

LaboREM - A Remote Laboratory for Game-Like Training in Electronics

Franck Luthon, *Senior Member, IEEE*, and Benoît Larroque

Abstract—The advances in communication networks and web technologies, in conjunction with the improved connectivity of test and measurement devices make it possible to implement e-learning applications that encompass the whole learning process. In the field of electrical engineering, automation or mechatronics, it means not only lectures, tutorials, demos and simulations, but also practical labwork for training with real-world devices that are controlled remotely. To make e-labs attractive, they should be easily implemented and accessed on the web by a client. This keypoint raises technical issues that are recalled in this paper. Nonetheless pedagogical issues are equally important. The benefit of a remote lab must be evaluated and compared to simulation labs or hands-on. Here, to foster student motivation, a game-like scenario embedded in a learning management system is proposed.

Index Terms—E-learning, game-based learning, industrial engineering, labwork, motivation, online education, virtual instrument.

1 INTRODUCTION

THIS paper deals with a remote laboratory called LaboREM, developed for training in electronics, where students can build their circuits using a remotely controlled robotic arm. It is implemented for e-learning in industrial engineering. Indeed, Bayonne Technological University Institute in Anglet, France, promotes the introduction of distance learning for the education of students in electrical and mechanical engineering, maintenance and computer science, either to learn to do teleworking or for lifelong learning.

As part of the academic curriculum for the Bachelor of Science degree in industrial engineering, the course of Analog Electronics (ENA) addresses the following topics: operational amplifiers, active filters, feedback loops, oscillators, regulators. It is reckoned as 3 ECTS credits (European Credit Transfer System), of which one half corresponds with practical labwork. The ECTS is a system for measuring and recognizing credit for student learning, designed to help mobility of students within the European Union. One standard full course semester corresponds to 30 ECTS credits. The learning objectives of ENA are to implement basic electronic functions (amplification, filtering etc.) with simple systems based on OpAmps, and to use instruments for test and measurement. The practical work assigned to students consists in the characterization of electronic circuits. The course consists of 45 hours per student, of which 15 hours are dedicated to practical labwork (four hands-on sessions lasting 3 to 4 hours

each). Part or all of this labwork can be done remotely.

The lab platform is based on the design and control of Virtual Instruments (VIs) for the management of remote experimentation through the web, together with the use of a Learning Management System (LMS) for the management of students and for the collaborative work supervision. The client-server architecture that allows remote control of instruments in real-time, with the technical management of both the list of experiments and the stack of users, is similar to many other works listed in [1], [2]. The originality of the proposed work is twofold: (i) a feeling of the lab (immersion) via the use of a video camera and a robotic arm for placement of components, plus the optional use of computer vision and image processing to address user-specific requests to see the equipment in detail (zoom-in for displaying instruments or device under test); this is intended to mimic both the user eye and the user hand; (ii) a game-like scenario (treasure hunt) that is implemented as learning approach, with an attempt to mimic the behaviour of students when they work close together (collaborative work through use of chat, forum, hall of fame, Top 10) and with a learning itinerary that is adapted to each student (difficulty level depending on the evaluated knowledge and motivation).

Some authors (*e.g.*, [3], [4], [5]) already addressed the coupling of remote labs with LMS, or the coupling of virtual labs with games [6], but to the best of our knowledge, the present work is one of the first attempts to mix three views together in a pedagogical perspective: remote lab, LMS and game.

