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Distance Education on Automatics and Electronics through Remote Labs

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Abstract

Distance learning imposes specific challenges to provide quality education. Technology is a great opportunity for educational improvement. In this work we analyze some challenges and we have shown that with the proper use of technology it is possible to overcome them. We introduce here a set of remote laboratories currently being used for control engineering education in our university, which contribute to teach several control engineering topics like perception systems and the use of sensors and actuators, cybersecurity and penetration testing of IoT smart sensors and similar devices that can be found in industry, computer system architecture and low-level programming of microprocessors to implement fast control algorithms. The value of this work lies not only in the utility of remote labs as learning tools but also in their implementation following IEEE standards and integrating modern devices and communication protocols with industrial application.

Keywords: Virtual and remote labs, Perception and sensing, Internet of Things, Sensor networks, Remote servicing.

Educación a distancia en automática y electrónica mediante laboratorios remotos

Resumen

La educación a distancia impone retos específicos para proporcionar una educación de calidad. La tecnología es una gran oportunidad de mejora educativa. En este trabajo analizamos algunos retos y hemos mostrado que con el uso apropiado de la tecnología es posible superarlos. Presentamos aquí un conjunto de laboratorios remotos que están siendo utilizados actualmente para educación en ingeniería de control en nuestra universidad, y que contribuyen a enseñar varios temas relacionados con la ingeniería de control como sistemas de percepción y el uso sensores y actuadores, ciberseguridad y pruebas de penetración sobre dispositivos inteligentes IoT o similares que pueden ser encontrados en la industria, y arquitectura de sistemas con computador y programación de microprocesadores a bajo nivel para implementar rápidos algoritmos de control. El valor de este trabajo no es sólo la utilidad de los laboratorios remotos como herramientas de aprendizaje sino también su implementación siguiendo estándares del IEEE e integrando dispositivos y protocolos de comunicación modernos que tienen aplicación industrial.

Palabras clave: Laboratorios remotos y virtuales, Percepción y sensores, Internet de las cosas, Redes de sensores, Servicios remotos.

1. Introduction

Distance learning requires a specific methodology. Depending on the selected learning strategy there are some additional constraints that do not exist in face-to-face learning (Warren and Churchill, 2022). Technology can be used to cope with these constraints, providing a learning experience like in-person learning. With the advent of information and communication technologies this gap between in-person and distance learning has been reduced. For instance, now it is possible to provide a live lecture over the internet or using

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remote meeting applications to interact with the students. Then, the learning experience can now be closer to a face-to-face learning. In the field of engineering, it is not easy to reduce the gap because providing practical experience without direct access to experimental laboratories is a challenge. The concept of remote lab arose several decades ago and today it is not new. There have been many research works related to it. Nowadays, remote labs are used with success not only in distance learning institutions but in common learning ones. During the COVID-19 pandemic these tools enabled people to continue their studies in engineering preserving the practical vision and training required for engineering disciplines (Wu, 2022).

2. Challenges for distance learning in automatics and electronics

2.1 Content

Automatics and Electronics are two disciplines that require an important theoretical background in Mathematics and Physics, however, when working with engineering students it is very important that they experience how the theoretical concepts are used in real applications, and that they acquire the required competences to design new systems and that these competences are aligned with the industrial needs of staff education (Dobslaw *et al.*, 2023).

Today, industry is constantly evolving in the fields of Automatics and Electronics. There are new technologies that future engineers must master, from new communication protocols or IoT to AI, without forgetting that engineers must acquire self-learning competences from a strong theoretical foundation. Configurable labs make it easy to adapt the content to the students and industry needs.

2.2 Added value

Technology in these fields is changing fast and the demand for knowledge from industry is different on a daily basis. The creation of a laboratory is often an important investment for the educational institution and if the technology life cycle is short, the return on investment can be low. From an economic viewpoint the decision to establish a new laboratory is always complex (Nan, 2011).

Remote labs are not only a substitute for in-person educational laboratories. They add value that can improve the return on investment. For instance, a remote lab can be operational 24/7. Although they can require an important investment in IT infrastructure, current universities usually have a very good IT infrastructure, and a new remote lab can use the existent one without additional cost.

2.3 Improved quality

The initial idea that remote experience is worse than in-person one should be analyzed deeper (Zeman *et al.*, 2025). In-person laboratories are designed to allow the teaching staff to interact with the students and the information about their performance can be gathered in-situ, on the other hand, remote laboratories are designed to operate with support from IT technologies. Current IT technologies can be a driver of improved user experience and better performance evaluation. IT technologies can help the students to better understand complex concepts if the experiments are designed to use them properly and, on the other hand, the use of the system can be monitored in order to get real and objective data about the use of the system by the students.

Remote labs can be standardized, and they can be designed to contribute to the continuous improvement of the educational institution. They can provide different user experience and information not only based on results but on every intermediate task. The data can be used to make decisions aimed at improving the system for the future, not only from a technological viewpoint but also on a educational one.

2.4 Additional transversal competences

Distance education lacks direct means to improve some personal competences, although they develop other competences that are highly valued in the business world. Students are alone, this fact does not support social competences, however, students develop other ones like personal responsibility, self-motivation, and so on.

