# REMOTE LABORATORIES IN ENGINEERING EDUCATION: AUTOMATION SYSTEM DESIGN

**P. Zenzerović[1*] – A. Belin[2] – V. Sučić[1]**

[1]Department of Automation and Electronics, Faculty of Engineering, University of Rijeka, Vukovarska 58
[2]Croatian Society for Educational Technology, University of Rijeka, S. Krautzeka 83

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***Abstract:***

*This paper deals with the usage of a remote laboratory as a platform for integrating learning into engineering education. . It also shows a concept and partial implementation results of a remote laboratory for designing automation systems. Advantages and disadvantages of such a system are elaborated from the didactical, technological and economical point of view and accordingly, their results are presented. Also, an overview of simulation and implementation results is included.. Finally, directions for future work and an on-line application have been outlined.*

## 1 Introduction

Nowadays, the world requires an increasing number of electrical engineers, especially in the field of automation and embedded systems. The teaching facilities, as universities, high schools, institutions for specialized trainings etc. are adapting to meet these needs/requirements by increasing the number of places available for this study area, sometimes neglecting the quality of the educational process. The focus is therefore on problems arising from the transfer of practical knowledge from the lecturer to the student, bearing in mind the existing challenges such as limited time, adequate laboratory space, and equipment etc.
Another point/aspect is computer integration - one of the main megatrends of modern technology. There are many outcomes from computer integration such as internet, computer aided technology, communications, mobile communications etc. Computer integration technologies have been disseminated and infiltrated into many engineering fields, giving us huge possibilities of acting at a distance. Therefore, computer integration program/technology motivates and runs the development of many remote learning platforms in all educational fields.
The authors of this paper propose the usage of an e-learning remote laboratory platform that can be used in the field of automation system design. The proposed approach is based on the philosophy that universities and other educational facilities should evolve from being institutions that provide (students with) instructions to institutions that produce learning [1].

## 2 Remote laboratories: main opportunities and challenges

With the usage/utilization of remote laboratories, a lot of solutions to everyday problems can be drawn, but also some challenges arise. A recent study [2] analyzing the impact of new technologies on engineering education has introduced remote laboratories as a separate technology in the survey. The research results (based on 1830 participants, being all engineering educators) are presented not only in terms of cross-discipline and cross-

[*] Corresponding author. Tel.: +385(0)98886600;
*E-mail address:* paolo.zenzerovic@cset.com.hr

*Table 1. Educational technologies in electronics – worldwide.*

| Technologies | Percentage |
|---|---|
| Simulators | 16,34 |
| Remote labs | 11,11 |
| E-Learning Platforms and Architectures | 10,46 |

*Table 2. Educational technologies in electronics – Europe.*

| Technologies | Percentage |
|---|---|
| Simulators | 20,00 |
| Remote labs | 15,00 |
| E-Learning Platforms and Architectures | 13,33 |

technology but also in terms of cross-country and cross-continent comparison. This article presents (announces) and interprets the results of the disciplines of electronics, electrical and computer engineering and electronics.

Table 1 represents the top three educational technologies used in the field of electronics with no geographical region filtering. Table 2 represents the top three educational technologies used in the field of electronics with geographical restriction to Europe.

The missing values represented in cumulative percentage in Tables 1 and 2 present all other used technologies [2]. From the above data it is clear that remote laboratories, e-learning platforms and architectures take second and third place just after simulators. However, if we take into consideration that a remote laboratory in its essence is an e-learning architecture, then it is clear that e-learning solutions take first place overall.

Table 3 shows the survey results for the impact of remote labs with its major challenges and expected time it takes to complete technology adoption process due to these challenges. The data is filtered for electrical and computer engineering, electronics and education. These challenges are numbered as follows [2]:

1 - Better understanding of new ways of interacting with students;

2 - Creativity in designing learning experiences;

3 - Development of better technology infrastructures;

4 - Technology maturity levels;

5 - More funds for further development and implantation;

6 - New pedagogical methodologies applicable to technology.

The entire estimated technology adoption process can take two to three years. The major challenges vary considerably between disciplines showing us thus indirectly the current state of technology. In the field of electrical and computer engineering, the major challenge to be addressed is getting more funds for further technology development and for implementation of existing conceptual solutions. On the other hand, in the field of electronics, the major challenge to be faced is developing a better technology infrastructure, which indirectly raises a challenge of getting funds to develop the infrastructure.

