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# SEITI RMLab: A costless and effective remote measurement laboratory in electrical engineering

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**Abstract**

e-Learning emerged as a way for enhancing the quality of education and providing accessible distance learning to allow learners to study beyond regular class time, transcending the mandatory presence of teachers and the availability of classrooms by providing the necessary resources and services. One of the main issues of e-learning, especially in engineering education, is the lack of online educational laboratories. Practical work remains a considerable burden as engineering educational programs focus on handling real equipment. These last are only accessible within a restrictive schedule and might be unaffordable for low budget institutions. The need is clear for interactive platforms that enhance the motivation and controls the regulation of workload for each student. In this paper, an overview about online laboratories is given and a simple approach of remote lab is suggested. The proposal of our research team (Team SEITI) can be used for carrying-out experiments that require neither assembly nor physical changes until the results are obtained unless a technician, that must be present in the laboratory, acts on equipment. The idea is to set up a real-time measurement retrieval laboratory that requires the involvement of a technician to act on instruments and will grant access to a large scale of students.

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## Introduction

Formerly, learning was based exclusively on face-to-face teaching, which consisted of classroom learning, either individually or in a group, and under the supervision of a teacher. This learning mode offers a direct exchange with the teacher and other learners, but requires frequent movements and freedom to respect a specific timetable.

The evolution of information technology and the pervasiveness of the emerging information and communication technologies, in our present society, led to their involvement in the delivery of educational content and their integration into educational institutions. This has contributed to the emergence of e-learning, which can be defined as the provision of a learning opportunity for those who are geographically distant. It provides means that allow learners to study, outside of the limiting timetable and without the presence of teachers, by providing them with the necessary resources and services.

Moreover, teachers and learners, especially in the scientific and technical disciplines need an environment that allows them not only to do their courses, tutorials and communicate, but to perform their practical work (PW) too. Hence, the need to introduce a new form of laboratory, which can be accessed remotely to meet the real issues of: (i) expensive industrial equipment that cannot be moved or duplicated, (ii) realism of the local representation of the industrial environment, (iii) risk and safety while handling high-voltage equipment, (iv) in terms of pedagogical needs, the number of equipment needed is far outweighed by the large number of students.

Remote labs are educational materials that go further than virtual labs, based only on simulations, and grant distance access to laboratory equipment through the Internet, and allowing their configuration, supervision, and measurement retrieval.[1]

Such a solution offers several advantages such as: (i) remote manipulation of real equipment and synchronous telemetry is intended to offer real data acquisition over the Internet instead of using simulated data, (ii) real-time demonstrations during lectures, (iii) all class students can do the PW despite the large number of students comparing with the number of workbenches, (iv) students can access the PW from home, (v) workbench can be shared with students from another institution, (vi) safer platform by avoiding the mishandling of high-voltage equipment, (vii) allowing real-time delivery of laboratory material and ensuring a global access to a large audience on the Internet other than the original targeted population

(e. g. on a national scale, the project aims to create a remote PW center accessible to different schools and universities).

This paper presents a platform for a costless and effective remote measurement laboratory in electrical engineering. It aims to present all the necessary steps for the modeling of a remote laboratory (expression of needs, formulation of objectives, definition of pedagogical contents, and environments) and tools. For this end, a computer architecture and an environment suitable for distance learning with a pedagogically and ergonomically effective interface is suggested to ensure better dissemination and integration of educational content and to reproduce, as closely as possible, the system that should be handled. At the end of the experiment, a survey was conducted and the students were interviewed in order to assess the outcome of the platform.

## Related works

Nowadays, a lot of institutions are developing and using their own solutions of online laboratories. Many initiatives emerge in the literature to provide shareable experiences. While some of them are remote laboratories, the others stand for repositories or indexation systems with functionalities like advanced searching tools, booking systems, recommendation system, and multiple parameters filtering mechanisms.

This section reviews the objectives and scope of some representative projects. Amongst them, we can highlight the following.

### Online laboratories

*iLAB*: A multidisciplinary lab, developed by The Massachusetts Institute of Technology in collaboration with Microsoft Research, implements a highly extensible environment that could serve a potentially infinite number of users and online laboratories. It provides a framework that can support access to experiments that can be rigorously defined before execution starts, or in which the student can customize the procedure of the experiment in real time.[2]

*ISILab (Internet Shared Instrumentation Laboratory)*: Developed at the University of Genoa and based on a modular system named ISIBoard, it authorizes real experiments execution and manages concurrency among users who remotely drive instruments and carry out experiments of scalable complexity that deal with basic electronic measurements via the Web, but only allows users to conduct practical work with predefined experiments.[3]

*RemotElectLab*: Developed at the University of Porto, it is a reusable, easy replicable and highly flexible remote lab platform for experimenting electric and electronic circuits. It offers an exact replication of the real lab that enables the students to modify certain predefined parameters in the circuit under test (CUT), implement all the circuits proposed during normal electronics teaching lab classes, and allows voltage or current measurement at different nodes of the circuit remotely.[4]

