

International collaborative learning using remote workbenches for 8-bit microcontroller courses

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ABSTRACT: Although many remote laboratory prototypes have been described in the literature during the past fifteen years, there is still a remarkable lack of integration with e-learning frameworks. Most of the proposed solutions do not go beyond technical aspects, which were important to overcome, the initial technical difficulties created by high communication latencies, firewall problems, etc. The work presented in this paper demonstrates how to balance technical and pedagogical concerns, and an international collaborative framework is proposed, based on remote workbenches, supporting 8-bit microcontroller courses currently available to students in Portugal and South Australia.

INTRODUCTION

Although e-learning tools have been used as a mainstream educational technology for more than a decade, there are still very few examples of content with embedded resources for laboratory work. Portability and reusability standards (e.g. Sharable Content Object Reference Model – SCORM) contributed to the development of sophisticated *learning objects* to convey theoretical content. An increasing awareness of the importance of designing collaborative learning activities by making use of asynchronous communication tools that come with every e-learning platform (e.g. discussion forums, wikis, chat, etc), has been witnessed.

Yet, in spite of many improvements and standardisation efforts, it is remarkable that practical laboratory work continues to be conducted in much the same way as it was before e-learning platforms were available. In other words, in many science and engineering courses, what is seen is that e-learning routinely is used to offer a wide range of educational activities, including storage and delivery of content, as well as support for interactive and collaborative activities, but remains remarkably far from the laboratory workbench and from everything related to practical laboratory activities.

This dissociation between e-learning and laboratory activities has not prevented the development of Internet-access to the workbench, and many examples of *remote laboratories* have been available in the literature since the early nineties [1-6]. However, the vast majority of such examples were proposed as stand-alone technical experiments, instead of being offered in the form of pedagogical building blocks, with well-defined learning goals and a clearly identified milestone in the educational roadmap, proposed to the students.

Even more disappointing is the fact that most remote experiments seem to ignore that workbench assignments are generally designed for teamwork, and that the Internet offers ample opportunities to set up collaborative learning environments. This scenario motivated the authors to look into the design and development of remote workbenches supporting international collaborative learning opportunities, and led to a project funded by the Australian Learning and Teaching Council, entitled *Enriching Student Learning Experience through International Collaboration in Remote Laboratories*. The project comprises various subject areas in electrical and information/computer engineering, including 8-bit microcontroller courses.

The work presented in this paper describes the workbenches and international collaborative experiments proposed to students at the Faculty of Engineering, University of Porto (FEUP), Porto, Portugal, and the University of South Australia (UniSA), Adelaide, Australia. A brief overview of remote laboratories, followed by a technical description of the workbenches available at FEUP and UniSA to support microcontroller remote experiments, is offered. An example of an international collaborative experiment in these workbenches is then presented. Subsequently, it offers concluding remarks and proposes directions for further research.

REMOTE LABORATORIES: A SHORT TECHNICAL AND HISTORICAL OVERVIEW

Simulation packages have been used to support computer-based learning in electrical and information/computer engineering since at least the late seventies/early eighties. Particularly after the advent of the personal computer, simulation gained importance for educational purposes, and led to comprehensive digital and analogue electronics design packages, which nowadays emulate sophisticated workbench instruments and are able to handle virtually unlimited hardware resources. Some of those packages support accurate model descriptions and exact replicas of instrument control panels, enabling the development of experimentation environments, commonly referred to as virtual laboratories.

On the other hand, Internet-access to the workbench initially was hampered by cumbersome technical solutions, and plagued by communication delays, firewall blockades, and other technical nuisances. National Instruments' LabVIEW was only able to support Web-access well into this decade, and remote laboratory architectures still struggle with standardisation issues. At the same time, remote access to a workbench is strictly an on-line activity, while simulation may be carried out on-line or off-line.