As regards our previous work, we evolved in the following way: in a first collaboration with the polytechnical university of Bucharest, Romania, an open architecture was proposed for remote lab, based on

• F. Luthon and B. Larroque are with the University of Pau and Adour Province (UPPA), in the department of Industrial Engineering, Bayonne Institute of Technology (IUT), Anglet, France.
E-mail: Franck.Luthon@univ-pau.fr

Manuscript received 18 Sept. 2013; revised Sept. 2014

the concept of plugins of VIs [7]. The deployment on client-side was a desktop application (*i.e.*, executable installed and running on the client computer). Next, a game-like scenario was conceived to boost student motivation [8]. Here, those ideas are put together within an LMS, so that the collaborative dimension is added to the remote labwork, together with the supervision of students' activity. We therefore switch to a web-based client application (accessed via a browser). Moreover, interaction tools for better immersion and motivation are proposed: a Top 10 score is displayed in real-time to motivate students by a challenge, and a robotic arm plays the role of the student hand for choosing and placing components to build the Device Under Test (DUT). The solution proposed here is an alternative to the virtual wiring of a relay switching matrix implemented in [9], [10].

The paper is organized as follows. In section 2, the motivations of the work are given with respect to the state of the art. Section 3 shows the technical choices for software architecture and hardware setup of the lab, while section 4 describes the game-like pedagogical scenario implemented via an LMS. An evaluation of the proposed application is given in section 5. The discussion in section 6 ends the paper.

2 MOTIVATION OF THE WORK

2.1 Issues and Requisites

Developing a remote lab may involve various issues. First, one can address the sociology of technical knowledge, facing a large public like undergraduate students, poorly educated audience, heterogeneous students that may need to repeat and revise many times, adults with a full-time job and hence heavy constraints and little day-time available, disabled people needing more time to complete an activity, people not affiliated to a university, etc. Here, we focus on 1st year undergraduate students that are teenagers of about 18-19 years old. For that typical target audience, who sometimes lacks personal motivation in their studies, we believe that both game-based learning and adaptive learning are good solutions to promote, as in [11] for computer science. Therefore, a game-like scenario is implemented in order to enhance students' motivation and autonomy.

Second, international cooperation between technological universities is targeted, especially in industrial engineering curricula, where practice on real-world devices is important. Universities that do not have modern instruments at their disposal may use hardware devices available in another university thanks to an Internet connection. This is part of the objective of the democracy of technical knowledge. Bayonne institute of technology already has strong partnerships with Latin America in the fields of management, business, commerce and computer science and aims to expand its partnership in the technical field of

industrial engineering, especially with Colombia, El Salvador and Mexico. To this end, some issues are of utmost importance for users: (i) comfort (ease of use both for students and tutors); (ii) extensibility (ability to deploy new experiments on the web); (iii) portability (easy installation on client side).

Third, another major concern is the financial aspect. Indeed, in the present economic climate worldwide, drastic cuts have been made by governments in their education budget. One must reduce the costs of teaching by all means, especially if one wants to face the educational mission in technical fields that are demanding in lab activities. Mutualization of expensive equipment thanks to e-labs is thus a good solution (no need to buy any expensive software at the client side, no need to buy many instruments but one). This is part of the economy of technical knowledge.

A final keypoint is to alleviate the constraints on non financial resources (human, space and time constraints, apart from money) induced by hands-on activities (need of teachers, rooms and dedicated time slots, apart from need of high investments). The sharing of resources and infrastructures [12] is then part of the ecology of technical knowledge, for a sustainable society. In such an open context, scheduling between users and security are issues to take into account.

2.2 Related Works

Practice is known to be an essential part of learning in engineering education [13], as long as clear learning objectives are assigned (*c.f.* ABET criteria where 13 fundamental objectives are listed). As assessed by a study on the efficiency of virtual laboratories [14], almost 50% of learning takes place during labwork.

The pros and cons of the three types of labs (hands-on, virtual and remote) are wellknown [15]. Virtual labs are based on simulations only (mathematical models implemented in a computer), whereas remote labs use real-world instruments in a physical lab [16]. Virtual and remote labs belong to the generic group of e-labs, made possible thanks to the development of Internet. They are the modern counterpart of traditional hands-on labs that take place in front of real-world devices. Since access to real-world labs is restricted due to high number of students, cost of equipment, supply and maintenance needs, e-labs are great alternatives to alleviate those constraints [1]. A specific argument in favor of real remote labs (compared to virtual labs) is the fact that nowadays in industry, more and more engineering activities take place remotely, for example the maintenance of systems or control of processes through a computer interface located in a distant supervision room (SCADA: supervisory control and data acquisition). Hence, there is a strong need to educate students to this new way of working.