*VISIR (Virtual Instrument System in Reality)*: Developed at Bleking Institute of Technology, it is an open source remote laboratory project that uses a breadboard that allows the user build a CUT from the beginning virtually, uses a switching matrix to transform the student's scheme to a real circuit and then enables him to retrieve real measurements.[5]

*NetLab*: Developed at the University of South Australia, it is an online remote laboratory project that uses a circuit builder to allow remote electronic circuits wiring and measurement. It is used by teachers and tutors for demonstrations during lectures, and offers to students a mean for conducting their experiments remotely on real laboratory equipment. It gives the user the impression of conducting hands-on experiments through its realistic graphical user interface that incorporates buttons and knobs behaving like they would on real equipment.[6,7]

*RwmLab (Remote Wiring and Measurement Laboratory)*: Developed by The Western Michigan University, it is an easily replicable, fully reusable, and highly flexible remote lab for teaching electronics to undergraduate students that addresses real-time remote wiring of electrical and electronic circuits. It allows students to remotely connect instruments, change their settings, and retrieve real measurement over the Internet instead of using simulated data. RwmLab behaves as a local multi-circuit board on a common distributed panel, allowing to "physically" wire an electronic circuit in the laboratory over the Internet. The measures obtained remotely match the ones collected in the conventional, which allows students to achieve, check, or complement their practical work assignments at home.[8]

*LaboREM*: Developed at the Bayonne Technological University Institute, it is a platform that promotes distance learning for the engineering students. It incorporates a video camera and a remotely controlled robotic arm for placement of components to allow students to build their circuits. It is based on the design and control of Virtual Instruments for the management of remote experimentation through the web, implements a game-like scenario as learning approach, and uses Chamilo and Dokeos Learning Management Systems to manage students and supervise the collaborative work.[9]

*ArPi Lab*: Developed at the Slovak University of Technology in Bratislava, it is a general purpose and operative remote laboratory, which is physically built on Raspberry Pi and Arduino development boards. It is designed for practical experimentation in automation and process control related education and provides various experiments in thermal plants, magnetic levitation, and hydraulic systems.[10]

*iSES (the Internet School Experimental System)*: Led by the Charles University in Prague, it is an open remote laboratory system that allows the simple construction of remote experiments via paste and copy approach of pre-built typical blocks. It uses a basic ISES hardware and ISESWIN and ISES WEB Control kit as software for control and data transfer and supports real-time remote data acquisition, data processing, and control of experiments.[11,12]

*PEMCWebLab*: Led by the Brno University of Technology and funded by the European Community via the Leonardo da Vinci, 2006 program, it is a remote-controlled laboratory for experimentation in basic fields of Electrical Engineering especially in Power Electronics, Electrical Drives and motion control. It grants access, via a web-based tool, to remotely controlled and monitored real experiments that are located in different universities.[13,14]

Meanwhile, many online repositories or laboratory management systems are dedicated to develop, publish, and share remote labs.

*LabShare*: Funded by the Australian government and led by the University of Technology of Sydney and sponsored by six universities, its aim is to create a national network of remote sharable laboratories to support cross-institutional sharing of remote labs as a consortium of Australian Technology Network Universities who would share remote laboratories. LabShare targets civil, mechanical, and electrical engineering and offers several functionalities (i.e. booking, system and queuing option...).[15,16]

*LILA (Library of labs)*: Developed at the University of Stuttgart and co-funded by the European Commission, it is an online portal that allows sharing and exchange of experiments. It's a project that aims at building a repository of online lab experiments shared between universities on a worldwide scale and integrating virtual and remote lab experiments into Learning Management Systems.[17]

*WebLab-Deusto*: Developed by the University of Deusto, it is an Open Source remote laboratory management system that provides a scalable software infrastructure and uses web standards suitable for mainstream web browsers, and adapts to mobile devices. It provides an inter-institutions coalition of remote laboratories and can host remote experiments developed by other projects.[18,19]

*UNILabs (University Network of Interactive Laboratories)*: Developed at the National Distance Education University in Madrid, it constitutes a network of web-based laboratories in which different Spanish universities take part. The network is used to host an expanded range of virtual and remote laboratories and provide a large collection of web-based labs. Based on the use of a free authoring tool for building user interfaces, it offers several updated modules in the automatic control field. Theses virtual and remote labs are deployed into Moodle, which facilitates their management and maintenance.[20,21]

*Lab2Go*: Developed at the Carinthia University of Applied Sciences, it is a repository project that offers a common framework to gather and depict online laboratories according to the semantic web technology. It provides references to online resources and implements enhanced search mechanisms and other data handling features to enhance the browsing of the repository.[22]

## Remote labs vs. Virtual labs

Actually, and for many years, hands-on activities have been the only way to conduct well-structured experiments. Thanks to the advancement in information technology, conventional hands-on laboratories structure and processes have been redesigned and expanded to distance laboratories to meet the aforementioned needs. This kind of labs is now playing a crucial role in teaching technical courses. Thus, virtual labs, simulators and remote labs can be used in engineering education as alternatives for regular hands-on labs (Figure 1).