It is also worth noting that in the first two fields, from the didactical point of view, the second major challenge to be addressed is creativity in designing learning experiences. This challenge may be driven from the fact that the very presence of technology in education does not make it educational. In order to serve the purpose of education, it must above all have a strong didactical value.

Moreover, Dale's Cone of Experience, mentioned in [3] states that people remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say and write, and 90% of what they say and make while performing a task. Accordingly, technology should find a way of overcoming this challenge because it has a significant educational potential to simulate reality. This potential is the crucial issue in designing the most important part of a learning process - the experience.

As regards the creative part of experience designing, technology should enhance the quality of interactive learning methods by transposing the learning control from the teacher to the student through various engaging situations. Therefore, the student could be offered various opportunities for manipulating the content and also for coming up with their own solutions.

As regards time and resource management, a typical problem that should be addressed in most learning facilities is time usage efficiency of existing laboratory equipment. In most universities, teaching laboratory equipment and laboratory space is shared among a lot of lecturers and students. Mostly, the laboratory spaces are occupied more than 90% of

*Table 3. Impact of remote labs with its major challenges and expected time for adoption.*

| Disciplines | Votes (%) | Time to adoption (years) | | | Challenges (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | <1 | 2-3 | 4-5 | 1 | 2 | 3 | 4 | 5 | 6 |
| | | 32,43 | 45,95 | 21,62 | 8,11 | 18,92 | 16,22 | 10,81 | 37,84 | 8,11 |
| Electronics* | 16,35 | 17,65 | 58,82 | 23,53 | 0 | 41,18 | 41,18 | 0 | 11,76 | 5,88 |
| Education | 15,38 | 18,75 | 43,75 | 37,50 | 12,50 | 0 | 43,75 | 6,25 | 18,75 | 18,75 |

*Electrical and computer engineering

the working time/hours of the universities. Of course, not all courses use all teaching and learning equipment, but in most cases equipment not used during the course cannot be accessed due to the laboratory space occupation, thus lowering the efficient use of the laboratory equipment. Also, very often, laboratory space is limited so that it can accommodate an average of 10 to 15 students at a time. The students spend most of their time setting up the experiment they need to perform and a smaller amount of time acquiring the needed data. Taking this fact into account, time usage efficiency of laboratory equipment is once again lowered.

By using remote laboratory platforms, those problems could be easily solved since the end user of the platform can access laboratory equipment from any place at any time using network technologies. Also, the need to use equipment during the configuration phase of the experiment is eliminated by introducing not only off-line and on-line into laboratory utilization but also a dynamic scheduling system for equipment reservation and usage which is to be incorporated into the platform.

Apart from common problems solvable by using remote laboratories, a key factor in their utilization should be an option of easily integrating learning objectives of two or more courses into engineering curricula.

Taken as a whole, during their studies in Engineering Sciences lecturers and students are focused on a single technical subject without sufficient cross-disciplinary integration of knowledge and experience [4]. This produces students who generally have very poor ability to integrate both theoretical knowledge and practical experience into two or more subjects and to apply them to real life engineering problems [5, 6].

In order to take a more integrated learning approach and to create a feasible model for acquiring practical knowledge in engineering education, universities should provide laboratories equipped with different types of equipment (i.e. microcontrollers, digital signal processors, analog signal processing modules, power electronics modules, electro-mechanical actuators, networking interfaces, software development platforms etc.) and accordingly, give students the possibility to use them as parts of a single system. It is understandable that due to increasing complexity of systems this requirement is almost impossible to be met by universities. In the area of automation system design, the problem can be divided into several sub-problems/sub-issues providing:

- Different system controllers (microcontrollers, programmable logic controllers, digital signal processors etc.);
- Different peripheral devices (electro-mechanical actuators, indicators, input modules, network interfaces, sensors and sensor arrays etc.);
- A system for changing physical interconnections between all modules used in the system (routing of analog and digital signals):
- A controlling possibility to manage system resources.

The model of a remote laboratory shown in Fig. 1 provides a solution to the postulated problem.

## 3 Remote laboratory hardware

The above shown remote laboratory consists of a main server computer, a number of different controllers, a number of different peripheral devices, a system for flexible interconnections between the two and a number of remotely accessible equipment.

The main server computer acts, on the one hand, as a web server, which enables the end users to have an access to the whole remote laboratory system and, on the other hand, as a system controller to the system. It also runs the end user graphical interface software for system development.

