Embedded web server for remote laboratory access for undergraduate students studying electronic engineering

E.Otoakhia, T.Jenmanachaiyakun, A.Afaneh, S.Alzebda, M.Mani, O.Sonbul, A.N.Kalashnikov
Department Electrical and Electronic Eng,
Nottingham University,
University Park, Nottingham, NG7 2RD, UK

Alexander.Kalashnikov@nottingham.ac.uk

***Abstract*—This paper describes an approach for the development of an embedded web server that facilitates a remote access for a laboratory experiment for distance learning purposes. The experiment involves measurement of a volt-ampere characteristic of a semiconductor diode by setting the voltages applied to it remotely over the Internet. The learner observes two autoranging multimeters over a live video feed in order to record the applied voltages and corresponding currents. The system architecture developed for this project allowed use of low-cost components and rapid development. The total cost of consumables was below £200 except for the internet protocol (IP) camera.**

Keywords: remote laboratory, embedded web server, measurement of volt-ampere characteristic of a semiconductor diode

I. Introduction to Remote Laboratories and Motivation for This Development

Distance learning is a well-established trend in modern university education that allows widening participation, reducing cost, and accessing some more specialized learning resources that are not available locally. Traditionally good subject textbooks were used for distant learning that delivered the core knowledge and exercises for the learner, while a local instructor provided feedback. Contemporary communication technology facilitated delivery of additional materials, such as online tests, lecture notes and slides, recorded podcasts, and lectures. Feedback is provided to the learner when a written piece of work is assessed.

However, in many subject areas, particularly in engineering, getting practical experience in the use of up-to-date instrumentation and measurement procedures is particularly valuable for the learning process. This experience is conventionally gained during laboratory sessions.

Design of a laboratory-based learning environment requires finding the fine balance among several pairs of contradictory considerations. For example, close supervision and assistance from a lab demonstrator is frequently not effective because these impart a poor influence on the learner's initiative and excitement associated with hands-on discoveries in the lab, in addition to the costs involved. Another contradiction requires balancing learner's ideally nonrestricted access to the lab equipment with safety and cost risks. In many cases the experimental setup needs to be checked before the equipment is switched on to prevent any potential harm to the learner. Some experiments must be conducted in the presence of other persons in the laboratory only, e.g., if harmful fumes or electric shock can occur during the experiment that might incapacitate the learner. Some equipment and instrumentation can be easily damaged if not connected or operated appropriately.

A conventional time-proven approach for laboratory sessions in science and engineering is based on the use of specially prepared workspaces with at least partially pre-assembled and pre-wired operators. The learner initially completes the setup, and after a check from a lab demonstrator, performs experimental assignments largely on her/his own. This scenario seems, to some extent, compatible with remote access, if necessary actuators and remote control means are available. Equipment suitable for this purpose was developed for high throughput automated testing on production lines and for various supervisory control and data acquisition (SCADA) systems long ago. These systems usually required proprietary components and costly networking and integration that prevented their deployment for mainstream education. Recent developments in publicly available Internet infrastructure and software stacks and in low cost microcontrollers and network adapters considerably reduced costs associated with remote access.

For the above reasons, various educators put substantial effort in the development of educationally sound remote-access laboratories for distance learning. A Google search on "remote laboratory" returns about 20,000 hits, and there is an entry for "remote laboratory" in Wikipedia. Among the notable projects undertaken in the field, there is a Labshare project in Australia that secured funding of 111 million Australian dollars [1]. Descriptions for various remote

This development was supported by a Lord Dearing fellowship

laboratory access developments are available online (e.g., [2,3]).

It is important to differentiate between a remote laboratory and a virtual laboratory. The former delivers a first-hand laboratory experience remotely, while the latter simulates a laboratory on a computer screen(s). If a virtual simulator was to be developed to include setting times, limited precision, noise and drift of the instruments, and high-quality computer generated imagery (CGI), a virtual laboratory would provide learning outcomes compatible with these of a surrounding laboratory. However, virtual learning environments are cost effective for training of highly specific professionals (e.g., pilots, surgeons) only and are rarely used remotely. Remote laboratories usually utilize a live video feed from a real laboratory [1-3] that costs considerably less than a realistic CGI.