Why then should one be interested in offering remote access to workbenches? There are a number of reasons, namely: 1) physical characteristics of devices can be observed only in the workbench, 2) multi-disciplinary experiments are easier to set up on the workbench, and 3) simulation cannot convey important practical information that is offered only by experience [7]. If one wants to compare the slew-rate of an operational amplifier against its datasheet specification, one definitely needs to work with a real device. In the case of chemistry experiments with simple mechatronic control systems, it may be easier to provide Internet access to the workbench (where most of the instruments used will already support a TCP/IP connection), than to set up a simulation environment able to model the electronic control system, pneumatic devices, chemical reactions, etc. Last but not least, simulation packages do not give students the necessary skills to assemble a printed circuit board, to recognise the smell of an overheating device, to relate sound and speed of rotating parts, etc.

As a consequence, remote experimentation and simulation have their own places in the range of educational tools needed in engineering education, and it should not use one or the other irrespective of the application domain and learning goals. As well, of course, none of them replaces the presence of the student in the real lab. It is also worth mentioning that mixed-reality labs (connecting physical and virtual devices) are also possible, and may be particularly of interest in multi-disciplinary areas, such as mechatronics.

Technical details of remote laboratory architectures are not relevant within the scope of this paper, but it is important to distinguish between two main implementations – those supporting interactive experiments, and those limited to queued experiments. In the second type, the user uploads the experiment request, including circuit stimuli and configuration. This information is stored in an experiment queue, with the requests sent by other users, and is used by the system to sequence and set up the experiments. The results are then stored on a server or sent by email to the students. This type of solution is entirely appropriate to very short (μs to ms) or very long (hours to days) experiments. On the other hand, in many subject areas, the experiment duration is often about one hour, and the students will prefer to carry it out interactively in real-time. Many electronics experiments fit well into this category and, in such cases, Webcams frequently are used to increase the awareness of dealing with a real experiment, as in the case of the microcontroller remote workbenches presented in the two following sections.

FEUP REMOTE WORKBENCH FOR 80C51-BASED COURSES

FEUP's 8-bit microcontroller remote workbench architecture, shown in Figure 1, identifies the following main blocks:

1. The e-learning server (Moodle), which hosts learning content and provides the gateway to the workbench.
2. The laboratory server, which manages the workbench(es).
3. The workbench itself, comprising the NI ELVIS workstation and a general purpose 80C51 microcontroller board.

The National Instruments' Educational Laboratory Virtual Instrumentation Suite platform (NI ELVIS) was selected as the main building block for these workbenches, since it comprises all the required instruments, including digital inputs and outputs that control the operating conditions of the microcontroller board (e.g. to reset the CPU, emulate input keys/local switches, etc). NI LabVIEW was used to design the interface and control panels, shortening development time and simplifying the integration process. Figure 2 shows a close-up view of the 80C51 microcontroller board and prototyping area of the NI ELVIS laboratory station, where a small printed circuit board with seven LEDs is present. The seven LEDs, controlled by one of the microcontroller parallel ports, were arranged to emulate the seven dots of an electronic dice, according to the laboratory script presented further down. A Webcam positioned over the LEDs provides a live image feedback from the workbench and enables students to observe the effects of the uploaded code.

All work assignments comprise on-line and off-line components (in relation to being connected to or disconnected from the remote workbench). The students start their work off-line using KEIL's μVision development tools (a demonstration version is available as freeware from KEIL's Web site (www.keil.com), which include a compiler and a

debugger. The debugger is illustrated in Figure 3, and offers a powerful simulation environment, where students validate their code before connecting to the remote workbench.

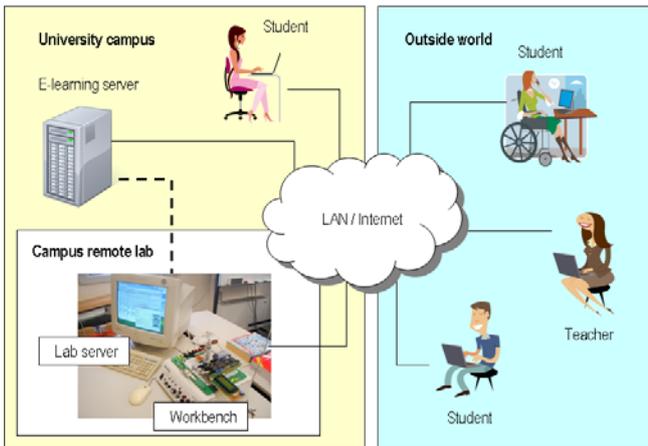


Figure 1: Overview of FEUP's remote workbench.

