

Hands-on Software Engineering Labs via the Web: Game Changing in Online Education

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ABSTRACT: The paper addresses the issue of offering hands-on engineering labs via the web. The hands-on feature refers to the functionality of the lab, which is preserved whether the lab experiments are done over the web or with student's physical presence in the lab. After an extensive review of remote labs, examples of lab stations are described from the area of software engineering, where software development is done remotely and then software modules are uploaded and tested on the lab stations. This type of lab can be called *invasive*, since the essential element of an experiment is the replacement or modification of the software module controlling the remote equipment. This is in contrast to regular remote labs, which are non-invasive. Two lab stations are presented in more detail, one for a wireless sensor network and another for a remotely accessible microcontroller. Several observations are made regarding the usefulness of this technology and prospects of adoption in software engineering programs.

1 INTRODUCTION

Online college education is a rapidly growing phenomenon, which is evident from all kinds of sources: newspapers, professional magazines and research journals. It has been especially valuable for students whose access to college campuses is difficult and results in their inability to attend, for example, due to a large physical distance, a specific ailment or disability, or a professional reason, such as stationing on the sea or in a remote area.

However, in engineering and in computing, in particular, unlike in other disciplines, among multiple problems to solve, online education has one additional challenge: remote use of laboratories. Labs are an essential curricular element of providing high quality education in all engineering and computing disciplines, and replacing hands-on student experience by a virtual substitute may not always be

the best choice, since it deprives students of the actual experience of putting their hands on the equipment.

This paper addresses the remote labs challenge by outlining the historical development and use of a hands-on web-based lab (called remote labs) in science and engineering, and presenting real-time software engineering lab at Florida Gulf Coast University (FGCU). It consists of a number of lab stations designated for remote software development and testing. The stations are designed for use in high level courses in software engineering, such as real-time systems, embedded systems programming, and software project courses, and involve the following equipment:

- microcontroller for remote data acquisition and control
- single-board computer with real-time kernel for remote access to experiments

- multicore processor for remote development of a network game
- wireless sensor network for remote control and uploading new modules to the sensors
- robotic arm controller for remote use and development.

Two stations are presented briefly in this paper.

The approach is original, because it allows students and developers of software for embedded systems not only to operate remotely the lab devices via the web interface, like in other engineering disciplines, but program the devices from remote locations and test the developed software by uploading it to the remote device and seeing its operation (with the assistance of a webcam) without ever entering the lab physically. In this view, it is game changing, because it will ultimately cause a significant expansion of the ways students of software engineering and computing disciplines can learn online.

The rest of the paper is organized as follows. Section 2 discusses the concept of remote laboratories and its recent history in various engineering disciplines. Section 3 presents lab stations developed by the author and mentions the lab assessment process, and Section 4 provides a summary.

2 REMOTE LABORATORIES

Laboratories and experiments are compulsory in engineering and science education. Traditionally, physical (hands-on) labs were exercised, following the principle known as "learning by doing." With the advent of the Internet and a proliferation of respective technologies, it became possible to offer the same functions of the lab over a distance, which created a phenomenon known as remote labs (also called web-based labs and online labs).

This section discusses the evolution of remote labs in engineering and compares them with traditional hands-on labs.

2.1 Early history of remote labs

The concept of remote engineering labs came into play as early as at the mid-nineties (Taylor & Trevelyan 1995, Atkan et al. 1996, Stancil 1996, Arpaia et al. 1997), and maybe even earlier (Aburdene et al. 1991). Since then, a large number of papers appeared in various journals and at multiple conferences.

A variety of issues arose back then on creating remote labs and using them in teaching, among those technical and pedagogical issues. What is particularly interesting are the views on the need for such labs and on the impact such labs may have on the effectiveness of teaching.

In an early talk given to the Hewlett-Packard Advisor Council, one of the early proponents of remote labs, Dan Stancil (1996), outlined a rationale to create and operate such a lab:

- use of the lab when it is physically not open;
- widening access to equipment for students;

- sharing instruments among multiple universities;
- remote access to expensive equipment the university cannot afford;
- savings on travel time and expenses;
- possibility of remote maintenance and support.