The different controllers, peripherals and their basic necessary hardware indispensible for the operation are placed in sandboxes. A sandbox represents a

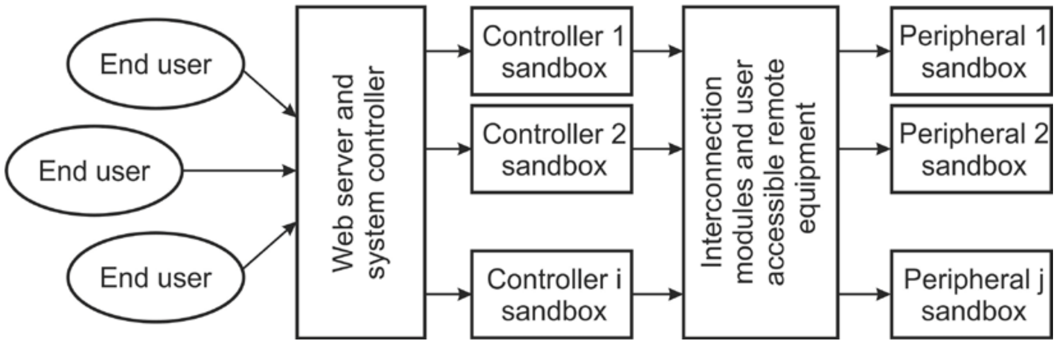


*Figure 1. A generalized model of the remote laboratory.*

minimal group of hardware employed by an end user.

A typical controller sandbox could be a microcontroller, which would consist of the chosen microcontroller, a controllable frequency oscillator and a controllable power supply. A typical peripheral sandbox could be a device for human-machine interfacing, such as an alphanumeric LCD, seven segment displays etc.

In the remote laboratory system there is an option of connecting a larger number of controller and peripheral sandboxes, thus enabling the end user to use devices in the university curricula.

The key parts of the system are interconnection modules. These are bidirectional switching matrices that enable the end user to connect one or more of the controller sandboxes to one or more of the peripheral sandboxes. The end user is thus given the possibility to use different modules as parts of a single system, thus overcoming the main challenge of a typical university laboratory. In this way, a basic platform for learning integration into the field of automation system design has been created. The part of the system that allows for remote configuration of hardware is called the "Soft-wiring" module and represents the biggest technical and economical challenge in the system realization.

## 4 The soft-wiring system

The soft-wiring system at a high abstract level is shown in Fig. 2. The system is used to interconnect any/all pins of the first bus to any/all pins of the second bus. This system can be implemented in a few ways, depending on the selection of interconnected switches (switching primitives). The options are switches, relays, multiplexers and demultiplexers, analog multiplexers, crosspoint switches and FPGA technology. A recent study done by Lamza, Zenzerović, Sučić [7] has shown the advantages and disadvantages of all mentioned options for physical implementation.

The first implemented version of the system [8] based only on microcontrollers and their typical peripheral devices apply analog multiplexers for interconnecting the two busses. This solution has been tested and positive results have been given. The disadvantage of this solution is the number of integrated circuits needed to interconnect two 32 bit wide busses, and the area needed on PCB boards. The proposed solution uses FPGA devices which minimize the overall cost and area needed for PCB design. The complete implementation details are given in [7].

All implemented soft-wiring system solutions rely on pre-defined hardware components. Their architecture cannot be modified by the end user, thus, the interconnection module has to be developed so that all the switching components needed to connect any pin of the first bus to any pin of the second bus are present in the system. This is why the topology of the primitive switching network used in all interconnected modules is complicated and grows significantly both in complexity and price in accordance with the number of pins of the interconnected busses.

In most of the cases, however, one pin of the first bus, i.e. connected to the chosen end user controller will be connected to one pin of the second bus, i.e. connected to the end user peripheral. This results in very low efficiency of capacity utilization of the used switching primitives. Nevertheless, all interconnection locations/paths/facilities/architectures must be rendered possible for the end user. This is why a dynamic soft-wiring system is proposed.

