

Pedagogical effectiveness of remote laboratories for measurement and control

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ABSTRACT: Remote laboratories for measurement and control represent an ever-growing field in the distance teaching of engineering graduates. They emerge as a valuable tool for teaching difficult matter, simulating complex theoretical models and performing remote real time experiments with often-expensive laboratory equipment. Pedagogical effectiveness of those laboratories has been a subject of discussion and surveys for quite a long time. Negative and positive results have been reported throughout the years, but constant improvements and innovations in the way the teaching material is delivered to students have greatly increased satisfaction amongst e-learners. In this article, the pedagogical effectiveness of distance education is reviewed, with a special focus on remote laboratories for measurement and control. Different theoretical approaches for teaching material presentation are discussed, as well as the assessment of the accomplished results.

INTRODUCTION

Laboratories in engineering and scientific education play an important role for the development of students' practical skills and contribute to their professional development. Conventional *hands-on* laboratories provide live interaction with the equipment and produce real experimental results under supervisor's control. However, they are expensive to establish and operate, and have limited availability. The advancement in Internet technology and the development of new software packages for simulation and data acquisition have paved the way for alternatives to emerge in the form of virtual (simulated) and remote laboratories [1]. Virtual laboratories (VL) imitate conventional laboratories by computer simulation of the experiment. They provide good pedagogical experience by means of appropriate virtual models for simulation of processes that are hard to understand. On the other hand, models are only approximations of the real processes and cannot be complete substitutes for real experiments. VLs contribute to better understanding of complex systems and are much less expensive, and have no time restrictions compared to real laboratories.

In the last ten years, development and distribution of high-quality data transmission technologies over the Internet, combined with new approaches in the areas of software and hardware systems for measurement and control, have significantly changed the traditional way of developing practical skills in undergraduate students at universities. Conventional *hands-on* laboratories have been complemented, and in some instances completely replaced, with a new generation of educational systems, namely remote laboratories. Remote laboratories are now a major area for studies, discussions, designs, developments and assessments in thousands of papers, found on IEEE Explorer and in other data bases.

Remote Laboratories (RLs), sometimes called *hybrid* laboratories, are true technological laboratories, which deliver quality distance education to geographically dispersed users. Compared to the traditional and virtual laboratories, they are comprehensive in terms of teaching materials, related simulations and corresponding remote experiments. They are also flexible and not restricted in time and place, and inexpensive in terms of cost per student. RLs for measurement and control present one of the fastest growing fields of education in engineering at universities. They are expandable and provide e-learners with safe access to often very expensive or dangerous equipment (such as high voltage testing or industrial high power motion control) for the price of a local internet connection. Remote users can access the experiment through the university's Ethernet or wireless network, or through the Internet, from another university, at home or even overseas. The client software provides real time virtual measuring instruments and equipment with animated buttons and knobs, thus replicating real instruments and equipment present at a host location. When started, software automatically connects to the remote server and exchanges specific information to setup the required experiment. Then, the server communicates with a software control application, which applies the required signals to the experimental workbench equipment and reads the measured values in real time by means of specialised data acquisition boards. Web cameras deliver live video and sound streaming from the experimental side, thus enhancing the feeling of a real test environment.

The aim of this article is to explore the theoretical resources and discussions regarding educational values of RLs, in particular those for measurement and motion control, available in a broad pool of literature sources, and to analyse conducted surveys and questionnaires. English-language literature indexed in three electronic databases (IEEE, Science Direct and Google Scholar) and reference lists were searched up to June 2010 using search keywords such as *remote laboratory*, *teleoperation*, *distance education*, *motion control*, *survey*, *pedagogical effectiveness*, etc. Overall, more than 100 articles were discovered, but for the purposes of this article many of them were excluded, mainly because they discuss other aspects of RLs. Eighteen articles were fully reviewed as relevant to the subject matter of this article.

OBJECTIVES, METHODS AND CONCEPTUAL APPROACHES IN CONTEMPORARY DISTANCE EDUCATION

In general, users of RLs are supplied with a relevant teaching material, to allow them to create a model and simulate its behaviour in a virtual environment and finally to perform a remote experiment on real equipment. The laboratory reports contain simulation and measurement results and comparisons between them. Thus, two educational values are achieved: learning complex theory and learning practical skills, both critical for the development of engineering undergraduate students. To accomplish that, different methods and conceptual approaches have been established throughout the years.