However, the bottlenecks of remote labs lie in the interaction with instruments and the interaction between people. Therefore, smart software is needed

[17] between hardware and humans in order to: (i) design an open (flexible enough) architecture for distant control of hardware devices (technical need) and (ii) develop tools and interfaces to enable and track the cognitive behavior of the user in a distant instrumentation application (human need). Such pluridisciplinary projects require teams with various skills: teachers (tutors) that build labwork activities and evaluate students, cognitive science experts (to conceive scenario models), human-machine interface designers, computer science programmers, network and system managers, technicians for maintenance (service available 24 hours a day).

The complementarity of activities is also well known: a mixed pedagogy including hands-on, simulations and remote control is preferable, which is called blended learning [18]. However when distance activities are developed, motivational features are very important for the self-regulation of learning. As an example, a motivation controller based on fuzzy logic is implemented with Java and Moodle in [19]. This allows to estimate student motivation, and hence to propose the best workload with respect to various parameters (autonomy, performance, participation, anxiety).

To assess the quality of remote labs, there is a strong need for evaluation, both technical and pedagogical. Evaluation of usability of the lab infrastructure (hardware and software) is necessary [20]. To get real-time knowledge of the state of work of a student and for automatic assessment procedures, the use of an LMS is mandatory [21], [22], [23]. In [24] a theoretical model to assess the knowledge and learning progress in an embedded, non-invasive way is proposed in the context of digital learning games, in place of the classical formal tests that students have to pass. It points out the importance of an appropriate balance between gaming and learning, and between challenges through the game and abilities of the learner.

3 ARCHITECTURE OF THE LAB

3.1 Software Model of the Platform

The software should ideally enable a completely connectible application, enable an easy installation by the client, run in real-time, communicate easily with hardware devices, communicate easily with clients, enable extensibility (to plug in new experiments), manage all the resources and users (hardware, humans), implement collaborative work. It should allow a teacher to be able to add easily a new remote lab activity into the LMS course as stated in [25]. The choice of network technology to build the architecture should therefore be compliant with various issues like accessibility, reusability, portability, security, scalability, interoperability, traceability. The importance of software universality versus software power dis-

cussed in [17] leads to the conclusion that a service-oriented architecture (SOA) should be adopted.

Design and implementation issues for remote labs are discussed in [26]. A formal reference model for weblabs described in UML language identifies the major functions that a remote lab with SOA must support in order to yield the proper quality of service (Fig. 1, where SLA stands for service-level agreement). Purposefully, four main entities are outlined in this

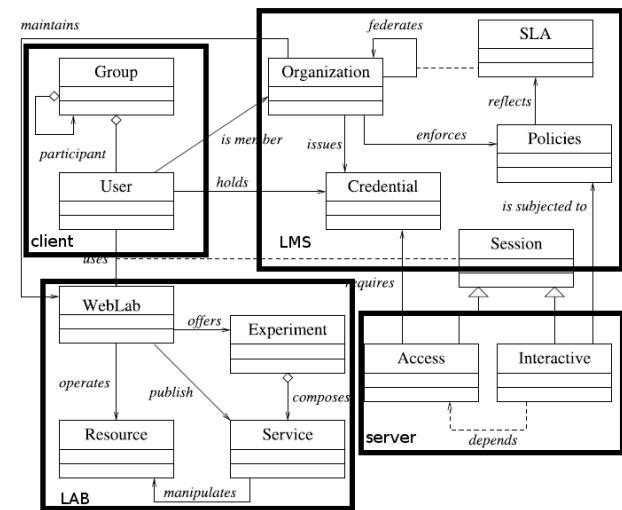


Fig. 1. A reference model for weblabs from [26].

figure: (i) the client that uses the lab, (ii) the lab that operates the hardware resources for experiments, (iii) the LMS that organizes the learning activity, and (iv) the webserver that gives access to the platform.

