University policy. This requirement is satisfied by the ‘https’ encryption feature of SGD. Other remote control software options may not, by themselves, offer the same level of security. For adequate security they would have to be run over a virtual private network (VPN) which is not necessary if SGD is used. Other reasons for selecting SGD were existing in-house expertise for its support, upgrade and maintenance. SGD supports a range of operating systems such as Microsoft Windows and Apple Macintosh both on the client side and the laboratory side.

There are two main types of laboratory resources that are available to students. These are resources that are software based only and resources that include experiment specific laboratory hardware. Examples of software resources that students can access include professional versions of Finite Element Modelling (FEM) software and Geographical Information System (GIS) software. As shown in Figure 1, the remote user gets access to both types of resources through the SGD server. To save space most laboratory work that is based only on software resources are run from virtual machines (Lasky and Murray, 2007), but to students they appear as normal machines. The virtual machines are created within the application servers shown in Figure 1. Currently hardware based laboratory work are accessed through normal PCs.

The booking server shown in Figure 1 manages student access to laboratory resources. The remote laboratory co-ordinator maintains the booking software and allocates access privileges to teaching staff who, in turn, are able to allocate access privileges to students. Although only some of the features of the booking system are fully operational, it is already being used by teaching staff and students.

As shown in Figure 1, students will have access to storage space allocated on their home drive to save relatively large working files. Smaller files may be uploaded to the remote client's computer via the webmail server. This facility allows students to collect data as part of their laboratory work for later processing and/or inclusion in their reports.

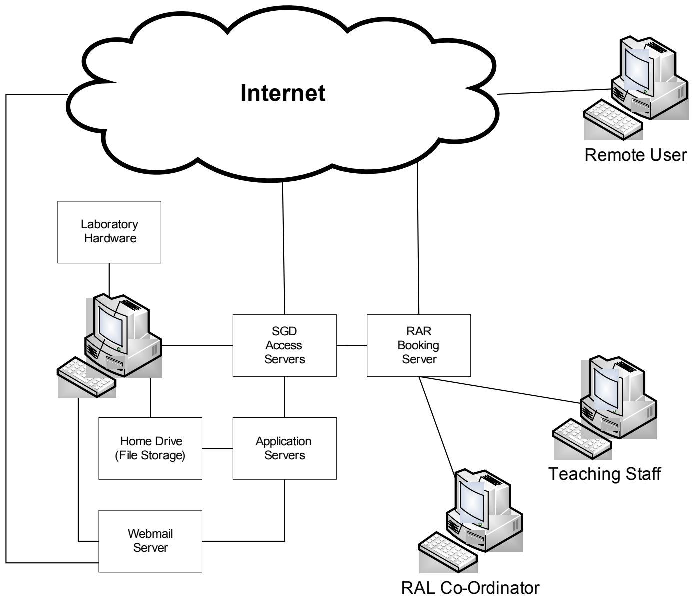


Figure 1: Information System Architecture for Remotely Accessible Resources

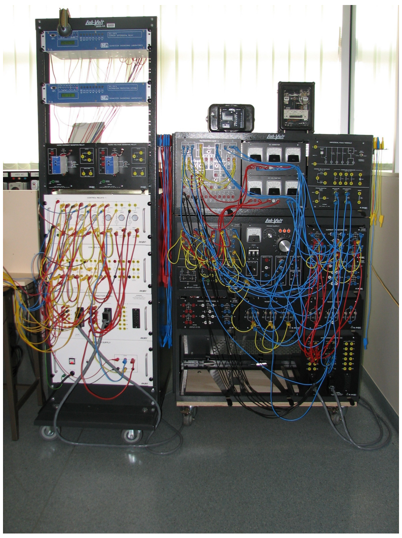
Examples of Remotely Accessible Laboratory Teaching Resources

A small range of the University's laboratory resources are now remotely accessible. Software only resources include finite element, power system analysis and GIS computer programs. Laboratory hardware that is remotely accessible includes a transformer protection training system and a model air powered launcher. These are shown in Figures 2 and 3 respectively.

Hardware based remote laboratory work invariably requires an interface layer between the hardware that is being tested or experimented on and the laboratory computer. This interface layer is needed for control and data acquisition. The following examples illustrate different approaches to implementing systems for control and data acquisition.