Later on Stancil (1999) formulated the likely benefits of remote labs in electrical engineering:

- possibility of configure circuits and get results very quickly, which encourages exploratory activities more than in a physical lab;
- flexibility to login and complete assignments from any place and at any time;
- broader access to expensive and/or specialized equipment;
- preparing students to work in a "remote mode", which is becoming increasingly common in the workplace;
- enabling hands-on experience in distance education courses.

Cooper et al. (2002) analyzed various approaches to remote labs, in an international project, focusing on learning objectives, which included the ways to help students to accomplish the following:

- identify objects and phenomena;
- learn facts;
- learn concepts;
- learn mathematical relationships;
- learn a theory or models;
- learn how to use laboratory instruments;
- carry out standard procedures;
- learn to plan investigation to address specific question or problem;
- learn how to process data;
- learn how to use data to support a conclusion;
- learn how to communicate results of work.

Trevelyan (2004) outlined very early lessons learned from nearly 10 years of operation of remote labs. Among other things, he stated that "students using remote access laboratories operated equipment for much more time than in conventional laboratory classes, and learning outcomes seem to be significantly improved as a result." It was also clear to Trevelyan that "This allows students the time they need to explore the differences between theory and real equipment behavior for themselves."

Nedić et al. (2003) and their multiple followers (for instance, Winckles et al. 2011) used a number of criteria to compare three types of labs against each other, listing their mutual advantages and disadvantages (see Table 1).

Table 1. Comparison of hands-on, virtual & remote labs (Nedić et al., 2003).

Setting	Advantages	Disadvantages
Hands-on	real data real equipment interact. collaborative work interaction w/ supervisor	time/place restrictions expensive supervision required scheduling required
Virtual	good to explain concepts no time/place restriction interactive medium low cost	idealized data lack of collaboration no real equipment
Remote	real equipment interact. no time/place restriction realistic data & cost calibration	virtual presence only

Corter et al. (2004), on the other hand, conducted an interesting assessment study comparing remote labs to hands-on labs in mechanical engineering. Their main objective was to see whether remote labs are as effective as hands-on labs. From the data collected by the authors, it turns out that students view both types of labs as essentially equivalent in effectiveness. The factors included in the questionnaires for both labs were as follows: preparatory instructions, data acquisition component, lab report, team work, and physical presence in the lab.

Regarding the remote labs themselves, the most highly rated aspects were: convenience in access, convenience in scheduling and reliability of setups. The lowest scores were given to the criterion named "feeling of immersion".

2.2 Period of development of remote labs

After an initial period remote labs really took off, in various disciplines around the globe. The focus of developments was still on technology and educational aspects.

Ma & Nickerson (2006) and several others (for example, Elawady & Tolba 2009) compared hands-on, virtual and remote labs taking into account the ABET educational criteria for laboratory learning (understanding concepts, and developing design, social and professional skills). They took into account technical issues, such as access mode and infrastructure, as well as pedagogy. The results for pedagogy are shown in Table 2.

Table 2. Pedagogy issues comparison for different types of labs (Ma & Nickerson 2006)

Setting	Advantages	Disadvantages
Hands-on	real data & equipment interaction w/ supervisor collaborative work can do trial & error	supervision required time restrictions
Virtual	greater pedagogy value totally safe environment flexibility/ease of use enhancement through animation	no real equipment no supervision no real equipment
Remote	good for distance learn. feeling reality with data focus on concepts focus on professional skills	social skills not devel. design skills not devel.

Lowe et al. (2007) followed the same principal ABET criteria to analyze factors impacting learning outcomes with remote labs. They reviewed existing literature with respect to the following:

- understanding procedures and time on task;
- social and instructional resources;
- student preference for lab formats;
- learning style of students;
- prior learning and experience;
- tutor assistance;
- group work and collaboration;
- interaction;
- mental perception of hardware;
- presence and constructs of presence.

Especially, the concept of presence has received a significant attention in this and various prior studies, with respect to remote labs, due to a separation of learner and equipment. The authors elaborated on three types of issues related to presence: telepresence, social presence, and instructor's presence.

Multiple well-developed labs have been created over the years and their full descriptions have been published. In one of these projects, named iLab (Harward et al. 2008), three types of remote labs have been defined:

- batched experiments, where the entire course of the experiment is specified before the experiment begins;
- interactive experiments, where the user monitors and controls one or more aspects of the experiment during its execution;
- sensor experiments, where the users monitor and analyze real-time data streams without influencing the phenomena being measured.