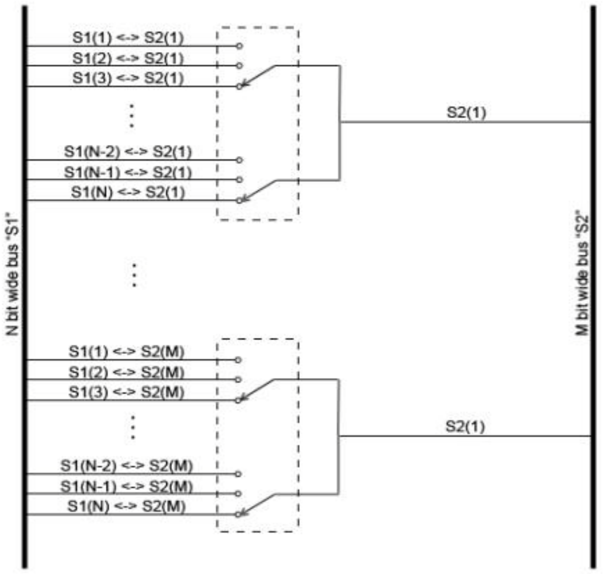


*Figure 2. The soft-wiring system.*

## 5 The dynamic soft-wiring system

The dynamic soft-wiring system is implemented into FPGA technology. It facilitates the end user to connect any/all pins of the two busses in a bi-directional manner. The end user must define the two pins that will be connected and the direction of the data flow. The data flow direction can either be constant or dynamically change according to some external signals.

After the user has specified all the interconnected signals using the graphical assistant on the remote laboratory web page, the data is compiled into the VHDL description language for FPGA. The generated VHDL code describes the hardware switching components to be implemented. After the generation of the VHDL code, the code is then compiled and programming files are generated with FPGA programming suite. This system uses Altera FPGA devices and Quartus II programming software for the system implementation. The programming software runs on the web server of the remote laboratory and it is not directly accessible by the end user. To use the system, the end user does not need to know anything about FPGA technology or VHDL coding.

The main advantage of such a system is that it creates only an amount of switching primitives that is actually to be used by the end user, thus lowering drastically the complexity of the interconnection module, and making it cheaper to implement. For comparison purposes: the soft-wiring system used about 70% of the used FPGA while the dynamic soft-wiring solution can be fitted in less than 5% for an extensive end user system. Accordingly, this gives the opportunity to use considerably cheaper FPGA with less programmable cells, reducing thus the cost of implementation by about 6 to 7 times.

The disadvantage of such a system is the need to have a development studio for FPGA running on the web server. Also, the programmer for the FPGA device has to be used, which adds cost and a certain complexity to the system. Providentially, for teaching purposes, a free version of the Altera Quartus II can be used in the system, and programmers and boards can be bought with a discount, which makes the dynamic soft-wiring solution the first choice for system implementation.

## 6 End user interaction with the system

Existing solutions in the field of remote laboratories facilitate their end users to change some variables before the experiment runs at the remote location. This undoubtedly includes changes in voltage source parameters, current source parameters, and frequency generator parameters etc. After the values have been preset by the end user, the experiment can be run. The data is then acquired and sent to the remote end user via the computer network infrastructure. Most of the existing solutions employ commercially available generators and measuring equipment with USB, serial or GPIB communication protocol. This is actually a good but very expensive solution. This is why specialized input and output modules have been evolved/built up to be used with a remote laboratory described in this paper.

The input modules are divided into two groups: general usage measuring modules and specialized measuring modules. The generally used developing modules are employed to acquire data (logical states) of every pin of the controller being developed (on) by the user. The acquired data can then be displayed in the form of graphical user elements in the web application designed to access the remote laboratory.

The specialized modules were built up in order to acquire data from certain peripherals that need higher sampling frequencies, such as multiplexed seven segment displays, alphanumerical and graphical liquid crystal displays.