Diverse terminologies are used in the literature to depict labs offering online or virtual experiment. To avoid confusion, all the different types of distance labs are explained in the following.

Virtual labs, simulation labs, and simulators can be used interchangeably and refer to labs where each real experiment is simulated or virtualized via the use of a software[23] and does not involve the use of any specific device or instrument. It can be used in certain experimental activities where simulation is enough, does only require the use of an ordinary computer, and can be accessed through an interactive user interface with usually high visual rendering where students can handle the experiment parameters and view its outcome.

In virtual laboratories, the instrument is replaced by a software program that reproduces, approximately or fully, all its functions.[24] The platform may also incorporate several distinct virtual devices necessary for the implementation of the experiment as for workbenches in electrical engineering (Figure 2).

Alternatively, remote or online labs have been available via internet for nearly two decades[25] and can be defined as educational resources that provide an interface to interact remotely with real workbenches. Those workbenches contain lab instruments (e.g. multimeters, power supplies, motors, and generators) that are

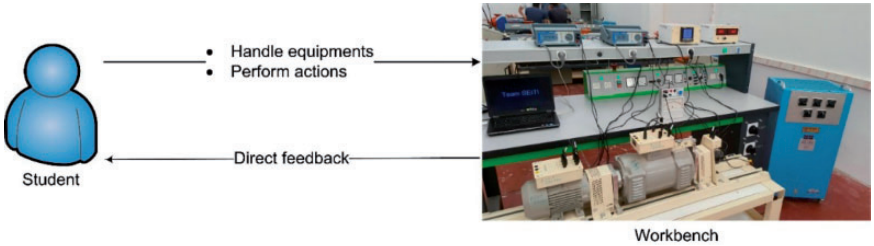


**Figure 1.** Hands-on lab.

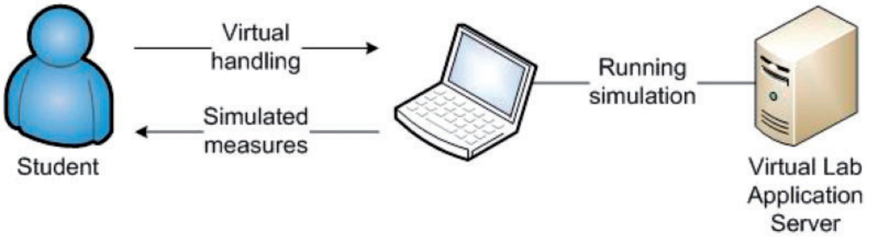


**Figure 2.** Virtual lab.

separated from the learner, but can be accessed, configured, manipulated, and monitored using the Internet to perform the experiment.

Remote labs allow learners to have access to practical learning materials without time and location restrictions (Figure 3). Which means that the experiment can be performed anywhere there is Internet. In other words, "If you can't come to the lab the lab will come to you".[26]

Each type of lab has thorough pros and cons. While virtual laboratories can be used by a large panel simultaneously, with only the computational power as a limit without additional costs, remote ones are more expensive to create and maintain because they require real hardware to run experiments and additional equipment for online access (Table 1).

Both types allow learners to carry out experiments safely from any place in the world which means that learners cannot damage the instruments while adjusting settings, because in one hand virtual labs are just made of software and on the other hand we can easily define limits and restrictions in remote ones.

Unlike virtual labs, remote ones provide a valuable lab experience by providing extended access to real devices, and simulators can never perform exactly the same as real hardware in all cases because it is impossible for them to include all the experiment's parameters. Moreover, remote labs offer the chance to work in the remote mode that has gained a lot of importance in the professional field.

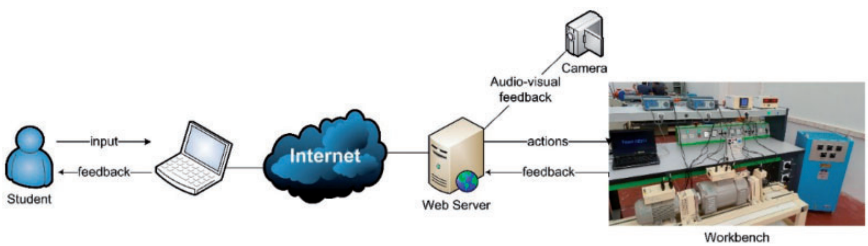


**Figure 3.** Remote lab.

**Table 1.** Characteristics of virtual and remote laboratories.

| | Virtual labs | Remote labs |
|---|---|---|
| Accessibility | Not limited | Must respect a schedule |
| Cost | Low | High |
| Learning | Suitable for unlimited use | Learn how to work in a remote mode |
| Maintenance | Software updating | Instrument maintenance and software updating |
| Realism | Reasonable | Low |
| Reliability | Yes | Yes |
| Safety | Yes | Yes |