The authors discuss a number of fundamental questions related to pedagogy, among them:

- What experiments are best suited for remote labs?
- Is there an appropriate integration of online and hands-on labs that is optimum for a given subject?
- What principles should guide the design of the client interface?
- What pedagogical materials should be given to the students before taking the lab to best engage their interest and optimize their learning?
- How best support students who are taking the lab remotely at random times?

Gravier et al. (2008) gave the following account of the advantages of the remote labs:

- lowering the cost of lab equipment purchase, due to increase opportunities of sharing;
- security of users, data and devices;
- observability of sessions by multiple users at the same time;
- avoiding the dangers, if the physical experiments are dangerous;
- accessibility for the handicapped people;
- increased availability due to the geographical and temporal advantages.

They notice, however, that there exist an alarming diversity of solutions among remote lab projects and essentially "every laboratory project implements its own software architecture". This fact causes the lack of reusability and portability among various projects and labs. They also point out to other related factors that could be improved, such as: interoperability, collaborativeness, and convergence with Learning Management Systems (LMS).

Auer & Gravier (2009) summarize the advantages of remote laboratories as follows: reducing obstacles related to cost, more efficient use of facilities, reduced technical support, removing limitations of physical access, benefit for people with special needs and employees who commute.

Cooper and Ferreira (2009) give a firm rationale for remote labs, listing a number of advantages, including the following:

- studying at a distance from an institution offering a course;

- sharing prohibitively expensive equipment among multiple institutions;
- coping with large number of students with a limited physical lab space;
- extending access to students with disabilities;
- to which one could add avoiding harsh laboratory environment (gases, fluids, microorganisms etc.).

Based on their multiyear experience with using remote labs, they list several lessons learned over a period of nearly ten years:

- importance of removing/minimizing accessibility barriers;
- importance of pedagogical strategy;
- need to evaluate pedagogical effectiveness;
- relative difficulty of automation or remote control;
- necessity to formulate learning objectives and make respective design decisions.

Gomes and Bogosian (2009) list the following benefits of using remote laboratories:

- offering similar flexibility as simulation labs with respect to lab space and students' schedules;
- accessibility at any time;
- useful as a supplement for regular lab assignments;
- overall better scheduling of activities;
- better return on investment due to shared resources;
- ease of collaborations around the world;
- support for autonomous learning;
- support for students with disabilities;
- prevents equipment damages and ensures safety;
- meets the experimentation needs of distance education.

In the same article, multiple labs are reviewed in several engineering disciplines, including:

- electronics and microelectronics;
- power electronics and electric drives;
- control engineering and automation;
- robotics;
- microprocessor, reconfigurable, and embedded systems.

This brings us to the most recent developments in remote labs, which is discussed in the next subsection.

2.3 Most recent work on remote labs

Following the initial period of developments in second half of the 1990's, a tremendous progress has been made in the first decade of this century, in the design, implementation and offering of remote labs in engineering and science courses. Many of these developments and respective trends have been described in two recent collections of articles (Azad et al. 2011, Zubía & Alves 2011). Below we review some of the issues, which came up in the development of remote labs, and the most recent solutions to selected problems.

Technical, pedagogical and administrative issues, which were mostly addressed and resolved in the first decade, have become gradually replaced by other kinds of problems, more relevant to the relative maturity of this technology. These new problems arose mostly from expansion of this technology and from attempts to make it have more substantial impact on education in individual science and

engineering disciplines. The focus has shifted from the equipment to the user and software connectivity.

An excellent review of remote labs published recently (Tawfik et al. 2012) sets the stage for articulating most of the problems in remote labs being currently addressed. The paper gives a thorough overview of technological issues at the connectivity level. A key diagram in this study, similar to Fig. 1, reflects the architecture of such labs. Each element of the architecture is then addressed separately: GUI for the remote clients, Internet protocol software, servers, and device interfaces (called controllers).

