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► **To cite this version:**

Bruno Darracq, Bastien Vincke, Pascal Aubert. A Platform for Remote Laboratories in Applied Physics. Lecture Notes in Networks and Systems, 2023, Open Science in Engineering Proceedings of the 20th International Conference on Remote Engineering and Virtual Instrumentation, 763, pp.349-359. 10.1007/978-3-031-42467-0_32 . hal-04461145

HAL Id: hal-04461145

<https://hal.science/hal-04461145v1>

Submitted on 16 Feb 2024

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A Platform For Remote Laboratories In Applied Physics

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Abstract. Remote Laboratories (RLs) can be an efficient tool to acquire practical skills to complement face-to-face laboratories. The development of an RLs platform requires dedicated equipment and software tools to facilitate the access and control of the equipment. Other tools for communication between users and supervision of student activities by teachers are also necessary to support the learning process. This article presents a RLs platform used for practical activities in applied physics curricula at Paris-Saclay University. The platform combines a Guacamole server to access and share material resources and a Moodle environment for digital services, including virtual classrooms. We set up different remote actions to make RLs as close as possible to real laboratories. We decline these remote actions in three examples of RLs in electronics, acoustics, and material physics.

Keywords: Remote Laboratories, Remote actions, Applied Physics.

1 Introduction

The number of tools for distance learning has increased dramatically over the last 20 years. Numerous technologies based on Learning Management Systems (LMS) now allow learners to follow distance courses in various topics. These platforms are dedicated to learning theoretical concepts in Science, Technology, Engineering, and Mathematics (STEM).

More recently, the emergence of Remote Laboratories (RLs) has opened the way for distance learning practical work [1]. It is a critical contribution, particularly for curricula with a large laboratory load, such as technician or engineering education. However, some technological issues must be overcome to ensure the efficiency of a RL compared to a real one. For example, the software interface for accessing and controlling the lab equipment must be simple enough and not be an obstacle to learning. Managing lab resource allocation, guaranteeing the safety of the equipment, and implementing the possibility for teachers to communicate with students and supervise their remote laboratory work, are also crucial points. Several solutions have been

proposed to address these issues. For example, VISIR platforms provide very realistic interfaces for RLs in Electric and Electronics Education [2] and also tools to get automatic feedback on the student's work [3] ; iLab platforms provide large-scaling Digitized or RLs for Physics [4], [5], [6]; the environment Lab4CE for Computer Education provides a powerful analytics tool [7] for supervising student activities ; the LABENVI project proposes RLs in Electronics and Optics for full remote curricula [8]. Note that iLabs, VISIR and LABENVI platforms have spread to a large international community [9], [10], [11], [12] and the commercial sector [13].

Recently, and especially during the COVID pandemic, other technologies have emerged to facilitate remote access to RLs and student monitoring [14].

2 Contributions

During the COVID period, the Institute of Technology of Paris-Saclay University set up a RLs platform which has been enabled to ensure the continuity of education during the period of lockdown, mainly for practical activities with the implementation of a small number of RLs in STEM education [15]. Since students have returned to classrooms, this platform has evolved into a dedicated tool that turns out to be an efficient complement to face-to-face teaching. With the financial support of the Paris-Saclay University, we have increased the offer of RLs and set up a pedagogical service to assist teachers to introduce RLs in their courses.

This article presents the main features of this RLs platform. We will start by defining the ideal remote lab (section 3). In section 4, we present the material and functional architecture of the platform. Section 5 focuses on the critical issue of remote actions to be implemented in RLs.

3 The ideal remote lab

Ideally, we would like students to do remote practical work in the same conditions as when they are physically present. We have therefore synthesized all the actions carried out by the students. The first need is to be able to communicate with a teacher but also with the students. Moreover, students often carry out discussions in small groups. Furthermore, they must have access to all available computer resources.

During a practical course, they are required to handle materials. Specifically, they must set up their equipment, wire the manipulation, use instruments to generate signals and acquire measurements. They often have to make linear or 3-dimensional displacements. The result of a TP is usually visual. They must be able to react to the results obtained, modify parameters and observe all the consequences of the modifications made. We have made it possible for students to perform all these actions remotely.