## Rationale for remote laboratories in electrical engineering

Practical work is essential for developing skills of applying theoretical knowledge in real-life problems. In fact, institutions need to find a solution to provide learners with relevant online practical experiences. In the case of electronic engineering and while learners need to handle real devices to retrieve authentic measures and gain the targeted practical skills, virtual labs cannot provide such kind of real experiences. This lab should not only allow students to send commands, receive feedback and measurements, and execute the experiment on real instruments in the lab remotely but also should provide solutions to the needs in terms of:

### *Accessibility*

In hands-on activities, access to the laboratory is limited by the availability of both the instructor and the lab simultaneously. Online labs offer flexibility to the learners to operate experiments anytime and anywhere subject to having access to a computer or terminal capable of running the application, while in remote labs learners must queue and follow a certain schedule to conduct experiments and a common web browser is the only required application for the remote user.

Moreover, and to reduce discrimination against disabled, institutions should grant access to students with disabilities who may not be able to access a laboratory and operate laboratory equipment. In this sense, no one can argue with the potential benefit of remote experiments to remove or at least minimize accessibility barriers.

### *Economic burden*

The institution should look at the financial resources and equipment before considering doing some PWs. Under-equipped institutions are coping with the heavy financial charges of buying and maintaining required instruments in conventional laboratories with the intention of maintaining the effectiveness of laboratory practical education.

To deal with those economic factors, remote laboratories should be accepted as new possibilities for under equipped institutions, and so we can think of collaboration between institutions in order to share equipment and resources to expand their list of experiments, enrich the educational experience, and produce better learning as well as reduce costs and satisfy economic constraints.

Table 2 shows an exact estimation of a complete workbench cost that can be used by only a group of student at a time and in one experiment, and considering the increasing number of students the need is clear for a low-cost and financially sustainable laboratory.

**Table 2.** Estimated workbench cost.

| Equipment | Code | Qty | Unit price | Line total |
|---|---|---|---|---|
| Autonomous position 4000VA | BZV-40D- | 1 | 3814.52 | 3814.52 |
| Asynchronous machine | MAS20 | 1 | 771.39 | 771.39 |
| DC machine | CB50 | 1 | 5112.98 | 5112.98 |
| Tachymetric dynamo | DYTA2 | 1 | 598.98 | 598.98 |
| Bench with wheels for machines | | 1 | 358.93 | 358.93 |
| Resistive load | CH20 | 1 | 1291.91 | 1291.91 |
| Torque / Speed display case | TAGA | 1 | 2025.91 | 2025.91 |
| Electrical quantities measuring station | DIRIS A40 | 1 | 1622.21 | 1622.21 |
| Portable automatic multimeter | MX5060 | 2 | 390.78 | 781.56 |
| Ampermeter | | 1 | 448.66 | 448.66 |
| Black security cable | 402S-N | 20 | 4.92 | 98.40 |
| | | | Total (excluding tax) | 16,925.45 € |

## *Pedagogical needs*

Low-budget institutions can only provide students with a small number of accessible systems compared to large numbers of students. Equipment units are insufficient for all the potential users within some experimentation, which makes their hands-on labs have highly poor utilization rates.

To cope with that, we might think of working in groups. Unfortunately, this solution is not effective enough because the students' available time slots are limited, which makes scheduling more sessions considerably impossible. Tutors claim that, sometimes, PW sessions do not take place in the most appropriate order for all groups and so, some students have no choice but to conduct their experiments before taking the corresponding lecture which is pedagogically ineffective.

In the current subject, and for pedagogical purposes, the number of students per workbench should be between two and three.

Because of the handling of high voltage equipment and for safety reasons, a workbench should not be used by a single student. The presence of another person is mandatory, if a sudden threatening event occurs, to trigger the emergency stop and alert administrators.

It is also hard for a single student to take instant measurements on multiple devices at the same time. And in case of misunderstanding or partial assimilation of a concept each student will automatically refer to the teacher which will restrain his analytical skills.

The use of the workbench by two or three students gives them the opportunity to discuss about the experiment and to help each other, which will enhance their collaboration and analytical skills.

On the other hand, if the number of students exceeds three, we find ourselves in a situation of congestion where all students won't have the opportunity to act on equipment. Limiting their interactions with equipment will surely weaken the skills acquired during the session.

These conditions made us explore the possibility of adopting an online lab. No one can argue that it is crucial to identify the experimentation's needs, objectives and expected outcomes to choose the suitable kind of online lab. In electrical engineering, learners need to interact with real instruments and collect real data. While virtual labs might discard some important aspects of the real experimentation and "oversimplify" it, the remote lab should be preferred.

### *Flexibility*

A well-designed remote laboratory is capable of accommodating new experiments, PWs and instruments easily. And it can be replicated and adapted to the needs of each institution.

### *Accuracy in the measurements*

A remote system guarantees the accuracy of real-time measurements as those obtained in hands-on experiments.

## System architecture

Figure 4 depicts a scheme of the overall system architecture.