Gustavsson et al argue that not much has been done to define perceptible objectives in the development of quality distance learning engineering education [2]. Some RLs have been established without clear vision what they aim to accomplish. The Virtual Instrument Systems in Reality (VISIR) project has as a main goal of creating a community of collaborating universities and other organisations, standardisation of a common laboratory platform and sharing resources and teaching material thus reducing the running cost per student.

NetLab is an example for quality human-system interface [3]. Its distinctive Graphical User Interface (GUI) includes: animated photographic images of instruments, chat window, control window, telepresence via a web camera, variable components and a circuit builder for interconnections between electronic components and instruments. As reported by Bauer et al, it is unique and sets world benchmarks in terms of real time experimentation on real laboratory equipment, allowing for collaborative experiments, supported by the team communication, which is relatively rare in other remote laboratories [4]. Students can collaborate sitting next to each other in Adelaide or from different locations in Adelaide and Australia, as well as liaising with students from Singapore and Sweden in joint experiments [2][5][6]. The developed intercultural and communication competence is important for working in teams with members separated geographically, increasingly common in the globalised employment market.

The versatile Power Engineering and Motion Control Web Laboratory - PEMCWebLab [7] is a major contribution in the field of distance education of motion control systems. It is formed by universities in eleven European countries, participating in the E-learning Distance Interactive Practical Education (EDIPE) project. Eighteen comprehensive online courses, providing high-quality theoretical documentation (including additional literature and references), interactive animations, simulations, exercises, remote engineering experiments, questionnaires and even photo-galleries of remote experiments, have been developed. Learning methodology is divided into:

- pre-task theory presentation, modelling of experimental mechanism and analysis of the simulations;
- experimental validation by real remote experiments;
- comparison of the different control methods and writing reports;
- feedback - communication with the instructor, study of additional theoretical material;
- feedback actions - improvements in the remote laboratory functionality and theoretical documentation.

The objectives in the development of the courses are of an educational and technical nature. The former are related to how to design the courses in a way that e-learning material is presented to students in an understandable and interesting manner. This includes an appropriate real remote experiment that provokes student interest and provides an online contact with teachers and instructors. The latter is how to prepare reliable quality equipment for the remote test bench, including electrical/mechanical parts that should be robust and withstand any damage due to students' errors.

Bauer et al presented the DelfWebLab, a remote laboratory for power electronics experiments, participating in PEMCWebLab [4]. The steps of the design process are described and the objectives of the laboratory are defined. Some of the specific objectives to be achieved by students are:

- to understand the structured design and methodology;
- to be able to analyse the existing system in a structured way;
- to divide complex systems to subsystems;
- to understand the differences between simulations and real processes;

- to be able to select an appropriate equipment;
- to program a microcontroller and control a real system, etc.

With respect to the theory, there are two interesting conceptual approaches. Focusing on the learning process rather than on the remote experiment, Balestrino et al [8] present an advanced telelaboratory for robotics and control systems, which is organised as a compilation of learning objects instead of experiments. Learning objects are *any entity, digital or non-digital, which can be used, re-used or referenced during technology supported learning* [9]. Their fundamental requirements are described as technological support, a guided learning path that students are supposed to follow, user traceability tools, presence of didactic material, immersive facilities and self-assessment tools.

Another pedagogical approach is introduced by Leva et al, where the concept of *realism* and its particular adaptation for the purposes of undergraduate education is discussed [10]. Further, a system comprising of four components is evaluated for realism *physical system modelling, control specification and design*, *controlled system simulation and assessment and control system implementation*. Because of its complexity, this model, and *de-facto* the idea of realism, is more suitable for higher levels of knowledge and education, usually above the undergraduate level. Therefore, some simplifications of the model have been adopted, which authors describe as *deliberate* declines. Based on those ideas, a remote teaching laboratory for control of automatic systems has been created, namely CrAutoLab. Its main principles are defined as *simple plants*, realistic *data*; *simple control schemes*, realistic *structuring*; *simple regulators*, realistic *implementation*; *simple problems*, realistic *design*.

REMOTE LABORATORIES AND *THE SEVEN PRINCIPLES FOR GOOD PRACTICE*

In 1987, Chickering et al postulated the *Seven Principles for Good Practice in Undergraduate Education* [11], which later was adapted in conjunction with the new tendencies in technology developments [12]. With the addition of some important remarks regarding RLs, good practice for effective use of computers, the Internet and other communication media are cited and explained below:

1. Encouraging contacts between students and academics - the constant communication between students and teachers, facilitated by new electronic communication media, will be a decisive force in increasing students' motivation and involvement. This will help in solving of a variety of problems easily and will contribute to better integration of students in an educational environment. RLs contribute to teacher-student communication by means of integrated teaching tutorials, which are sometimes *live*, and students can express their opinions about problems experienced during the experiment.
2. Developing reciprocity and cooperation between students - positive markers for good learning are collaborative learning and social skills development, opposite to the competitive and isolated one. It is surprising how computer-based education, in particular distance education, has encouraged spontaneous student collaboration. Machotka et al emphasise how important are the collaborative, cooperative and non-competitive types of learning for students to develop important skills such as team-work, decision-making, etc [13]. The authors received an Australian Learning and Teaching Council Competitive Grant 2009-2010 on *Enriching Student Learning Experience through International Collaboration in Remote Laboratories*, using NetLab for domestic and international students' teaching and practical classes. Nafalski et al describe NetLab as *one of the most user-friendly and, at the same time, most sophisticated collaborative remote working environments in the world* [14].
3. Using active learning techniques - it is important not only to listen and memorize the teaching material, but to participate in discussions, workshops and *apprentice-like* activities. In that aspect, remote laboratories contribute to *learning by doing* because students are involved in the whole teaching process, including the creation of a simulation model of the process they study, experimentation with it in a virtual environment, then testing it in a real remote engineering experiment and, finally, comparing the results and discussing the factors influencing the differences. Reguera et al suggest that by working in a group connected through the Internet to a remote physical system, and then conducting Web-based controlled technical experiments, students extend their depth of knowledge in areas of control systems, programming, database and Web-based applications [15]. The authors conclude that students feel motivated because *seeing is believing* and *doing is understanding*.
4. Giving prompt feedback - assessing students' work and presenting students with a feedback for their level of knowledge, helps them to focus better on learning. Computer based e-teaching, and remote laboratories in particular, provide different kinds and levels of assessment, keeping track of all students' efforts and performance. Feedback is given in different forms. Bauer et al describe the structure of the feedback subsystem in PEMCWebLab [4]. Providing students with *evaluation results and suggestions on learning* greatly improves their performance and capability to work with the remote laboratory. Significant role is also played in the communication between learners and trained instructors via e-mails, discussion forums, chat-rooms, etc.
5. Emphasising time on task - introducing new technologies to manage time and effort that students spend on their study may increase their learning capabilities. Different teaching strategies have been developed recently to extend student activities and stimulate them to put more effort into the learning processes. One good example of how students may be organised to finish their tasks on time, is offering the flexibility enabling them to work from home or from an Internet-café at a convenient time. This is accomplished by using a booking system, integrated into almost every RL. Booking systems are comprehensive and effective management systems that allow students to register or check-in into a university's database, book a remote experiment and conduct the experiment. Typically,

the results are stored and used later for assessment. Another solution is a batch processing - parameters of experiments are sent by students to the RL and the experiments are conducted automatically later at a time available, and stored in a database. Examples for well developed booking systems are those integrated in NetLab [3], which is an open system, available to everyone who registers under a real or fictitious name, and the Moodle booking system, etc [16].

6. Communicating high expectations - if teachers expect more from students, they will get better results. A well-known way to motivate students is to publish their work, for example. New technologies can create *powerful learning challenges that drive students to not only acquire information but sharpen their cognitive skills of analysis, synthesis, application, and evaluation* [12]. There are many examples of how students are challenged to show their creativity, talent and knowledge in performing difficult tasks to prepare and execute a remote controlled experiment. Bauer et al describe how students participating in DelftWebLab, are involved in the whole design process step-by-step: to simulate the system they will experiment with; to write a program for the microcontroller which will output specific signals for controlling a power converter; to assemble a breadboard; to run the real control experiment and measure the real signals from control points; to compare the waveforms of the simulated and measured real signals and conclude why there are differences in terms of delays, noises, etc [17].
7. Respecting diverse abilities and ways of learning - every student can work better in a specific way when presented with the opportunity to show his/her talent. Remote teaching provides different educational methods. Thus, every student with his or her specific learning capabilities will find the method most compatible with his or her personal learning method and accomplish the required task. Buiu presents an integrated online motion control training package, which exposes the teaching material (the theory of motion control) to pupils, students and technicians in completely different ways by theory, videos, simulations, games, quizzes and remote controlled experiments [18].