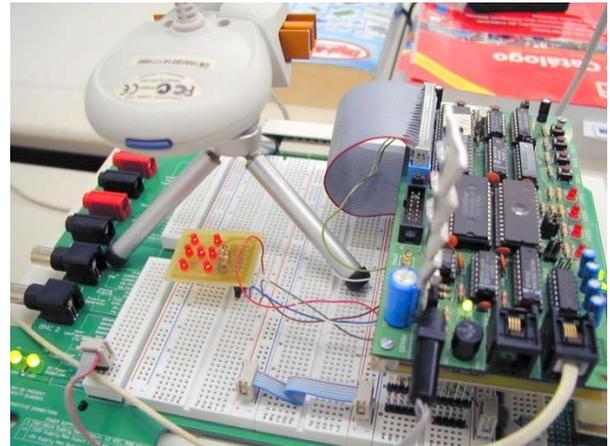


Figure 2: Close-up view of the remote experiment.

When the code compiles and runs without observable errors, the students are ready to connect to the remote workbench. The work on-line is supported by the two windows illustrated in Figure 4: one for code upload and status display (back), and the other one supporting interaction with the remote hardware and offering collaborative tools (front).

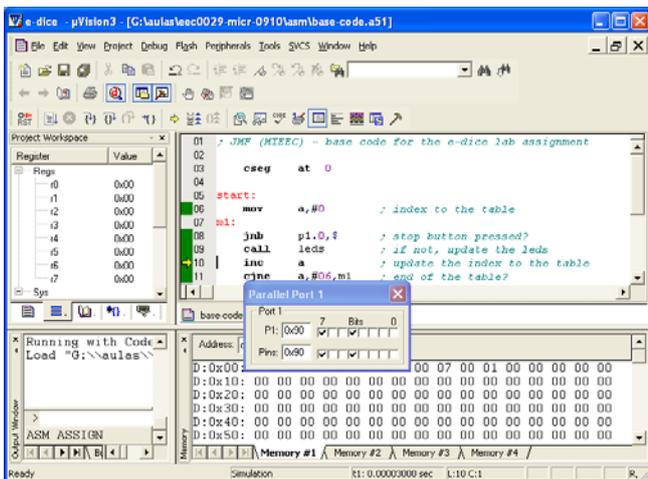


Figure 3: Off-line tools (KEIL's μ Vision).

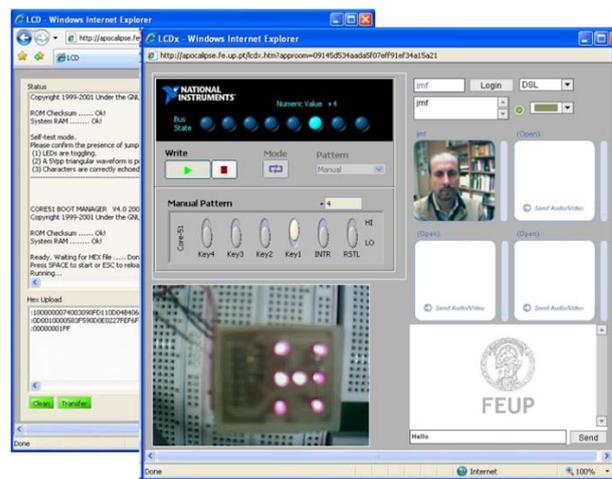


Figure 4: On-line interface panels.