Remote labs reinforce additional transversal competences of the students improving their future productivity when they finally enter the industry as engineers (Lockett *et al.*, 2026). Digital competences are reinforced in this way better than in face-to-face learning because all the interaction between the student and lab is through digital means. An example can be AI. The use of AI assistants can help the students to understand how AI can be properly used to improve their productivity in a world where AI is being strongly integrated into the business world, without losing acquired knowledge.

2.5 Specific tools

There are many tools that have been used traditionally to develop practical tasks for teaching Automatics or Electronics. A lot of them can be used for distance education, for instance specific simulators or general-purpose tools like MATLAB and Simulink, but they require that the student owns a software license or device to work at home. These tools are commonly used by in-person education students as an aid to their study process or to make assignments at home (Rossiter, 2023). They do not provide the same value for the student as a physical laboratory.

The concept of laboratory is far from this kind of work. A laboratory must have a set of defined experiments and some form of guided supervision. It implies a set of tasks specifically designed to ensure that the student acquires a specific knowledge defined by the academic staff. For distance education through remote labs what provides that kind of supervision is the IT software tool.

2.6 Integration

Even for in-person learning the use of Learning Management Systems (LMS) is common today. Physical Labs are defined as special tasks for the students that complement the acquired knowledge with practical training. LMS is usually configured to gather the results of lab tasks as a quiz or a written exercise.

Remote labs are complex IT applications, and they can be developed to be integrated into the LMS to improve the user experience. There is recent research activity searching for this integration (Pena-Molina, 2022).

3. Automation and Electronics Laboratories in Operation

This work is done for an educational institution with many years of experience in distance education. In the field of Industrial Engineering the academic staff has considered remote labs as a strategic issue from several years ago.

Educational programs have evolved in the last years to meet new technology and industry demands. Currently, there are some remote labs in operation to ensure practical training in Automatics and Electronics that are providing services to several courses.

For this institution these tools are more than a way to support learning. Remote labs are an important research line where technologies related to automation, electronics, communications and software are developed and implemented. Although the application in the institution is related to education and training, those technologies can be transferred to the industry for different applications.

We can look at remote labs as production infrastructures where some users get access remotely and can interact with them. In the field of education, the system restrictions are similar to those in an industrial facility, although the activity is not critical.

The remote laboratories introduced in this paper are developed with the aim of complying with the standard IEEE 1876-2019 for Networked Smart Learning Objects for Online Laboratories (IEEE, 2019). Standardization is a very important matter in order to create a large and complex remote lab infrastructure.

The Higher Technical School of Industrial Engineering offers several degrees (BSc and MSc) where Automatics and Electronics are important disciplines. Its large number of students makes it the largest university in Spain in terms of student enrollment in the field of Industrial Engineering. The students are non-localized, and they access the courses and laboratories remotely. This fact implies that although remote labs are not an application as critical as an industrial one, due to the high number of users, the IT infrastructure and the remote lab applications must be reliable, secure and accessible, and labs must be integrated with other remote teaching technologies too.

In this work three remote laboratories in the field of Automatics and Electronics are considered. They were operational during the academic year 2025/2026 at the Higher Technical School of Industrial Engineering.

Table 1: Remote Laboratories of this work and their education level

Lab	MSc	BSc	Micrograde
Perception	Yes		
Cybersecurity	Yes		
Computer Arch.		Yes	Yes

3.1 *Perception Systems Laboratory*

A remote laboratory to support learning in the use of sensors and actuators was developed for a course on Perception Systems with both analog and digital inputs or outputs in order that students can access real hardware remotely. This lab is built on several Arduino boards and a Raspberry Pi. The Raspberry Pi is connected to the TCP/IP network and manages the Arduino systems. The system is accessible from the LMS that is based on Moodle. The students can access the system, reserve a period of access and enter the system at the previously reserved slot time. The student can upload the code to access different sensors or send a signal to some actuator to an Arduino system. The system has a web camera that through a streaming server provides a video stream that can be shown inside the LMS as shown in Figure 1.

The student can learn without owning an Arduino board and the experience is like the implementation of the circuit with an Arduino at home. The only difference is that the student does not assembly the electronic circuit on a prototype board. It is previously done.

This lab works with non-smart sensors. In this case, the control logic of the components must be implemented at the micro-controller board. This lab shows the students how to access and control sensors and actuators using C language.

Figure 1: User Interface of Remote Lab on Perception Systems with a menu of its integrated sensors. The language of the application is Spanish

3.2 *IoT and Cybersecurity*

IoT has experienced great development over the last few years. Most IoT devices are based on small micro-controllers with a few sensors and/or actuators and communication capabilities.

Due to their simplicity, they do not contain complex software to provide high level security themselves. In an industrial facility these kinds of devices can be a security risk.