LaboREM should be compliant with this model. Compared to other solutions, the main differences are as follows: the collaborative tools are provided by the LMS, not by the remote lab itself, contrary to NetLab [27], [28] which offers a booking system and collaborative tools without using any LMS. In our case, the LMS is in charge of almost everything (authentication, trace recording, data storage), apart from the actual task of interaction with hardware. Compared to the iLab shared architecture from the MIT [29], which is based on a service broker, labservers and labclients (with additional storage and scheduling services for interactive solution), our project is less ambitious since a single labserver is in use and most of the services are taken in charge by the LMS: only the queuing management to give access to experiments is handled by the labserver itself (in place of service broker).

3.2 Client Communication Techniques

3.2.1 CGI scripts (Batch Mode)

A first basic solution is low-level programming with http protocol: it means to use CGI scripts (common gateway interface) to transmit the information (PUT,

GET and POST instructions). It just implies uploads and downloads of data (input parameters and output measurements) via a desktop-client application [7]. One main drawback is that it only works in batch mode (asynchronous communication), so that real-time interaction is not possible (contrary to the two other solutions described in section 3.2.2 and 3.2.3 that can transmit continuous dataflows, allowing real-time control). Another drawback is that the desktop application has to be updated by the client each time the lab-server application undergoes a software upgrade.

3.2.2 Remote Front Panels

Another solution is to use the concept of remote front panels (RFP) available with NI-LabVIEW software. Starting from an existing VI including drivers to communicate locally with instruments, the web publishing tool, with remote control option activated, allows to create a HTML file so that a VI is visible and controllable from Internet. As soon as the lab application server (LabVIEW webserver) is started, the HTML file is accessible over the Internet through its specific URL address [30]. Therefore it is both easy for a client to use the lab (simple access via a web browser) and for a tutor to add a new lab activity: there is very little programming overhead needed to publish new VIs on the web. A good point is that the front panel seen by the remote client is exactly the same as the one seen within the local application: the interface may be rich and convivial (Fig. 2).

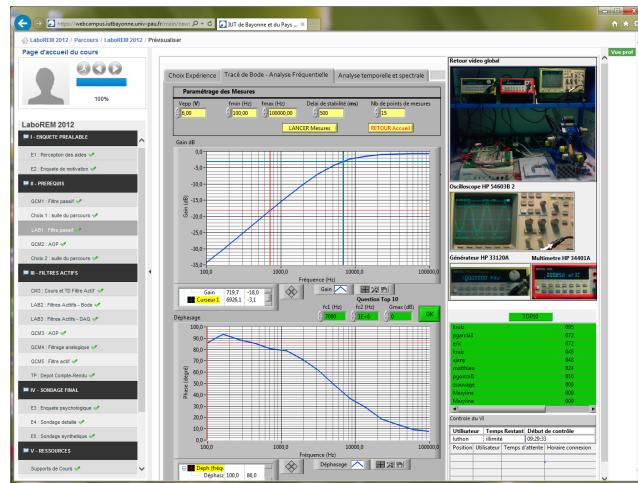


Fig. 2. Client rich interface showing a remote front panel: left) learning steps of the pedagogical scenario; center) results of experiment running (here Bode plots of a high-pass filter); right) video feedback of instruments, Top 10 list and queuing list of users.

One main drawback is that RFP client-server data communication uses a non-HTTP binary protocol. It is detected by some firewalls, anti-viruses, reverseproxies as non-HTTP communication and many clients

and IT group managers have rules for blocking it. A second drawback is that the client has to download and install the shareware LabVIEW RunTime Engine (LVRTE) which is a plugin of size 40Mbytes. Previously, there were strong browser restrictions to use this plugin: only Internet Explorer could display the LabVIEW user interface. Fortunately, since the latest release of LabVIEW, browser restrictions no longer hold: other browsers like Chrome or Firefox work with LabVIEW 2014 plugin. A third point worth mentioning is that the VI is executed on the server-side. Clients who are connected to the remote front panel, and waiting to get the control over the VI, can observe what the current client who has the control is doing. Note however that this can become a good point for student collaboration [31].