The Transformer Protection System

Supervisory Control And Data Acquisition (SCADA) systems are widely used in industry. A SCADA system normally includes Programmable Logic Controllers (PLCs). PLCs have switch control as well as analogue inputs and outputs. They interface to the industrial or laboratory plant either directly or through relays, actuators and sensors. The software part of the SCADA system allows a screen-based Human Machine Interface (HMI) to be constructed which enables an operator to send control commands to the plant being controlled through the PLC. It also allows selected data from the plant to be acquired through the PLC and displayed in an easily understood form on the HMI. The HMI for the transformer protection system is shown in Figure 2(b), which is a screenshot of what appears on the remote operator's desktop. It is essentially a mimic diagram of the plant to be controlled by the student. In this case the plant is a transformer that can be energised and connected to a load by means of circuit breakers represented by squares on the diagram. The remote user, can, through the HMI and PLC, close or open the circuit breakers and can initiate short circuit faults within or outside of the transformer. The rectangle representing the circuit breaker turns red when on and green when off. Students doing laboratory work are given the task of remotely programming a relay which is shown at the top left hand side of Figure 2(a). The relay monitors currents and opens the transformer circuit breakers if, based on user defined logic, it detects a short circuit fault within the transformer. The relay provides another means of data acquisition. Although this is not shown in Figure 2, students can open the relay's HMI and view remotely real time system data that is being continuously captured by the relay. In cases where the relay trips due to a fault, they can view current waveforms and other data for construction of the sequence of events just prior to the fault. General purpose equipment such as multimeters, wattmeters and oscilloscopes recently purchased by the University has computer interfaces. Students may also be given the option of operating them remotely for data acquisition. The top left hand side of Figure 2(a) shows a webcam which allows the remote operator view images of an alphanumeric display and a number of indicator light emitting diodes on the relay front panel.

(a)


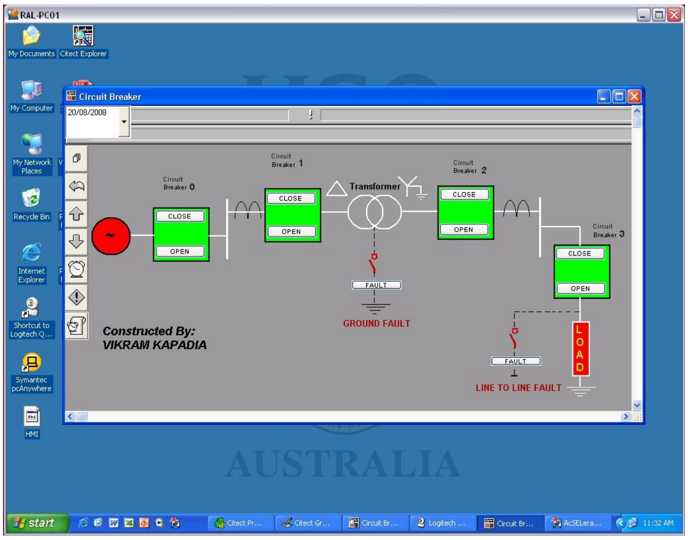
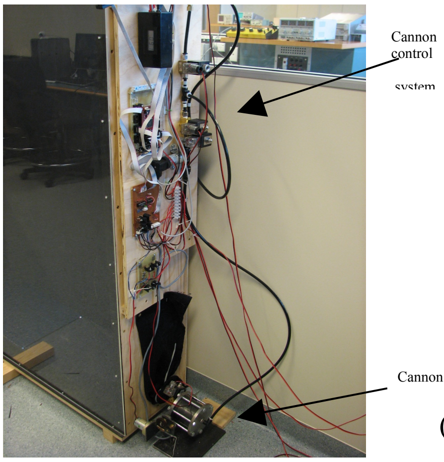
(b)


Figure 2: SCADA controlled network fault simulator. The (a)hardware under (b) software control.

The Air Powered Launcher

The ping pong ball launcher and range is being used in a third level, team based problem solving course, Engineering Problem Solving 3. As shown in Figure 3, the ping pong ball launcher consists of a small air reservoir and a barrel which are isolated from each other by a solenoid valve. Figure 3(a) shows part of the range and the control system. Figure 3(b) shows details of the launcher such as the air reservoir and the angle control mechanism. To fire a shot, the launcher is set to a certain angle, specified by the team, and the reservoir is filled to a certain pressure, also specified by the team. The shot is automatically fired when air pressure in the reservoir reaches the value specified by the remote operator. In general terms, the objective of the problem is for teams to perform some experiments and develop some engineering analysis which will enable them to specify an angle and a filling pressure which will cause a certain weight ball to land in any one of three target zones. Live webcam images of the ping pong ball trajectory is made available to the remote user.