The development described in this paper aimed at demonstration of a feasibility of a low-cost approach to implementation of a remote lab. This aim was pursued through the following objectives:

- select an experiment that is commonly performed by junior undergraduate students studying electrical and electronic engineering and that is suitable for a remote laboratory from both technical and educational points of view;
- develop a system architecture that allows extensive use of off-the-shelf components and rapid development of required custom components;
- undertake required hardware and firmware developments and integration;
- trial the development over the Internet and assess its provided usability and learning experience.

Each of the above objectives is covered in a separate section below. Section VI concludes the paper.

II. Volt-Ampere Characteristic of a Semiconductor Diode as a Subject of Remote Measurements

The following educational reasons prompted the selection of the measurement of the V-I characteristic of a semiconductor diode for a remote laboratory:

- it is an essential step in learning solid-state devices;
- this nonlinear component has many uses;
- an experimental graph can be compared with the commonly used right-angle approximation of this characteristic;
- the learner applies different bipolar voltages to the component and immediately measures related currents that vary by several orders of magnitude;
- measurements involve the use of two multimeters—one is used as an ampermeter and one as a voltmeter.

From the implementation point of view, this experiment requires remote control of a single power supply and an uncluttered workspace.

The setup can be prepared in advance, eliminating a possibility of accidental damage of a digital multimeter (DMM) in the ampermeter mode by improper connection or wrong measurement range setting.

University education necessarily includes assessment for major curriculum activities, and a remote laboratory should be no exception. In fact, a remote laboratory can both imitate conventional assignments and open new possibilities.

Testing the learner's understanding of the connections required can be done by presenting several pictures of possible wirings with one of them taken from the actual workspace that needs to be selected before starting the experiment. Incorrect selection(s) can downgrade the overall mark for the experiment.

Some additional penalty points can be set if the learner accidentally tries to exceed the rated current of the device when changing the voltage (the firmware will prevent an actual application of the excess current that would cause a component failure in a real laboratory setting).

Remote measurement allows connecting diodes of various types (e.g., silicon, germanium, Schottky and Zener ones) for different users at random. This feature is rarely implemented in real labs but is useful to restrict possibilities of plagiarism. The post-lab assignments may include identification of the diode type and exact part number out of some given set and/or various SPICE-based exercises, such as building a piecewise linear model for the component [4].

The learner's lab report is graded by the lab demonstrator, taking into account the considerations stated above.

III. Architecture of the Remote Measurement System

An approach used for the development of some previously developed remote laboratories could be generalized using an architecture presented in Fig. 1, which integrated diverse pieces of software running on the same computer server. The advantage of this architecture was its flexibility as it could be adopted for a variety of laboratory experiments and could run several diverse experiments from the same lab at the same time. However, development and integration require substantial expertise in diverse technologies that are difficult to apply to a small-scale project.

The architecture developed for this project is presented in Fig. 2. It included an off-the-shelf IP camera that, unlike web cameras, required no personal computer to operate. The camera (Axis M1054) broadcasts a live video feed from the lab workspace, showing DMM readings to the learner.

It was essential to use autoranging DMMs in order to accommodate a wide range of measurements without turning the DMM knob. An additional requirement was an absence of an "auto switch off" feature that would power down the DMM in a remote lab after a short period. The DMMs were powered from a mains adapter connected in the battery compartment instead of a battery (in order to eliminate the need of the battery replacement when it is discharged).

The embedded web server was developed based on software libraries and hardware developed by Microchip Technology Inc (Chandler, Arizona, USA) because of the availability of required expertise and development tools. Use of the off-the-shelf hardware (PIC32 Ethernet starter kit [5] for the development of the firmware and complimentary PIC32 I/O expansion board [6] to facilitate external connections) was found sufficient to implement the embedded web server itself. The Internet-related part of the firmware was based on the royalty free Microchip TCP/IP stack [7].

Remotely controllable power supplies are available from a few vendors. However, they usually do not operate bipolar output voltages and require use of communication protocols, such as General Purpose Interface Bus (GPIB), that are not common for general purpose embedded developments. As a result, custom development was conducted for this component.