The following features can be observed on the front panel represented in Figure 4:

1. Six buttons (marked Key4 to RSTL) were created to drive 1s and 0s to a subset of the device's control and data inputs. These buttons enable the user to set up functional (e.g. a run/stop button) or operational (e.g. reset) conditions.
2. Similarly, there are eight LEDs (above the six buttons) to display the logic value on selected nodes.
3. The live video stream, captured by the remote Webcam, is broadcast as real-time image feedback from the remote experiment.
4. Collaborative tools, comprising a video conferencing room supporting up to four users and text-based chat that can be recorded to save information needed for reporting the experiment results.

The remote workbench described in this paragraph was developed within a project entitled *Labs-on-the-web* that was funded by the Portuguese Ministry of Science, Technology and Higher Education, with support from the European Social Fund [8].

UNISA REMOTE WORKBENCH FOR PIC-BASED COURSES

In 2009 a remote laboratory, MicroLab, was developed at UniSA to enable collaborative work between Australian students at UniSA and Portuguese students at FEUP, as part of the project *Enriching Students Learning Experience through International Collaboration in Remote Laboratories* supported by the Australian Learning and Teaching Council (ALTC) 2008 grant with funding of \$A220,000 over a two-year period.

MicroLab has a similar architecture to FEUP's remote workbench shown in Figure 1. However, it is based on the PIC16F882 microcontroller and uses MPLAB IDE®, free software available from the Microchip® Web site for programming. The MicroLab graphical user interface (GUI) was developed to resemble the GUI of the previously developed UniSA remote laboratory NetLab [9] that has been successfully used in teaching since 2002 for onshore and offshore course delivery. As shown in Figure 5, the GUI includes a Web camera live view of the workbench for students to monitor performance of their program. Students can directly modify a sample assembly program provided by the system or can upload their own. Students can directly assemble the active program, after which the system lists possible errors in the lower right-hand corner of the GUI. MPLAB also allows the PIC microcontroller to be programmed in C language. All actions of the user are broadcast in the lower middle window. The system allows collaboration between concurrent users and, for that purpose, a chat window is included in the lower left-hand side of the GUI.

The microcontroller board was created specifically for the e-dice experiment developed by FEUP and thus includes seven LEDs, as shown in Figure 6. However, additional features such as a keyboard and an LCD display are included for more complex programming tasks. Students can interact remotely with the hardware via a virtual keyboard and virtual button, as shown in Figure 5. When pressed, the virtual button responds by activating a light. Similarly, the virtual keyboard responds by showing depressed keys. These animations give users a more realistic perception of the system.

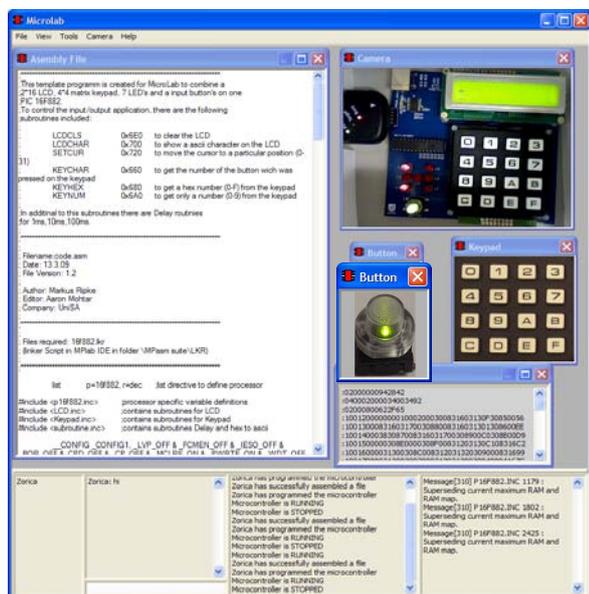


Figure 5: MicroLab GUI.



Figure 6: Close-up of the microcontroller board.

MicroLab is an open access remote laboratory; everyone with Internet access can create an account and access the system. However, the LabVIEW run time engine must be installed on the user computer and the user needs to book time before accessing the system.

Up to three students can access the system at the same time, which allows them to collaborate remotely on an experiment. Currently, the communication is supported only by chat, but work is in progress to integrate a video communication environment similar to the one used by FEUP, shown in Figure 4.