### *Actors of the system*

*Tutors*: produce the PW statement, schedule sessions, assist, and evaluate students.

*Technicians*: act on equipment, provide assistance to learners, monitor the workbench, and intervene in case of problems.

*Learners*: view the manipulation via video streaming, inspect real-time measured data and variations, consult the statement of the PW, consult the technical documentation of each equipment, set for the assessment associated with the PW.

### *Workbench*

The workbench contains several electrical equipment needed for the experiment and measurement instruments that can be connected to the application server in order to retrieve real-time measurement remotely.

The workbench will be detailed in the following section.

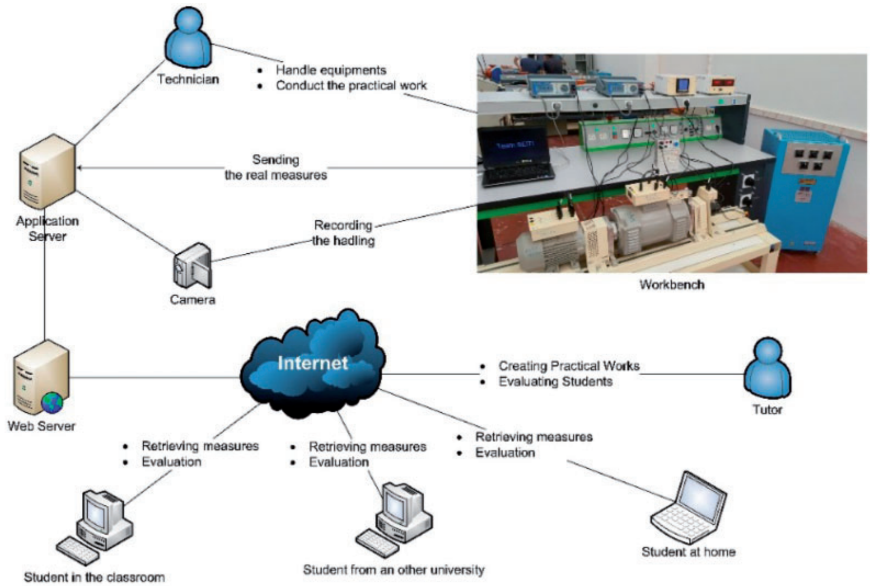


**Figure 4.** System architecture.

### *Application server*

The application server is a computer that hosts the control software or drivers of the equipment and is connected directly to the equipment by standards such as USB or Ethernet.

The measuring instruments that are incorporated are of two types: (i) instruments that possess a LAN connection and an embedded web server that provides a web page interface, (ii) instruments that possess a USB connection and can be accessed via a proprietary software.

This server is linked to a digital camera through a USB cable to ensure workbench supervision.

The Open Broadcaster Software is used to capture the video of the workbench; the obtained measures are integrated in the video in order to have only one flow that will incorporate all the information. And YouTube streaming services are used to ensure a good quality streaming at the beginning before developing our own solution.

### *Web server*

Web browsers are software tools that we are sure that the user would be mastering and using on any computing device, including mobile platforms. Therefore, distributing pedagogical material only through a Web browser is a judicious and sufficient choice.

The web server (Apache) contains all the information on the available experiments (workbench description, used equipment description, experiment, and learner evaluation) and integrates a database (MySQL) for saving authentication data, PW information and student results.

Once authorized, the user may subscribe to a remote PW session, which will take place during an already defined schedule. Then he can access the web page of the PW that includes: (i) PW statement, (ii) links to information about the used equipment, (iii) link to the corresponding course, (iv) video streaming, (v) a set of questions that the student must answer and a table where they must enter the obtained measures for evaluation purposes.

The video of the remote PW will only be available at the aforementioned session. This video will incorporate a live stream of the workbench and set of real-time extracted measures.

HTML5, CSS3, JavaScript, and PHP were chosen to develop the web platform, which will allow to handle the matters of flexibility and ubiquitous use of the application on mobile devices. This platform offers several interfaces for teachers to allow them to add easily new remote lab activities and for learner to enable them to carry out each experiment on the required hardware infrastructure through a user interface transparently.

### *Communication*

Our platform uses two different technologies to provide communication between clients and server, while JSON structures are used to transmit the data. The first one is provided through asynchronous AJAX/HTTP requests that are processed in the server side by a set of PHP scripts. The second uses a socket handler module to ensure a real-time data (data concerning the electrical measures retrieved) delivery.

## Pedagogical work

### *The workbench*

The workbench consists of test and measurement devices plus various other electrical devices. Figure 5 shows the typical experimental setup.

The power part of the system consists of a squirrel cage induction machine (B) and a DC machine (C). Each of these two machines can be operated in the two operating modes: motor mode and generator mode. The machine that operates in generator mode supplies a resistive electric load ($E$) with a maximum power of 3000 W.