(a)



(b)

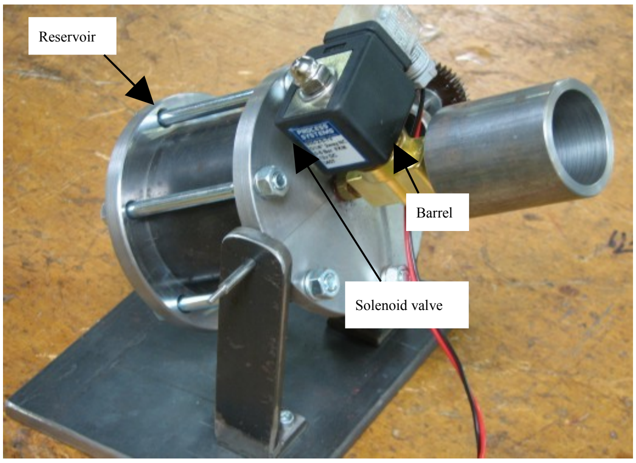


Figure 3: Annotated photographs of the (a) range and (b) canon used in the model firing range remote experiment.

The control system for the launcher is microprocessor based. Two solenoid valves are used, one to control airflow into the reservoir and one to initiate the launch. MosFETs are used as interface between the microprocessor I/O ports and the solenoids. A pressure sensor provides readings to the remote operator through one of the on-board analogue to digital converters. Launching angle adjustment is carried out by a motorised system controlled by the microprocessor through an H-bridge.

Options for Interfacing with Laboratory Hardware

From a data acquisition and control point of view there are significant differences between the air powered launcher and the transformer protection training system. No mimic diagram is used in the case of the air-powered launcher. That is not a serious disadvantage because there are only two pieces of control data required from the user and only one variable, namely pressure, that needs to be displayed. The user-interface is the HyperTerminal text window which allows data transfer directly to and from the micro-processor.

Remote laboratory experiments can also be created and maintained through the use of LabView from National Instruments. A typical implementation would involve data acquisition hardware (for example the Agilent 34970A series) and simple PC control of hardware experiments. Experiments can be configured to replicate laboratory equipment and experiments and have a suitable look and feel of real hardware, which helps engage the student with the experiment. LabView is also well suited to software only experiments, where it can provide the toolset to create simulations of generic electrical engineering experiments through to signal processing, image analysis, and process control. LabView's ability to create tamperproof executables also makes it an ideal environment within which to create remotely accessible virtual experiments.

The choice of technique for control and data acquisition would be influenced by a number of factors. A laboratory plant that involves high power levels and that is relatively complex in terms of the number of variables that needs to be controlled and monitored would most likely use a standard industrial SCADA system rather than a customised microprocessor system. The availability of expertise, the level of available funds and health and safety requirements are also factors to be considered before making a choice.

Conclusion

An overview of the infrastructure that forms the communication backbone for remote laboratories at the University of Southern Queensland has been presented. Justification for the choice of its configuration has been given. The infrastructure is meant for laboratory work that is based only on software as well as for hardware based practical work. Different options have been explored for data acquisition from and control interface to laboratory hardware.

The main functionalities of the infrastructure were tested by a few members of teaching staff and a small number of students both within Australia and overseas. Those initial users have all reported ease of connectivity and adequate data communication speeds especially for laboratory work that is based on software only. Some observed that data transfer speeds can drop to levels that are marginally satisfactory if webcam images are of high resolution. Two approaches have been adopted to resolve this. The first one is based on the idea that laboratory work should be designed so that the webcam image, while it is to be made available to students to enhance the feeling of reality, should not be a feature that is essential to successful completion of such work. Students are then free to remove the webcam image from the screen and achieve faster data transfer. Where live camera images are essential for the remote user to conduct laboratory work, the image should be processed such that only its essential content is transmitted. This could be achieved by a simple reduction of image resolution using standard features made available by the webcam manufacturer or by software that is customised to provide results that are optimum for particular applications.

Although some features of the remote laboratory communication infrastructure is not yet operational, students are currently using it to carry out a small number of laboratory exercises which are formal parts of their courses. Feedback from those students will be used to improve the system and also and encourage more teaching staff at the University to embed remotely accessible laboratory work within their courses.

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