The workspace included symbols of the power supply and the diode with terminals that could be used for wiring, the DMMs, and auxiliary terminals for making the necessary connections (Fig. 2).

This architecture allowed 24/7 unattended operation. It supported conducting the experiment after a preliminary check of the learner's understanding; setting the operating voltages remotely with the aid of a DMM visible through an IP camera; and recording the associated currents from another DMM. We assumed this scenario would be interesting to the learner and would deliver a first-hand laboratory experience remotely.

IV. Development of the Required Firmware and Hardware

Although Microchip's TCP/IP stack seemed sufficiently versatile for the communication required for this development, it did not include any web-authoring tools. General purpose authoring tools frequently did not account for the size of the web page created, but this size was of paramount importance to embedded web servers as the amount of memory available to a developer is very limited. Microchip developed two data formats (MPFS and MPFS2), in order to compress web pages for storage in an embedded system, and offered a free PC-based compression utility. However, the web page itself needed to be hand coded in order to keep its size as low as possible. On the other hand, contemporary Internet users expect a rich and versatile graphical user interface (GUI) and simply do not use outdated interfaces without good reason.

For the reason above, an additional software tool (TCP Maker Pro [8]) was used for this development. In addition to WYSIWYG web authoring TCP Maker Pro also links the developed web pages with firmware variables and provides templates for the subroutines that are called when a GUI control is manipulated by the user. It used various up-to-date Internet technologies for enhancing user experiences and compressed the designed web pages into a small memory footprint. This project required implementation of two sliders (coarse and fine) for the remote control of the power supply and a warning message that becomes visible if the user attempts to exceed a safe operating limit for the diode. The resulting web page is fully scalable in a web browser; various screenshots related to this development are presented in Fig. 3.

The remotely controllable power supply was developed using a single-channel audio amplifier with built-in short-circuit protection and thermal shutdown. These features were desirable for an autonomously operated device. The amplifier was mounted on a heat sink and was powered from a bipolar power supply, enabling high-power bipolar voltage output without any additional switching. The amplifier was counter biased to the middle output voltage of the serial peripheral interface (SPI) controlled digital-to-analog converter (DAC) and its gain was set to achieve its full operating range.

V. Initial Trials of the System and Ongoing Developments

Deployment of the development was complicated by the network security corporate practices, and a separate network was set up for the development and testing using Internet Explorer and Firefox browsers. Both browsers allowed immediate viewing of the motion JPEG (MJPEG) video feed and required plug-ins for displaying video feed coded in H.264. Internet Explorer showed arguably a smoother plug-in installation and viewing. An IP camera resolution of 800×600 was found sufficient for a clear display of the workspace (Fig. 4). The IP camera was used over wired connection only, and none of its other features were employed. Consequently a less expensive camera could be used instead.

At the time of writing, the development described in this paper is ongoing, and the essential additions that are being implemented include energy-saving features (dimming the lighting of the workspace when it is sufficiently illuminated by the sun; switching off all the operators except the web server when the lab is not in use) and provisions for the random selection of the diode at the start of the experiment. Further development will include scheduling, access, and grading enhancements implemented as separate PHP scripts housed on a separate Internet server. (Open source software called Sahara [9] can be used for such scheduling.)

VI. Summary and Conclusions

Remote laboratory assumes using real laboratory equipment that the learner can see in real time, taking readings from real instruments, and setting operating conditions using remote control tools. A remote laboratory needs a conventional laboratory setup, a video camera to display this setup to the learner, technical means to accept the operating conditions from the remote user, and some actuators to set these conditions.

A distinct advantage of the remote laboratory over even the real laboratory is the complete safety of the learner. An additional advantage of the remote laboratory is the possibility of checking user input before setting the operating condition in order to prevent accidental damage of the equipment. These advantages are provided without any human involvement, providing substantial cost savings and 24/7 operation.

The development discussed in this paper demonstrated a possibility of rapid development of a remote laboratory experiment on a small budget. Remote measurements of a volt-ampere characteristic of a semiconductor diode were implemented over the Internet with the total cost of consumables below £200, except for the IP camera.

ACKNOWLEDGMENTS

This development was supported by a Lord Dearing fellowship awarded to A.Kalashnikov in August 2010. E.Otoakhia and T.Jenmanachaiyakun contributed to the development via their MSc and BEng projects respectively.