The measurement part incorporates two multimeters (F) for measuring electrical quantities (currents/voltages), an amperemeter for measuring the excitation current absorbed by the DC machine, a mechanical-quantities (torque/speed) measuring device (H), which receives data in the form of a voltage from a tachymetric dynamo (D) and a measuring station DIRIS A40, which is used to measure and

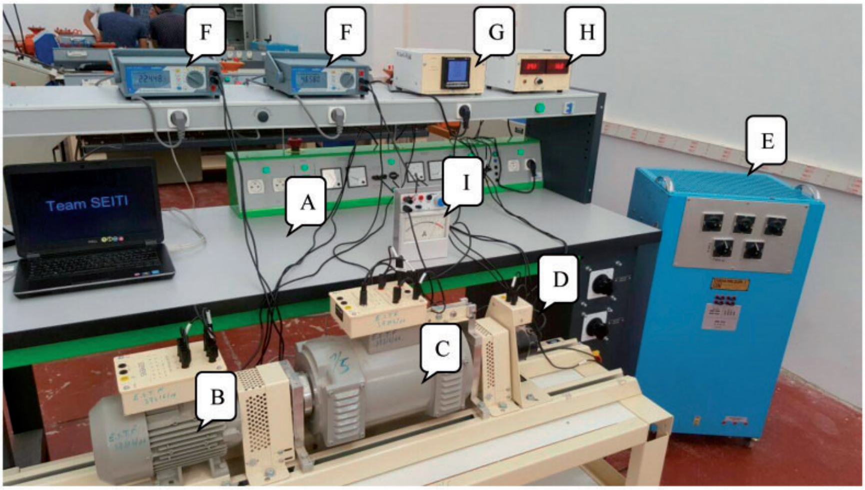


**Figure 5.** Hardware resources of the PW.

display the characteristics of the electrical network (G) that can be analyzed and operated remotely. The power supply and safety of all these devices is ensured by an electro-technical autonomous position (A).

## Prerequisites

The prerequisites of this PW are the basics in mathematics and electrical engineering.

## Structure and objectives

The experimental system is designed with the intent of reproducing as well as possible the behavior of the conventional lab. And the lab work is suggested to undergraduate students working in the fields of electrical engineering.

The objective of this practical work is the study of the three-phase asynchronous machine and the DC machine at the same time. First, the nameplates of both machines are studied, then a no-load test is carried out and finally a load test is realized. The three-phase network of the laboratory is: 220V/380V, 50 Hz. The bench below is the subject of two possible experiments.

The first one deals with the study of the three-phase squirrel cage asynchronous motor:

- The stator winding resistance is measured using a DC source in order to calculate the stator Joule losses.

- A no-load test is carried out in order to determine the iron losses $P_{fer}$ and the mechanical losses $P_{meca}$ of the studied machine. $P_{fer} + P_{meca}$ is called constant or collective losses.
- A load test is conducted in order to plot the torque-speed characteristic. To achieve this, a separately excited DC machine is placed on the same shaft as the asynchronous machine. Since the two machines are connected, the torque of the induction machine and the one absorbed by the DC machine will be equal. By measuring the torque by a sensor linked to the DC machine, the asynchronous machine torque will be measured.

The second one regards the study of a separately excited DC generator:

- A no-load test is achieved in order to plot the magnetization curve of the machine which matches the influence of the excitation current on the no-load voltage delivered by the generator at a constant rotational speed ($n$): $E = f(i_{ex})$ at $n = cst$.
- The speed of the DC generator is varied with a constant nominal excitation current in order to see the evolution of its no-load electromotive force in terms of the armature rotational speed.

A load test is performed in order to determine the influence of the load on the generator voltage at a constant rotational speed and a constant excitation current ($i_{ex}$): $U = f(I)$ at $n = cst$ and $i_{ex} = cst$.

## *Pedagogical approach*

Aware that PW has a strong impact on students' learning outcomes[27] and the fundamental challenges of a remote lab are technical and didactical, this work deals with both perspectives. The pedagogical outcome of remote laboratories in engineering has been figured out by tutors and teachers and related in the literature. Remote experiments have a considerable potential for collaborative teamwork and constructivist learning strategies by allowing students to benefit from a richer learning experience.

On the one hand, adopting an Inquiry-based learning and making in charge of their own learning process through an active exploration and interpretation of the materials has been proved useful to provide students with a better conceptual understanding and a stronger critical and logical thinking skills.[24]

On the other hand, offering to the students to work in a self-paced way rather than imposing them to work on a strict schedule, allowing them to carry on uncompleted experiments from home and to repeat experiments to confirm uncertain measurements, giving them the possibility to view lectures, examples, and take assessments at their own convenience when impediments occur, will surely make them work at ease and lead to satisfactory learning experiences.[28] Finally, in these approaches, problem conception must be motivating and inspiring for students to make them more interested in learning the required concepts on their own.[1] And the use of an interactive platform may enhance learners' motivation.

### *Learner assessment*

Assignments play a key role in any learning process and are considered as an important activity within any practical experimental work for the reason that they represent an inquiring approach to knowledge acquisition.