4 Architecture of the RLs Platform

4.1 Material Architecture

The material infrastructure (see Fig. 1) is built around a dedicated LAN network. We have chosen to separate the remote network from our institution's network for security reasons.

Our remote laboratory is equipped with two kinds of workstations. We have 18 physical workstations and 16 virtual machines. Indeed, we want to make a set of materials available to students that are sometimes only accessible through a USB port. It is, therefore, necessary to provide physical stations allowing the USB connection of peripherals. However, we have added two USB/ethernet switches that will enable to deport of USB devices on the network. These switches only work with some USB devices, and you have to be very careful in terms of bandwidth usage. For example, connecting USB cameras to the switch is impossible because the bandwidth will be filled with only two video streams.

To carry out the practical work, students use instruments: function generator, multimeter, power supply, and oscilloscope. We use new instruments with an LXI connection to access the device remotely. This LXI bus allows access to a front panel of the instruments through an Ethernet bus. Each device is then accessible by all the workstations (virtual or physical).

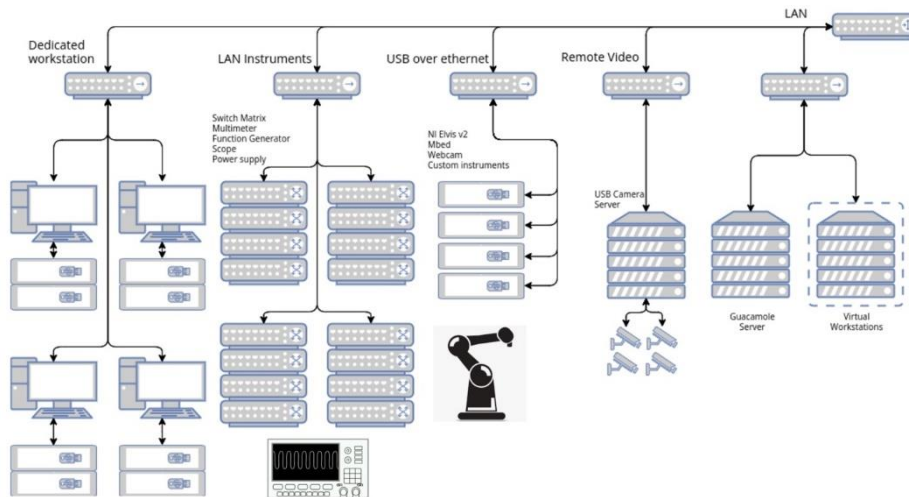


Fig. 1. Material architecture of the remote lab.

The students must carry out cabling to set up their manipulations during the practical work. We set up relay matrices to make a circuit between measurement equipment and

circuit components to realize this remote cabling. The teacher can do this wiring before the practical session or be part of the experimental work.

According to their size, some equipment is placed in racks and others on large shelves (see Fig. 2). The university's IT service ensures the network's operation.

We quickly noticed that it was essential to have visual feedback on the manipulation of the room in which the TP is located. Indeed, the student must understand very quickly that it is not a simulation but that he is handling real material and instruments. We have therefore set up a video server that collects the streams from 50 webcams and makes them available on the Ethernet network. We chose this architecture for cost and simplicity reasons. We developed two pan-tilt cameras to observe the whole room.

The platform manages more than 100 instruments, including classical instruments such as oscilloscopes, function generators, multimeters, and power supplies, and more specific equipment such as NI-myDAQ and NI-ElvisII+ boards [16], XBee modules, microcontrollers, and robotic arm. These equipment is deployed in more than 20 RLs for the Institute courses in Electricity, Electronics, Acoustics, Material Physics, and Industrial computing. The platform is now flexible enough to add other equipment depending on the type of RLs teachers want to implement.



Fig. 2. Our remote lab based on 19", 42U racks shelves.

4.2 Software Architecture

The software architecture is described in Fig. 3. The main objective of the software part is to allow the student to access all the software resources available in our infrastructure and to offer him the same simplicity of access as if he were in our institute.

We have based our approach on two types of software. The first type is relatively classical: Moodle and BigBlueButton (BBB). Moodle could allow the student to find all the course documents, take MCQs, submit assignments, etc... The BBB software is a virtual classroom software we used during the lockdown. It allows all the possibilities of a virtual class: sharing documents, microphone, sound, polling, group work, etc...