ASSESSMENT OF THE PEDAGOGIGAL EFECTIVENESS OF REMOTE LABORATORIES

Many studies have been conducted to assess the pedagogical effectiveness of RLs. Results from a study conducted among students [18] are presented and analysed using the *ten pedagogical principles for online learning* developed by British Educational Communication Technology Association (BECTA) [19]. Those principles and corresponding results can be summarised in the following order:

- Match to the curriculum - 74% of students agree that the motion control training package is relevant;
- Inclusion - the package is available to a wide range of students, including those with disabilities;
- Learner engagement - 52% agree that simulators have increased their learning motivation;
- Innovative approaches - 62% think they have learnt most from the theoretical material;
- Effective learning - 52% agree that they have learnt more than in the traditional way, and also 64% agree that the simulators have increased their learning capabilities;
- Formative assessment - described are the learning process and modules;
- Summative assessment - 42% agree that quiz and exercises contribute to the learning process;
- Coherence, consistency and transparency - how all the sources are developed and presented;
- Ease of use - 50% have completed the training without any help;
- Cost effectiveness - to access it at any time anywhere all you need is a Java-enabled browser.

The pedagogical effectiveness of a RL for experimentation in industrial electronics is discussed by Araujo and Cardoso, as part of a Labs-on-the-Web Science and Innovation Operational Program (POCI 2010) [20]. The major objectives in assessment of the pedagogical effectiveness are defined as: evaluating the impact of the remote experiments on students learning, in terms of initial and final expectations and in terms of students' and teachers' experiences with the limitations of that process. It is concluded that students do not have problems with the technological equipment and appreciate the autonomy to learn subjects. They feel motivated and consider RLs to be a good tool for collaborative learning, especially for people with special needs.

A recent study, conducted with the participants in NetLab reports that overall satisfaction is derived from the international collaboration between students [14]. In addition, satisfaction is drawn from the realism of the experiment and the booking system, which allows repetition of the experiment. However, the need for some improvements is also mentioned, especially about the critical role of the team leader for the successful collaboration in international teams. It is essential to mention how the knowledge and self-confidence in students grow during the learning process. The first year students express an interest mainly in using the integrated Web camera in test-bench. The second year students though show maturity and appreciate the opportunity to perform the experiment alone or in teams and repeat it when needed.

Balestrino et al report interesting results from two surveys - among students and among teachers and instructors [8]. While it is difficult to make comprehensive conclusions from a limited number of remote experiments, the overall response from students is positive in relation to interest in the theoretical material and experiments, complexity of use, etc. On the other hand, from teachers' point of view, the efforts and time they have spent to build the laboratory, to design the learning process and accomplish good results are comparable with those needed in the conventional laboratory. Some negative findings are described by Rojko et al [7]. They state that most of the students still prefer conventional laboratories and *hands-on* experiences, and learn more from them. Further development of new remote experiments, collaboration and cooperation with other RLs would shift the opinions in a positive direction. Despite the prevailing positive results from most of the surveys, it is recognised that at this stage RLs are still a complement, not a substitute, for traditional laboratories.

DISCUSSION AND CONCLUSION

The ongoing discussion and surveys about the pedagogical effectiveness and usefulness of RLs sometimes deliver conflicting results, but continuing improvements and innovations in the way the teaching/learning process is conducted, have greatly increased the satisfaction amongst e-learners. RLs for measurement and control deliver good solutions for use of shared resources and thus reduce the overall costs of engineering education. A well-developed RL offers real-time practical remote experimentation accompanied by teaching materials and related simulations, and becomes a valuable tool for e-learning. The authors of this article discussed some aspects of teaching qualities in distance education, keeping in mind different opinions, designs and surveys from the available literature, and their own experiences. In general, the following characteristics of remote laboratories can be concluded:

- Comprehensive pedagogical and methodological structure - students are typically first presented with theoretical material, then simulations based on the topic are conducted, and finally they perform a real experiment remotely. That gives them a true understanding of complex theoretical matters and practical realities. Conducted surveys demonstrate that students appreciate the autonomy to learn subjects, feel motivated and consider RLs as a good tool for collaborative learning, but as they do not believe that RLs can completely replace traditional laboratories, the feeling of reality and proximity still has to be improved.
- Flexible study and better time management - usually there is no need for a supervisor and limited need for support personnel; remote experiments are not restricted in time or place. An automatic booking system performs an effective job for checking-in and registering students in a university's database, as well as in effective time use of remote laboratory experiments.
- Good economic value - there is only the initial price of the equipment and the developmental work that can be done by postgraduate and undergraduate students. Since RLs allow facilities to be shared by hundreds of students from the campus site, other universities, home or overseas, the cost of education per student is much lower compared to a real laboratory with a limited number of test benches and support staff. However, from some teachers' point of view, the efforts and time they require to accomplish good educational results are comparable with those needed in the conventional laboratory.

The experience of others will be taken into account in the development of the University of South Australia's remote laboratory for motion control and feedback devices.

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