Assessments in our platform are used to evaluate students and their capacities according to explicit educational concepts (summative), and to revise and adapt the learning process to meet student needs (formative) in order to ameliorate the learning materials or even the platform.

To do this and at the end of the PW, students are asked to fill a multi-choice question (MCQ) quiz to assess their acquired knowledge and to fill a table to check the measurements they retrieved during the experimentation.

## Platform evaluation and discussion

The process of the platform evaluation is intended to contribute to continuous improvement. The main reasons of the evaluation are the optimization, upgrade, and correction of bugs. The environment is evaluated with regard to its effectiveness, the perception and expectations of students, and the learning effect and outcome with regard to the budget allocated by the institution.

The purpose of our investigation was to determine the opinion of students about our remote laboratory, in the Moroccan university context and especially in our own institute. We wanted to know whether the experiment was as effective as we assumed it would be and scroll through the problems and difficulties students might face while using it.

At the end of the course, students that followed the PW were asked to respond to a survey to assess the quality and impact of the use of our remote lab; both a technical evaluation and a pedagogical evaluation were conducted.

We divided a panel of 31 students into three groups: G1: 9 students, G2: 11 students and G3: 11 students.

The first group (G1) conducted the PW in a conventional laboratory first, whereas the two last ones (G2, G3) started conducting it remotely via SEITI RMLab. The first remote PW took place in a classroom equipped with computers and internet connection at school, while the other was done by each student at home. Then we switched the groups two times in order to make all students try conducting the experiment in all the offered ways.

G1: hands-on > remote at the university > remote at home.

G2: remote at the university > remote at home > hands-on.

G3: remote at home > hands-on > remote at the university.

The interval of time between each experiment for the same group was two weeks. And all the experiments took place in the first semester of 2017.

**Table 3.** Evaluated issues.

| | | |
|---|---|---|
| **i01**: Availability | **i02**: Ease of use | **i03**: Real time |
| **i04**: Level of interaction | **i05**: Autonomy | **i06**: Collaboration |
| **i07**: Documentation | **i08**: Accuracy of measurements | **i09**: Pedagogical and didactic efficiency |
| **i10**: Evaluation | **i11**: Help and Support | **i12**: Safety |

**Table 4.** Questionnaire sample.

| Question | Corresponding issue |
|---|---|
| Q01: Is the interface easy to use? | Ease of use |
| Q05: Being far from the remote Lab, did you feel yourself to be in control of it? | Autonomy |
| Q13: Are the technical details of instruments and other documents good and clear? | Documentation |
| Q18: Did the remote laboratory help to deepen your prior knowledge of the subject? | Pedagogical and didactic efficiency |

For the evaluation purpose a questionnaire, scoring the 12 main issues reported in Table 3, has been worked with about 20 questions. A sample is given in Table 4. The answers were rated on a 5-point Likert-type scale and for each question, the student should select the adequate grade from very bad (grade 1) to excellent (grade 5).

Students' ratings are graphically presented in Figure 6.

Results can be used to show us whether it is reasonable to continue the project or not and guide us on the possible improvements and rectifications. Despite these results are not meaningful enough to draw categorical conclusions from, they give rational indications for further research.

In order to fetch more accurate information, all the students were interviewed. The feedbacks gave us a clearer perception regarding students' ideas and position about the concept. Instead of discussing questions results here, we opted for discussing the issues that were addressed by these questions, which highlights more significantly our findings.

When exploring the students' satisfaction with the availability (issue 1) of the platform and real-time response (issue 3) we found that students claim not to have a good enough quality of internet connection at home or don't have internet at all, and so they cannot access the platform anytime they want to, which affected their impression of conducting a real-time experiment too. Furthermore, there was diverse opinion regarding the ease of use (issue 2) of the platform and that is due to the fact that some students are accustomed to the computer tool and so they didn't have any problems when conducting the remote experiment, while others have difficulties in handling the computer to conduct the experiment.

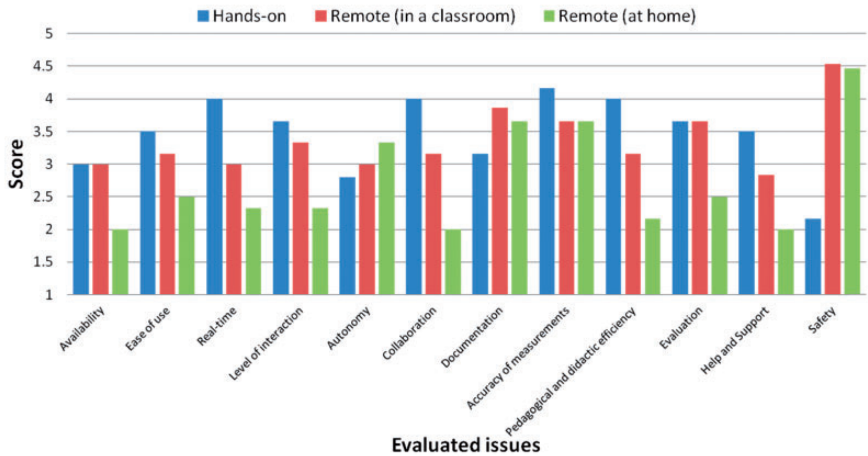


**Figure 6.** Evaluated issues students' ratings.
Note: for the questions that addressed the same issue, an average mark was calculated.
The average overall satisfaction is about 3.47/5 for group 1 (Hands-on).
The average overall satisfaction is about 3.36/5 for group 2 (Remote access, in a classroom).
The average overall satisfaction is about 2.74/5 for group 3 (Remote access, at home).