The second type is a remote desktop used via the Guacamole software [17]. It could allow students to access one of our 34 remotely accessible machines through the remote desktop. Thanks to Guacamole, students find exactly the same working session as when they physically connect to a computer of the institute. They can access all the software and documents stored in their network drive. It is a straightforward and secure provision of resources.

An exciting feature of Guacamole is the possibility of sharing computing sessions. This functionality has often been used during the Covid lockdown for collaborative, practical activities between students (students usually work in pairs) or for teacher supervision. Combined with a BBB virtual classroom, this resource-sharing feature is particularly efficient for distance learning. Using collaborative tools can also solve the problem of resource allocation for small student groups.

To simplify the platform's access to material and software resources, we gathered all information in a Wiki website [18]: how to access workstations, presentations, and instructions for using the RLs, links to Moodle resources and BBB virtual classroom, etc...

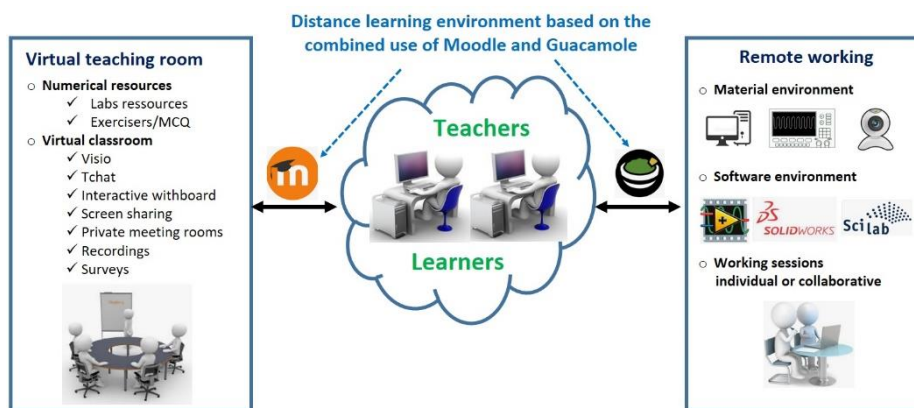


Fig. 3. Software architecture of the remote lab.

5 Remote actions

As mentioned above, in the ideal remote lab, users must be able to manage different types of remote actions. In this section, we illustrate the possibility offered by our platform to make remote wiring, moving, and controlling instruments.

5.1 Remote wiring

This wiring is sometimes made with flying wire, labdec plate, and soldered on a PCB. This wiring allows the connection of electronic components (resistor, capacitor, AOP...) and instruments allowing the generation and acquisition of signals. In order the students to do an electronic lab, they have to make a wire-based assembly. RLs do not

allow this action to be performed remotely. They mainly provide a pre-wired circuit on which the students will conduct their experiments.

We wanted to allow the students to have the freedom to achieve this wiring and also to be able to position the instruments in the assembly. We have reused the concept of switch matrix, which is very much used by industrials to test electronic boards. These matrices are organized in matrix form and composed of many relays to form a modular circuit and allow all possible configurations. To adapt these matrices to our use, we placed the instruments on the lines and the components of the circuit on the columns of the matrix. The number of rows and columns will have to be very important if we want to allow all the possible configurations. Indeed, if we want to use the usual instruments (power supply, multimeter, oscilloscope, etc.), we must have more than 10 to 15 lines for our matrix. For the columns, if we want to make a setup based on AOP, we will quickly need several columns (greater than 20).

There are commercially available arrays of this size. They often have excellent characteristics. In particular, they attach importance to the switching time, which must be as small as possible to allow many tests quickly. These arrays are costly, and the price rises with the number of relays. We do not need a low switching time for our lab, but we have specific needs. We want to maximize the number of rows and columns and have interfaces that we usually use: BNC or banana plug. To that end we chose to redevelop a relay matrix (see Fig. 4). This matrix is modular in every way: it can accommodate many relays depending on the need and adapt its interfaces using daughter boards. The cost is about 1.5€ per relay, which is very low compared to industrial relays.