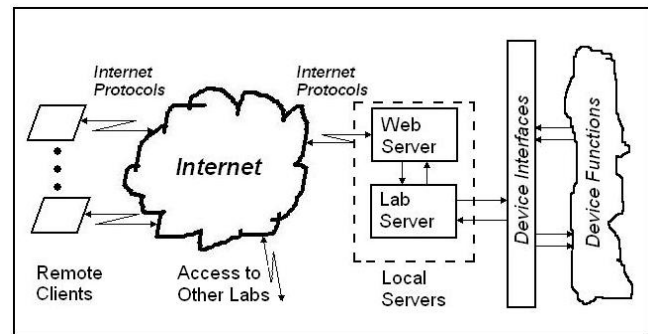


Figure 1. Architectural components of remote lab.

A similar overview has been recently given by Thames et al. (2012), although from a slightly different perspective and using different terminology. They overview a cross-section of assets and distinguish among: (1) human assets (including remote GUI), (2) communication assets (with all communication protocols), and (3) remote lab assets (including physical processes). An important motivation for their work is to make "progress towards the creation of standardized infrastructure and their system models."

Both these views of the architectural issues are compatible. Even though given from slightly different perspectives, they address all essential problems and show the big picture of remote labs. Selected works addressing architectural components from Figure 1 are discussed in the sequel, starting from the user/client perspective (left-hand side of Fig. 1), and ending at the equipment side (right-hand side of Fig. 1).

One substantial improvement, which can be made, is with the user interface on the client side. The current trend is to provide a unified set of interrelated components, called widgets, from which a user can create their own version of the GUI, the most suitable for a particular experiment. In this view, Bogdanov et al. (2012) argue for replacing monolithic GUI's with universal widgets that a user could re-aggregate dynamically to form their own personal environment and assemble lab modules on their own.

On the same side of the aisle, which concerns clients/users, the issue of mobility came up recently. Maiti & Tripathy (2012) address accessing remote labs from the perspective of providing the user with maximum mobility and freedom to perform experiments. In this respect, they study and compare different techniques suitable for developing platforms for mobile devices enabling lab access.

Moving to the middle of Figure 1, when user requests pass through the network, clearly Internet related issues become important. Out of many problems, which become important from the remote labs perspective, security is a topic worth particular attention. Many issues, in that regard, including lab security, for example, are not much different for remote labs than they are for other Internet based applications. However, remote labs bring up unique problems when one begins talking about multi-user access, lab distribution, collaborations, integration with other educational systems, etc.

From this perspective, an interesting article on routing and security was recently published by A. Diop (2012). It discusses a technique to provide centralized network management from a single location, to manage access to remote labs distributed over the network. The method, however, is based on a technology from single vendor, which is a disadvantage and may play a role in adopting the method if standardization is considered.

Another paper along the same lines discusses access to collections of distributed remote labs (Diponio et al. 2012). The authors' objective is to develop an extension of an existing remote lab system, so that distributed laboratory resources would be aggregated and accessible from a single location. The method would simplify and broaden gaining remote access to the lab via a federated architecture.

A detailed account of various issues related to remote labs at the Internet level has been given by Guimarães et al. (2011), based on data collected from lab usage. Several aspects of good lab design are emphasized, including: access control, security, quality of service and federated operation.

Successful collaborations in remote labs depend not only on resolving architectural issues and uniform access, but also on minimizing intercultural differences, since the collaborations reach across the world barriers. In this regard, a report by Nedić et al. (2011) breaks the grounds by providing insight into learning practices in highly distributed remote labs with intercontinental participation.

The progress goes even further than collaborations, making the labs into a virtual world to use it with SecondLife (García-Zubia et al. 2010), strictly integrating it with LMS systems (Abdellaoui et al. 2010, Lerro et al., 2012), creating degree programs in online or remote engineering (Pop et al. 2011), and articulation of the needs for standardization (Thames et al. 2012).

Moreover, since the very birth of this technology, it has been clear that remote labs offer unprecedented opportunities for students in remote areas and underdeveloped countries, but only recently this issue has been sufficiently articulated (Ayodele et al. 2011, Baffour et al. 2012).

On top of social and collaborative issues, labs accessibility, and their systematic analysis, what is always needed is a serious analysis of the effectiveness of labs in teaching. In this regard, the most recent study by Lang (2012) goes a little bit further than Ma & Nickerson (2006) and Elawady & Tolba (2009) and measures students perception of

acquiring professional skills, as per the ABET educational criteria. The students were asked to rate the level at which they acquired the following skills in the physics experiments they conducted: uncertainty estimation, measurement, mastering of physical controls of the apparatus, use of Internet for measurements and for other purposes, calculations, graphics, analysis, written communication, oral communication.