On the one hand, students assumed that they felt more autonomous while conducting the PW at home because they had to do it by themselves (issue 5) and acknowledged that all necessary documents were available whenever needed, unlike the real laboratory where they have to share a limited equipment documentation (issue 7). All of them argued that remote laboratory yielded reliable data measures which are also accurate and easy to retrieve while using the platform (issue 8) compared to the hands-on laboratory, and that when talking about security, obviously, remote experiments are safer than handling equipment directly (issue 12).

On the other hand, when asked about the efficiency (issue 9) students believed that conducting the PW in a conventional laboratory is more efficient on the grounds that: (i) handling equipment in a conventional lab was far more interactive than handling it remotely (issue 4), (ii) conducting the PW remotely reduced the opportunities of collaborating and made them feel isolated from each other (issue 6), (iii) their work cannot be evaluated and their acquired knowledge assessed without the presence of the teacher (issue 10), the lack of immediate tutor support to conduct the experience and of the teacher who can give extra information, explanations and assistance when needed disadvantages the use remote laboratories (issue 11).

Pedagogical efficiency was investigated deeper by comparing the academic results of each student in the different modes. Knowing that it is the same PW, students got approximately similar mark regardless of the type of the PW.

In assessing the overall outcome of the experience, students asserted that the remote laboratory was a valuable complement, enrichment and alternative to hands-on experiments, since, for a matter of safety, remote access is becoming the trend even in the professional world. They gave us some suggestion that were taken into consideration for future works.

## Conclusions and future works

This paper introduces and summarizes all concepts of distance PW in the engineering curriculum and presents the development of an effective remote lab at low cost and using open source software products. The development of the interface with HTML5 makes the solution suitable for low-speed connections and for any type of device. The project aims to offer an alternative to hands-on experiments to those who cannot access the real laboratories for the previously cited reasons. The conducted study results turned out to be promising and encouraging results concerning the feasibility and the outcome of the project especially for low budget institutions in underdeveloped countries.

The main originality of our proposition concerns at first the fact that the setup of the remote lab will cost nothing in term of financial budget. Furthermore, the highly flexible and evolutive structure of the remote lab will attract electrical engineering researchers in our university to carry on the project, extend the platform for more diversified experiments and ensure a totally remote assembly, setting adjustments and handling of the equipment.

The system described hereby proved to be of notable value for lecture demonstrations and student training either at school or at home, principally in an autonomous and student-centered context, but needs some improvements and ameliorations to better enhance the learner motivation and the learning outcome, indeed. Moreover, it turned out to be useful even for self-study, if instructions and assignments were well formulated. And the opportunity to conduct real experiments via any device that has an internet connection and incorporates a web browser seemed to be attractive for students, which is a highly desirable educational impact.

The present state of the project is accessible via the address www.lecoinducher cheur.com/rmlab/public/.

We target to make the system fully remotely controllable and allow students to modify the environment and configure the equipment being handled, which will make the platform accessible 24h/24, 7d/7 and increase the availability of the system. Then we'll incorporate a booking system to manage the access.

A session of PW implies a greater and more individualized exchange between learners and teachers than in lectures. In order to enhance collaboration and to ensure communication between learners and tutors and between the learners themselves, the platform will incorporate two types of communication activities: (i) Asynchronous via an e-mail platform and a wiki so a student can ask a question directly to a classmate or to a tutor or seek the response directly in the wiki;

(ii) Synchronous via a chat platform to allow students to talk to each other to discuss ideas or to request help.

We noticed that some reluctance from students who do not master or are not used to the computer tool, so the need is clear for creating a featuring video and a "how-to" to accustom students to the platform.

As we know, the quality of the PW is also worked out by the quality and completeness of the guiding documents. To cope with that, we will improve it by offering a richer documentation: (i) more appropriate lab work statement, (ii) richer technical documentation, (iii) richer course that would help students to review the theoretical knowledge necessary to understand the PW and enhance the learning outcomes, (iv) a FAQ where would be listed all commonly asked questions and answers in the context of the experiment.

We intend to extend the platform and offer a richer and more diversified set of experiments and once the platform is fully deployed and operative, it can be shared with other institutions or technological institutes of the university or even with other universities. For this aim, we think of building a national network of online laboratories to bring the experimental lab work by mean of remote real experiments to students from universities and institutions that cannot afford the expensive equipment and also to disabled students who, because of their state of health, cannot access the real laboratory.

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