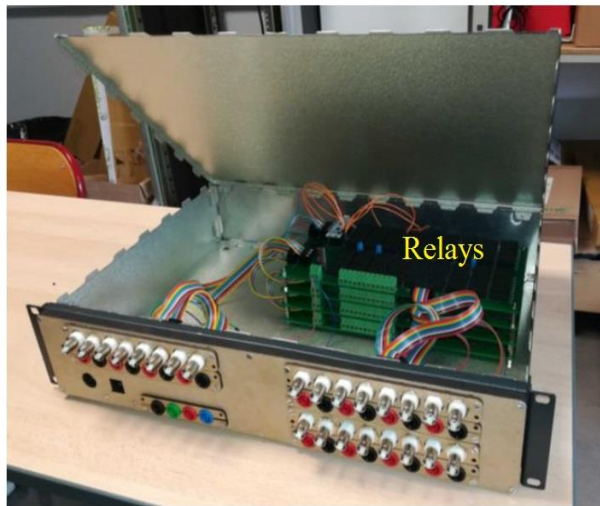


Fig. 4. Our custom switch matrix

Different uses of the switch matrix can be considered. For example, in a 1st-year electronics course, we need to design and characterize electronic circuits. For that, we connected the I/O of a NI-myDAQ board [myDAQ] to columns and electronic

components (resistors, capacitors, operational amplifiers, diodes) to lines. We developed a NI-Labview application to control the switch matrix and wire different electronic circuits (see Fig. 5). In the first tab of the application, complete control of the relay matrix is possible, so many circuits and measurements are possible. Note that we use lines for the connection between electronic components. The first column is used to activate each line. Virtual instruments (GBF, Oscilloscope) of the NI-myDAQ and Webcam can be launched directly from the interface. In the other tabs, a pre-configured matrix can be set to study classical electronic circuits (inverting/non-inverting AOP circuit, low-pass filter, etc.)

This application can be used by teachers (for example, during large or small class demonstrations) and students (for example, to revise a circuit for lab exams) by logging on one of the remote workstations of the platform.

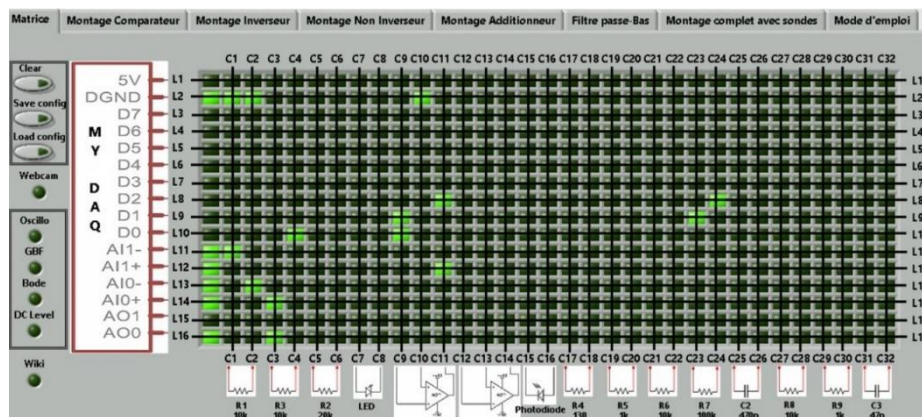


Fig. 5. Labview interface to study electronics circuits.

5.2 Remote moving and control instruments

Most real labs need to move objects. When the displacement is clearly defined, we can use a motorized axis. For example, in the Kundt experiment [19], we need to move a microphone inside a tube to measure the level of stationary sound waves. We designed this remote lab using a 1D motorized axis (RCP3 Robo Cylinder) attached to a rail on which a ball-bearing plate supporting the microphone slides (See Fig. 6).

The slider is programmed through the Modbus protocol. We developed a Labview application to control the microphone's position and access the webcam and the instruments. Two operation modes are possible: a manual mode, where the user can set the microphone's position in the tube and control instruments using their Virtual Web front side, and an automatic mode. Note that the Virtual Web front side of the oscilloscope is very close to the real one (see Fig. 7). Students need to be in the same working environment as the real lab. Instrument manufacturers (such as Keysight) have made great efforts in recent years to implement a very realistic HTML5 Virtual Web front side on the new range of LXI Instruments.