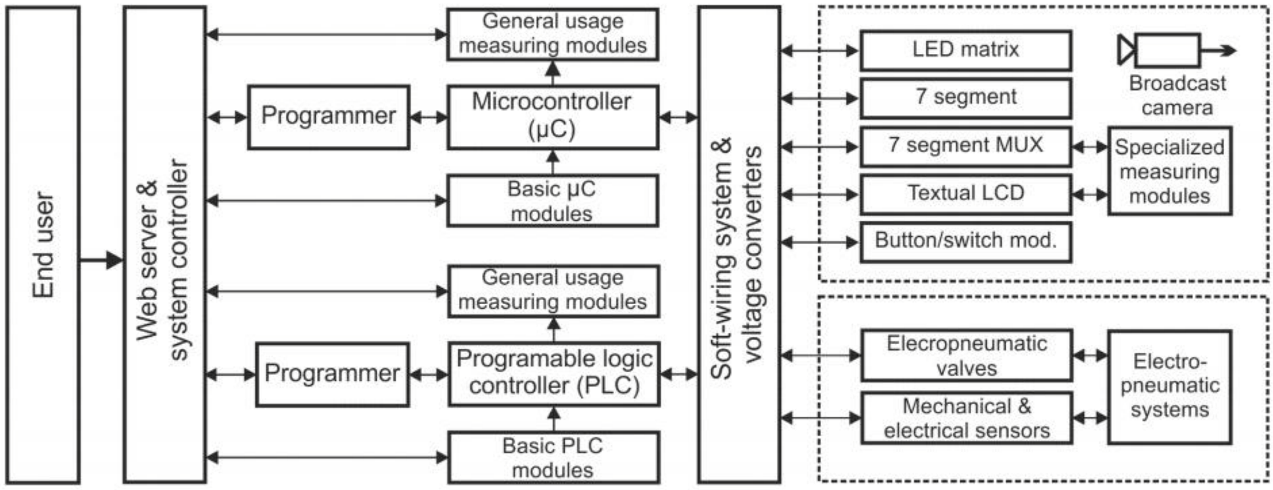


*Figure 3. Detailed view of the remote laboratory.*

To perform a remote control (To control remotely the inputs of the) of the inputs of the controller selected user, a specialized remote button module was developed. The module enables the end user to feed inputs to the controller remotely i.e. by using remote pushbuttons or switches to change the input states of the chosen microcontroller pins.

In the first implementation of the system [8], all the mentioned modules were developed as stand-alone devices. As the system proposed in this paper uses FPGA technology to implement the soft-wiring modules, all the input and output modules described before were therefore implemented as a part of the complete FPGA structure.

## 7 Remote laboratory components

Fig. 3 shows a remote laboratory with two controller sandboxes and two peripheral groups. . The depicted/described system is implemented in hardware so as to obtain complete functionality. Nevertheless, the system is not limited only to the very components shown in the Fig. 3 but it can be also easily expanded to accommodate more controllers such as digital signal processors, FPGA cores, SOPC solutions etc. as well as more peripheral systems and/or devices such as sensors, sensor arrays, electrohidraulic system components etc.

## 8 Conclusion

This paper has presented the concept and implementation of a remote laboratory for the design of automation systems. Both advantages and disadvantages of using remote laboratories for educational purposes have been discussed. According to a (mentioned) recent study, remote laboratories should/could be in use in two to three years, provided some general platform improvements were done. The authors propose the Soft-wiring and Dynamic Soft-wiring system as a solution for reconfigurability in the end user signal routing. The partial implementation of the remote laboratory has shown positive results and the concept of those systems has proved to be efficient.

Concerning the educational perspective, the presented remote laboratory platform has the potential to become an interactive method of learning that transposes the control of the learning process from the teacher to the student through various engaging situations which will allow for the students both to manipulate the content and to come up with their own solutions.

## References

[1] Barr, R. B., Tagg, J.: *From teaching to learning: A new paradigm in undergraduate education*, Change, 27 (1995), 6, 13-25.

[2] Martins, S., Meier, R., Castro, M. (Ed).: Engineering Education Report (2012). Retrieved from: http://ohm.ieec.uned.es/eer/.

[3] Finnis, A. J.: *Learning Technology: Myths and Facts*, International Journal of Instructional Technology and Distance Learning, 1 (2004), 5, 66-79.

[4] Pendharkar, G., Judge, S., Gredeskoul, O.: Multidisciplinary Integrative Learning and Assessment in Engineering Education, RMIT University, Melbourne, Australia, 2010.

[5] Huber, M., Breen, M.: Integrative Learning: Putting pieces together again, The Carnegie Foundation for the Advancement of Teaching, Stanford, 2007.

[6] Ilic, V.: Engineering practice: *A drive for curriculum change*, Proceedings of the International Conference on Engineering Education, Coimbra, Portugal, 2007.

[7] Lamza, S., Zenzerović, P., Sučić, V: *Software controlled flexible hardware interconnections: Existing solutions and a novel approach using FPGA technology*, Article submitted for publication.

[8] Zenzerović, P., Sučić, V.: *Remote Laboratory for Microcontroller System Design*, Proceedings of the $34^{th}$ International Convention MIPRO, Opatija, Croatia, 2011, 1685-1688.