REMOTE LABORATORIES: A TOOL FOR INTERNATIONAL COLLABORATIVE LEARNING

Each remote workbench is simply a technical framework with embedded communication tools and does not guarantee the collaborative nature of the experiments. Its pedagogical effectiveness relies on the laboratory script, which should help students split the tasks among group members, and explicitly indicate when it is time for individual work, and when the team should get together (proximally or by electronic means) for a discussion and joint work. The project now being funded by the Australian Learning and Teaching Council offers an international framework to design and evaluate experiments that exploit the collaborative features of remote laboratories. The laboratory script, briefly introduced in this paragraph, represents a first step towards that objective.

The experiment consists of developing the electronic dice represented in Figure 7, where seven LEDs represent the dice dots.

An international collaboration channel is established from the start, by assigning peer groups in both universities. The laboratory script introduces the technical context, and requests the students to meet for a first group session meant to build a common perception of the learning objectives and expected deliverables. As an example, the group is requested

to determine the 4-bit combinations that shall be written to the parallel port outputs, in order to display the six possible results, as shown in Figure 8.



Figure 7: An e-dice comprising seven LEDs driven by four microcontroller parallel port pins.

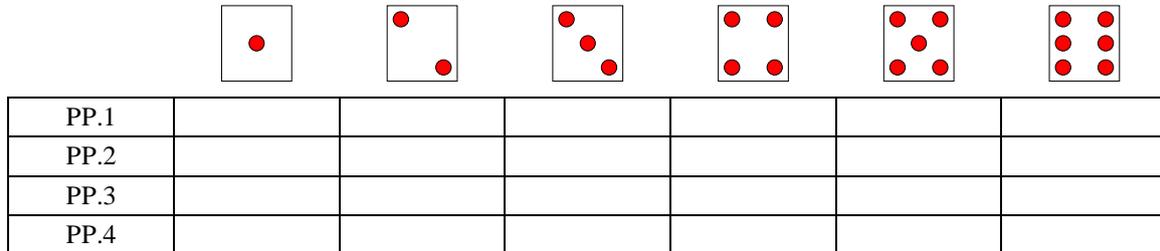


Figure 8: First task (joint work) – determine the output port combinations for each result.

The first session is also used to look into a basic code segment provided in the laboratory script to *roll the dice*. The students have to analyse the code represented in Figure 9, where an error is present, correct it, compile and validate it by simulation and, finally, upload it to the remote workbench, and observe its operation.

```

LOC  OBJ          LINE    SOURCE
1
----          2          cseg   at      0
3
0000          4          start:
0000 7400          5          mov    a,#0
0002          6          m1:
0002 2090FD          7          jb    p1.0,$
0005 12000E          8          call  leds
0008 04           9          inc   a
0009 B406F6         10         cjne  a,#06,m1
000C 80F2         11         jmp   start
000E          12         leds:
000E 83          13         movc  a,@a+pc
000F F590         14         mov   p1,a
0011 22          15         ret
0012 7FEF6FAF        16         db   7fh,0efh,6fh,0afh,2fh,8fh
0016 2F8F
17          end

```

Figure 9: E-dice experiment – the starting code provided in the lab script.

At this stage, the students will interact within local groups (UniSA and FEUP), but the video conferencing room also can be used to discuss doubts with their international peers. After this first stage, each student picks up individual development tasks, in the form of functional features that must be supported by the final application (e.g. different *cheating* modes, use of timers to control rolling speed, serial communication to enable configuration and control from a desktop computer, etc). Each group now works in split mode, and will meet again at a later stage, to integrate and validate their code segments. As soon as a working prototype is available, a second phase starts, where each group has to deliver a presentation to their international peers, explaining what was done and how it works. The prototypes developed by each group are then tested by their international peers, which will provide assessment information to the teacher in the other university.