3.2.3 Webservices

A third solution is to design an SOA based on the use of webservices. The advantage of webservices [31] is to conform to standardized communication protocol (fully compatible with any network and web browser configuration, no restriction due to firewall or antivirus, mobile device compatibility). The client interface may be thin (light). A specific URL address with command parameters generates dataflows in real-time, containing output data described in XML, TEXT or JSON format. This solution may even be easily deployed starting from a LabVIEW project (that provides a tool to build Restful Webservices) and using Silverlight and WebUI Builder. This alternative yields a remote interface to LabVIEW that avoids the use of the non-HTTP RFP protocol.

Its main drawback is that the remote graphical interface requires dedicated programming and is not highly sophisticated (Fig. 3 to be compared with center panel in Fig. 2). Moreover the inclusion of a

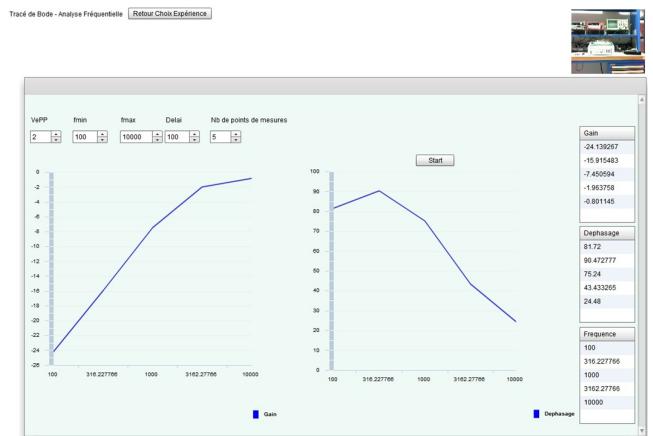


Fig. 3. Thin client interface based on Flash programming and web service data communication.

new lab activity is not straightforward since it requires some extra coding first.

TABLE 1
Comparison between webservice and Remote Front Panel solutions

Software side	Criteria	Remote Front Panel		Web Service // HTML5	
		Pros	Cons	Pros	Cons
Lab Server	Programming	Graphical langage, easy	Proprietary langage	Standard langage (XML stream)	Quite heavy
	Web Access	http Webserver	Proprietary protocol	http Webserver	-
	Operating safety	Good	-	Very good	-
Client	Interface	Rich, measurement tools (cursors)	-	Web based interface	Additional coding
	Requirements	Free software download	Plugin and runtime needed	None	-
	Compatibility (mobile, tablet, computer...)	HTML page	Browser restrictions	Very good	-

3.2.4 Proposed Technical choice

The three solutions have been implemented by the authors [7], [8], [32]. Notwithstanding, this is the 3rd solution using webservices (section 3.2.3) we clearly advocate, although we describe in the following the richer interface (Fig. 2) based on the second solution using LabVIEW RFP (section 3.2.2). The prospective use of HTML5, merging JavaScript and XML, shall be the best technical choice for the client software. Among others, this will allow to address the question of flexibility and ubiquitous use of the application on mobile devices (smart phone, tablet) [33]. This is of course very desirable for gaming purposes. Tab. 1 summarizes the pros and cons of RFP and web service solutions. Here, as the second solution based on RFP does not require extra-coding and provides a richer interface, we have implemented the remote front panel solution in our lab.