Coming back to the right-hand side of Fig. 1, one can enumerate multitude of devices and instruments that can be successfully connected to the network to enable remote labs (Azad et al. 2011, Zubia & Alves 2011). Several disciplines have entered the territory of remote labs, including marine sciences (S. Surma & J. Mikulski 2008, Casals-Torren & Bosch-Tous 2010, Velasco et al. 2012).

What is of interest in this project, however, is the accessibility of potential labs, which could be used in software engineering courses. This is less oriented towards measuring instruments and more towards devices used for computations. It is interesting to see a number of developments in this area, including labs with devices such as FPGA's (Morgan et al. 2012, Vera et al. 2012), robots (Dziabenko et al. 2012) and SCADA (Kirubashankar et al. 2011)).

Tawfik et al. (2012) summarize the results of a project integrating functions of such a laboratory, with combined lab stations composed of microcontrollers, Programmable Logic Devices (PLD's), Programmable Logic Controllers (PLC's), and measuring instruments programmed in Matlab and LabVIEW. Their objective is to provide lab integration according to ABET accreditation criteria.

Summarizing the accomplishments in remote labs, Castro et al. (2012) advocate and anticipate the following next steps in remote laboratories:

- 1 Creation of a global network of virtual and remote labs; and
- 2 Development on new e-learning standards to facilitate the exchanging of resource.

Interestingly, they mention several engineering disciplines (in addition to sciences), in which remote labs have been used for experimentation: electronics, control engineering, telecommunications, and physics, but do not mention software engineering.

This is our starting point in describing the need for remote labs in software engineering discipline.

3 REMOTE LABORATORIES IN SOFTWARE ENGINEERING

3.1 *Essence of remote labs in software engineering*

It may not be immediately obvious, but it should be made absolutely clear that the World Wide Web, as we know it now, has been created exactly for the purpose of remote access to the labs. The very first paper published on this technology was written by two scientists from the European Organization for Nuclear Research., CERN, in Geneva, proposing the creation of a protocol, which would allow sharing data and equipment usage among physicists around

the world, working on high-energy physics experiments (Berners-Lee & Caillieu, 1990).

While such drive by scientists to access instruments and experiments remotely has led to a significant progress in designing and establishing remote labs, it is the fact of the matter that these labs have not been used in courses in software engineering. There should be a different type of motivation for creating remote software engineering laboratories.

This had actually happened as long ago as in 1997 during the Pathfinder mission to Mars (Reeves 1997). In brief, a robotic device, which landed on Mars, got stuck due to an unidentified software problem, later during the mission recognized as, so called, priority inversion. Then, engineers at the ground control center corrected the software and re-uploaded it remotely to the device.

This sort of operation is substantially different than in all labs described above, used in sciences and engineering. Regular remote labs include measurement and control instrumentation and provide access for students to conduct experiments prescribed in the manuals or lab lessons to learn about certain scientific phenomena or engineering concepts. Thus, the labs can be called *non-invasive*, since the student is not intended to change the software, which runs the instrument or device, perhaps, with a few exceptions limited to selection of modules but never with complete change of software running the device, like in the case of Pathfinder mission.

In software engineering labs, the situation is completely different, because the essence of a lab is for the student to design, implement and test a software module on the equipment, accessible locally or remotely. Thus, the notion of remote lab in software engineering must be extended by a concept of *invasive* labs, where new software, good or bad, but developed by a student, is to be uploaded to the remote instrument or device to let he student learn software engineering principles to become a professional.

The operation of a remote device can be thoroughly tested, using a prescribed experimental method, which may include viewing by a webcam, but the objective of obtaining measurements is not to investigate any physical phenomena, but rather investigate how the software performs, whether it meets its specifications. In other words, the phenomenon, which is being investigated is not any physical process, but just the operation of software.

It is surprising that a description of this type of labs can be hardly found in the existing literature. A very thorough study of remote laboratories revealed only two relevant papers on this subject. First paper, by Karlsson & Hrissagis (2005), initially in the project objectives promises an arrangement, which could be called a remote software engineering lab, but later backs off stating that it was not possible to implement. The second paper, by Yin et al. (2008), describes a remote lab for an embedded system, but since the paper talks about measurements, it is not perfectly clear from the reading, what are the exact software engineering functions of the lab station.