A laboratory to train future engineers in how to mitigate the risks and how to build secure systems has been developed. This laboratory is built with Arduino boards, and the activities proposed to the students are Cybersecurity case studies for five communication channels with different OSI physical-layer technologies (UART, RS-485, I2C, BLE and Wi-Fi). The concepts that students work with this remote lab are monitoring, spoofing, AES encryption, man encryption in the middle attacks, bus scanning, bus monitoring, wireless scanning, WEP and WPA encryption, MAC filtering, denial of service (DoS) attacks, and so on. The user interface is like the interface of the previous laboratory, and these tasks are done remotely with a web browser.

An example is shown in Figure 2. In this case, the student programs an Arduino board connected to a RS-485 bus attacking the system. The data from the sensor can be gathered or fake data introduced by the additional device controlled by the student. The results on the Arduino screen can be seen in real time using a webcam.

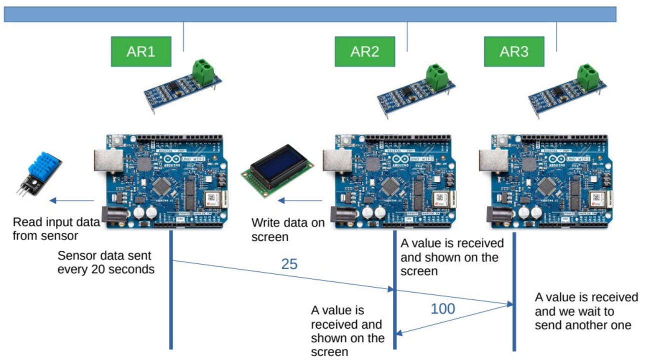

Figure 2: Description of a penetration testing activity in a system with RS-485 communications that students can test in the cybersecurity remote lab.

3.3 *Computer Architecture*

The last remote lab implemented in this area of knowledge is a hybrid laboratory. This laboratory is composed of virtual and real hardware. It is a virtual microprocessor system with the capability to be connected to real hardware through different interfaces and communication protocols. Students work with general purpose microprocessors instead of micro-controllers, and as the microprocessor is simulated, it is possible to use legacy systems with lower learning curve.

This laboratory allows students to experiment with different microprocessors without a large hardware investment.

In this work, virtual systems are implemented as services in a Linux server on Intel hardware. We use modern techniques to make these services reliable and scalable.

Our first implementation has been tested using it with a simulated Motorola 68000 system with I/O ports mapped in its memory address space and connected to a physical system (the user interface is shown in Figure 3). As in other laboratories, the student can see how the assembler programs modify the behavior of the real hardware through a video stream. The connection between virtual and real hardware is established using common communication protocols that we can find in many industrial facilities.

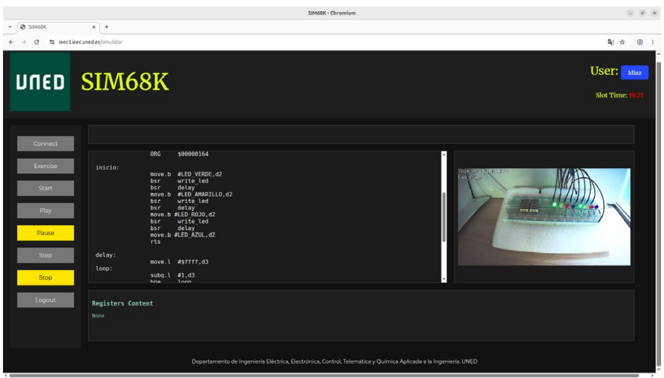

Figure 3: UI of the hybrid remote laboratory on Computer Architecture. A legacy simulated Motorola 68000 is managing a real electronic circuit.

The exercises explore different instructions of the microprocessor and how it can be used to make common programming tasks in an optimal way, from arithmetic operations to the use of pointers with arrays of characters, and the use of the stack. The students follow the programs and evaluate how these instructions modify the internal registers and the memory. An added value of this hybrid laboratory is the implementation of I/O connected to real hardware although the microprocessor system is virtual. They experiment actually how the writing of a value in a memory address implies a change in a physical device. The students can practice the use of microprocessor systems programmed in assembler language to control real systems. This task of controlling real systems in a fast and optimal way is important for future automation engineers, and it is a perfect complement to other laboratories based on programming micro-controllers in high level languages like C++ or python.

4. Conclusions

Although there are a lot of challenges to use remote labs as learning tools, when compared with traditional ones, they have shown that, in an increasingly digital world, they provide real value. They allow students to acquire not only knowledge in control engineering but additional competences useful for industry that can be a competitive advantage in the labor market. These tools have been positively received by the students. They start their lab task soon. We asked the first students using the latter laboratory for an initial impression and most of them answered positively. At this moment, we do not have the academic results to analyze a possible correlation between laboratories and evaluation, and we are gathering the results of a full survey (100 % of students with laboratory tasks done) with a wide set of questions. This will be the aim of a future research work.

The remote labs presented here have been running in real engineering courses. There are productive facilities in our working area. Many of the concepts we use may also be useful for industrial human resources departments interested in training their own staff with their own tools. Our recent work is based on standardization following IEEE recommendations. This contributes to make it more flexible and adaptable to fit different educational or training needs.

Following the evolution of these systems, we are interested in the natural evolution of contents trying to preserve a good academic background and providing an education with a practical experience closer to industry needs and business demands.

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