CONCLUSIONS AND RESEARCH DIRECTIONS

The international collaborative learning framework, described in this paper, was set up recently and its usage by students from FEUP and UniSA is currently under trial. The experience accumulated in the development and operation of the two remote workbenches offered the following lessons to the authors, some of which comprise directions that will be pursued in future research activities:

1. A remote workbench does not have to replicate a real workbench. There is a wealth of possibilities enabled by the use of computer-controlled instruments, in much the same way that a DVD can offer a far more informative

experience than watching the same movie in the cinema. It is obvious that one thing does not replace the other, but one should not discard the opportunity to look into embedding automated assessment features into the instrument control panels used by the students, just to mention one example.

2. As simulation environments become more sophisticated, there will be cases where the distinction between real and virtual worlds will not be possible by the naked eye (even live image feedback can be simulated, creating a false sense of reality). This convergence between remote and virtual labs will influence their respective application domains, and may have implications at the pedagogical level.
3. Remote laboratories increasingly are multimedia-based tools, particularly where image and animations play important roles. Such systems represent a rich learning environment for the average user, but actually may ostracise students with special needs, e.g. those who have visual or hearing impairments [10-12].

In general terms, it is expected to see a trend towards standardisation of the technical infrastructures, better integration into e-learning frameworks, and richer pedagogical features.

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REFERENCES

1. Lowe D., Murray S. and Lindsay, E., Evolving remote laboratory architectures to leverage emerging Internet technologies. *IEEE Transactions on Learning Technologies, Special Issue on Remote Labs* (2009) (in print).
2. Ma, J. and Nickerson, J.V., Hands-on, simulated, and remote laboratories: a comparative literature review. *ACM Computing Surveys*, 38, 3, Article 7, 1-24 (2006).
3. Gillet, D., Nguyen, A.V. and Rekik, Y., Collaborative Web-based experimentation in flexible engineering education. *IEEE Transactions on Educ.*, 48, 4, 696-704 (2005).
4. Corter, J.E., Nickerson, J.V., Esche, S.K. and Chassapis C., Constructing reality: a study of remote, hands-on, and simulated laboratories. *ACM Transactions on Computer-Human Interaction*, 14, 2, Article 7 (2007).
5. Lindsay, E.D. and Good, M.C., Effects of laboratory access modes upon learning outcomes. *IEEE Transactions on Educ.*, 48, 4, 619-631 (2005).
6. Nickerson, J.V., Corter, J.E., Esche, S.K. and Chassapis, C., A model for evaluating the effectiveness of remote engineering laboratories and simulations in education. *Computers & Education*, 49, 3, 708-725 (2007).
7. Abdel-Salam, T., Kauffman, P. and Crossman, G., Does the lack of hands-on experience in a remotely delivered laboratory course affect student learning? *European J. of Engng. Educ.*, 31, 6, 747-756 (2006).
8. Ferreira, J.M.M., Almeida, E.M., Figueiredo, I.M. and Leite, C.F., Labs-on-the-Web: a multidisciplinary project to evaluate the pedagogic effectiveness of on-line-labs. *Proc. European Distance and E-learning Network Annual Conf. (EDEN'2008)*, Lisboa, Portugal (2008).
9. Nedic, Z. and Machotka, J., Remote Laboratory NetLab for effective teaching of 1st year engineering students, *i-JOE Inter. J. of Online Engng.*, Kassel University Press, 3, 1-6 (2007).
10. Nevile, L., Cooper, M., Heath, A., Rothberg, M. and Treviranus, J., Learner-centred accessibility for interoperable Web-based educational systems. *Proc. 14th Inter. World Wide Web Conference (WWW2005)*, Chiba, Japan (2005).
11. National Instruments, Accessibility Requirements Compliance Matrix (2007), 7 December 2009, <http://www.ni.com/pdf/gsa/en/labview-508-accessibility-requirements-compliance-matrix.pdf>
12. Faias, J., Ferreira, J.M.M. and Leite, C.F., Accessibility and usability of online labs: real barriers in a virtual world. *CD Proc. Inter. Conf. on Remote Engng. and Virtual Instrumentation (REV'07)*, Porto, Portugal (2007).