REFERENCES

[1] Labshare project (Australia), materials available online on http://www.labshare.edu.au/, accessed January 2011.

[2] Internet Technology in Laboratory Modules for Distance-Learning (Norway & Sweden), materials available online on http://persons.unik.no/torfj/remotelab.htm, accessed January 2011.

[3] What are Remote Labs? (Canada), available online on http://remotelaboratory.com/, accessed January 2011.

[4] R.P.Santoro, "Piece-wise linear modelling of I-V characteristics with SPICE", IEEE Trans. Education, vol.38, pp.107-117, 1995.

[5] PIC32 Ethernet starter kit, available online on http://tinyurl.com/4mbbub7, accessed January 2011.

[6] PIC32 I/O expansion board, available online on http://tinyurl.com/6ycrtlw, accessed January 2011.

[7] Microchip's TCP/IP stack, available online on http://tinyurl.com/35aw9pd, accessed January 2011.

[8] TCPmaker - It Writes Your Embedded Web Server Code!, available online on http://www.tracesystemsinc.com/tcpmaker/tcpmaker.html, accessed January 2011.

[9] Sahara Labs, available online on http://sourceforge.net/projects/labshare-sahara/, accessed January 2011.

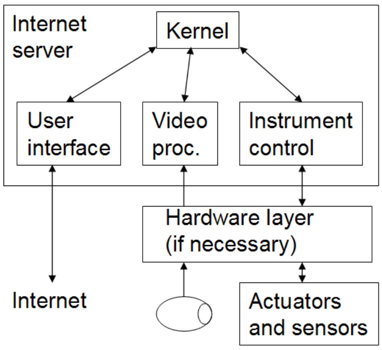

Fig.1. Remote laboratory based on a software server

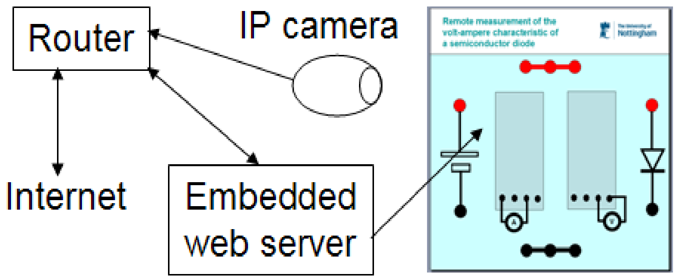

Fig.2. Architecture for the development decribed in this paper

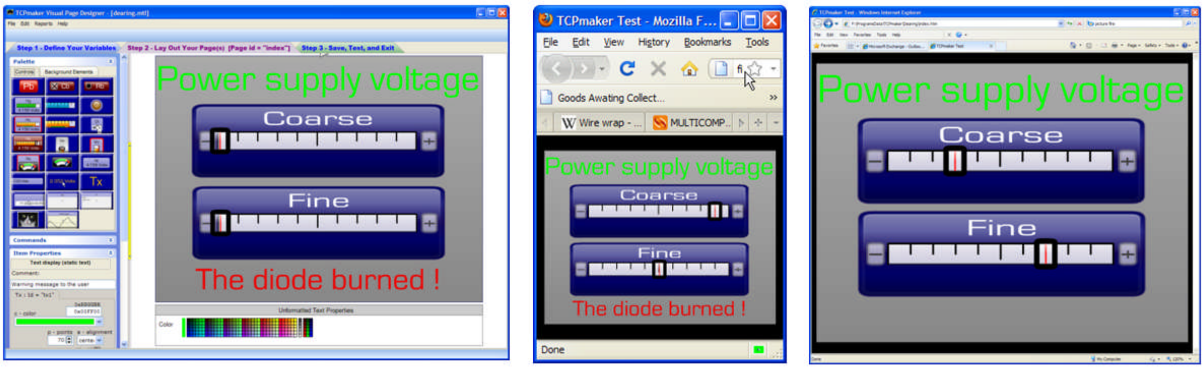

Fig.3. GUI under development (left) and operating under different conditions in Firefox (center) and Internet Explorer (right)

Fig.4. Screenshots of the workspace at different lighting conditions