Considering all the remote actions implemented in this experiment, students and professors can make the entire acoustic lab the same way as if they were in the real acoustic laboratory.

Acquisition of instruments programming skills is an important learning outcome in the second-year of Industrial Computing course. As almost all Ixi/USB instruments of the platform are programmable, students can design their own applications to control instrument using the Labview environment installed in the platform's workstations.



Fig. 6. Kundt experiment (left) and its Labview Interface (right)

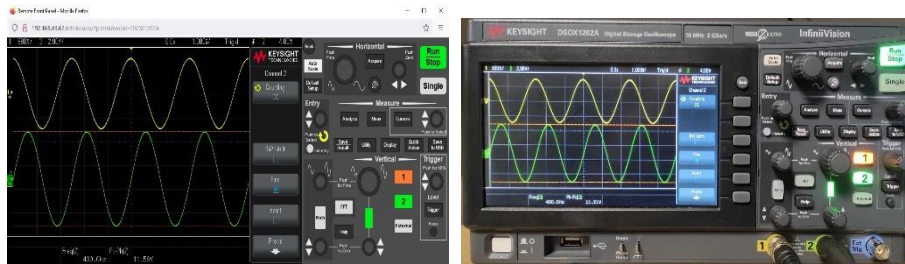


Fig. 7. Web (left) and real (right) front side of the oscilloscope

5.3 Securing experiments

For some experiments, it is crucial to ensure the safety of the equipment, especially in remote mode. For example, when you heat materials to high temperatures, you must ensure that the heating element does not continue to operate if an incident occurs, like a LAN network cut-off or a crash of the software interface. In a second-year Material Physics lab, we heat Pb-Sn alloys around 300 °C and investigate the temperature cooling curves (with thermocouples) to determine the alloy composition (see Fig. 8).

To ensure the safety of the experiment, we implemented an active safety mechanism. The Software interface sends messages every 5 seconds to a micro controller that acquires data from thermocouples and controls a power relay between the heating plate and the electrical socket. In case of a software crash or a LAN network cut-off, the micro controller does not receive the messages and closes the power relay.

We can also turn off the lab's power from the software interface thanks to a Wifi connected plug (note that each lab can be individually turned on or off thanks to the Wifi network of connected plugs).



Fig. 8. Remote lab using a heating plate

6 Conclusions and perspectives

The platform has been designed for a wide range of use cases, from simple access to personal working documents to the use of heavy industry software or full practical activities on RLs. The table 1 below provides a list of use cases from the feedback of early users since the platform became fully operational in early 2022. The analysis of Guacamole's logs revealed about 20 daily connections to the platform for an average time connection of 30 minutes. Most of these connections take place at night or at weekends, which means that the use of the platform is complementary to face-to-face teaching.

	Trainers	Learners
Access personal working documents	✓	✓
Use heavy industry software	✓	✓
Redo a part of a lab or full lab	✓	✓
Do a lab despite a disability	✓	✓
Revise for lab exams		✓
Carry out experiments in lectures and small classes	✓	
Train new teachers or people of industry	✓	
Share labs (ex. international cooperation, teaching networks)	✓	

Table 1. List of uses cases (not exhaustive)

First feedback from students indicates that connections involved many 1st and 2nd-year courses: electricity, electronics, acoustics, mechanics, computer programming, instrumentation, computer-assisted design, projects, and even communication classes.

Further developments are planned to improve the allocation and sharing of the resources (in particular RLs) and tools to supervise student lab works. Since September 2022, a training sessions has been offered to all teachers at the University of Paris-Saclay University to help them introduce remote practical activities in their courses and evaluate their added value.

Acknowledgment

The authors would like to acknowledge the University Institute of Technology (IUT) of Orsay's support as well as the undergraduate school of Paris-Saclay University through the project "Hybridation des formations d'enseignement supérieur" (20-NCU-0014), and the French network Polytech Group. They also wish to thank Max Montillet, Yacine Yahy, Gabriel Poggia for their technical contributions and our colleagues of the IT service of IUT, Benoît Tonnerre and Olivier Guilleminot for their great assistance.

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