3.2 Web-based software engineering lab at FGCU

Given the strong motivation for developing the labs, as outlined in the previous section, a web-based real-time software engineering lab with hands-on features has been created at FGCU, and has been used on experimental basis in project courses. General overview of the lab and its progress has been presented previously (Zalewski 2010, Zalewski 2013).

Below, two examples of lab stations are presented, where software development is done remotely and then modules are uploaded and tested on the lab stations. Stations' selection is dictated by the willingness to show the contrast between a home-made station consisting of a microcontroller and commercially available station with wireless sensor network. The hands-on feature is emphasized, which means that the functionality of an experiment is preserved whether the lab experiments are done over the web or with student's physical presence in the lab.

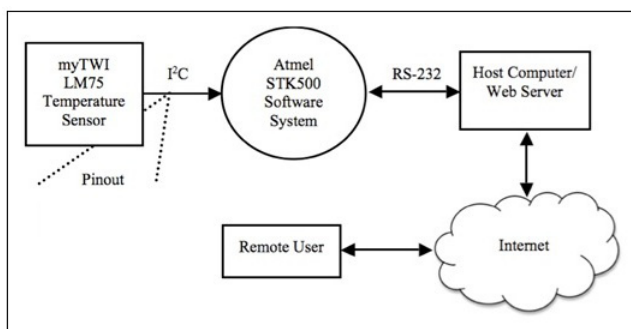


Figure 2. Web-based microcontroller station.

The first station is based on an Atmel STK 500 microcontroller board, which is connected to a temperature sensor (Fig. 2). Its operation can be programmed remotely by a user and viewed via webcam. Respective lab experiment is designed to verify students' knowledge of microcontroller's I/O and its programming in C and assembly.

While the first lab station has been developed locally, the second was commercially purchased. It is National Instrument's Wireless Sensor Network consisting of remote sensor nodes, which can handle attached sensors, and a gateway node, which has Internet connectivity and allows uploading control software to sensors (Fig. 3). The lab experiments are designed to verify students' knowledge of remote data acquisition and programming in LabVIEW.

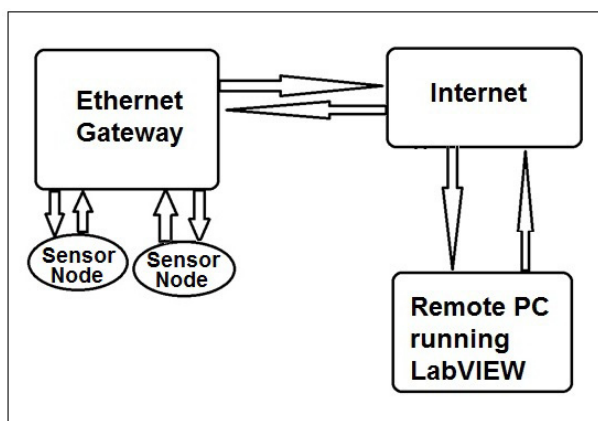


Figure 3. Wireless sensor network remote lab station.

The lab stations are not technically extremely complicated, which allows students to concentrate on the merit of experiments rather than on technicalities. An important issue is to evaluate the usefulness of individual stations and the entire lab. To do this, eight experts have been given access to the lab materials and later interviewed to answer ten questions concerning lab functionality, professional usefulness and pedagogy. Comments of the experts, as well as feedback from the students, are being implemented in successive version of the lab.

4 SUMMARY

Remote labs in science and engineering have nearly 20 years of history of development and usage. They are *non-invasive*, in a sense that the software controlling the experiment is preloaded and is not changed by the student. The essence of labs in software engineering, however, is to develop software to control experiment and upload it to the remote device to test its operation, thus, being *invasive*.

This paper reviewed the history of remote labs in science and engineering, outlining the most recent developments, and presented briefly two labs stations used on an experimental basis in senior project and embedded systems courses at the author's institution. It is concluded that remote labs will be further developed and used in online courses, due to their multiple advantages. A standardization process to unify some of the diversities in the labs has already started (IEEE WG 1876, 2012).

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