3.3 LaboREM Prototype Implementation

3.3.1 Network and Software Architecture

The network and software architecture is described in Fig. 4. It is based on the use of two servers. It

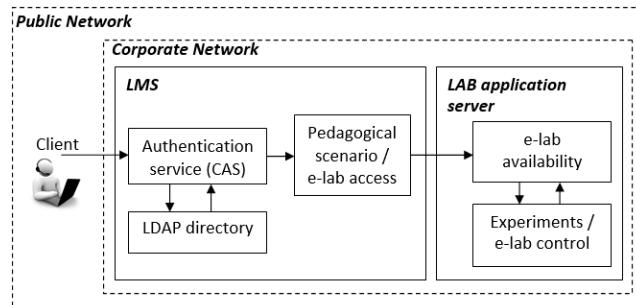


Fig. 4. Network and software architecture.

is designed to make the LMS (*i.e.*, the middleware

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including databases for management of users (using Lightweight Directory Access Protocol LDAP), authentication (using Central Authentication Service CAS), administration, learning tools, content packaging, evaluation, communication tools for collaborative work) communicate with the remote lab (*i.e.*, the hardware including instruments with software drivers and VIs). The labwork is accessed through the use of the LMS: this is simply achieved by calling, at some specific steps of the learning sequence, the proper URL address corresponding to the remote VI to pilot. The e-lab availability service is taken in charge by the labserver itself (queue of users). The e-lab control service is for piloting the remote devices (instruments, robot).

3.3.2 Server Side

In addition to the corporate webserver of the university for connection to the LMS via the webcampus, the application server located inside the industrial engineering department laboratory is another dedicated server (lab application server) for connection to the lab equipment (Fig. 5).

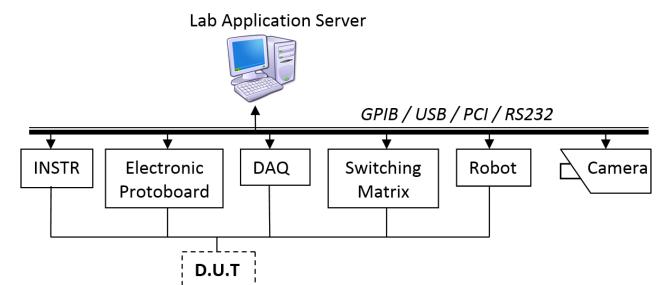


Fig. 5. Hardware architecture: DUT means device under test; INSTR means instruments; DAQ means data acquisition.

A typical hardware setup is shown in Fig. 6. It

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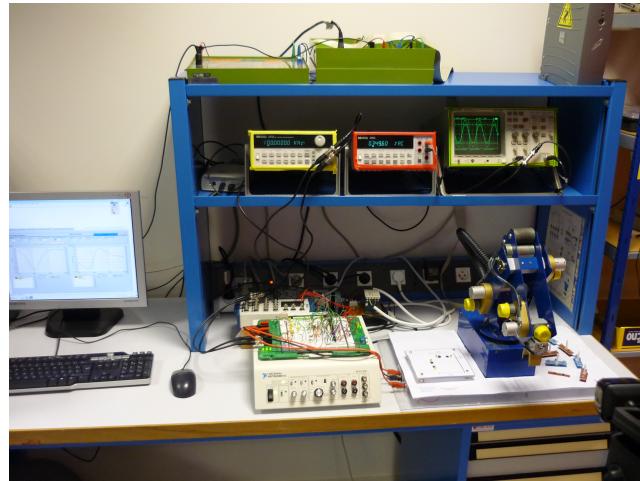


Fig. 6. Hardware resources on server side: instruments, DAQ board, on-off switch, electronic protoboard with connection matrix and DUT (here active filters), robot, camera (visible in the lower right corner).

consists of test and measurement devices connected through GPIB (waveform generator, multimeter, oscilloscope and spectrum analyzer, programmable power supply), plus various other hardware systems connected through USB, RS232, wireless or PCI communication bus (camera, data acquisition board, switching matrix with relays, on-off button, electronic protoboard, robotic arm, automatic background lighting).

The block-diagram of the lab application is shown in Fig. 7. The application is made of a virtual manager

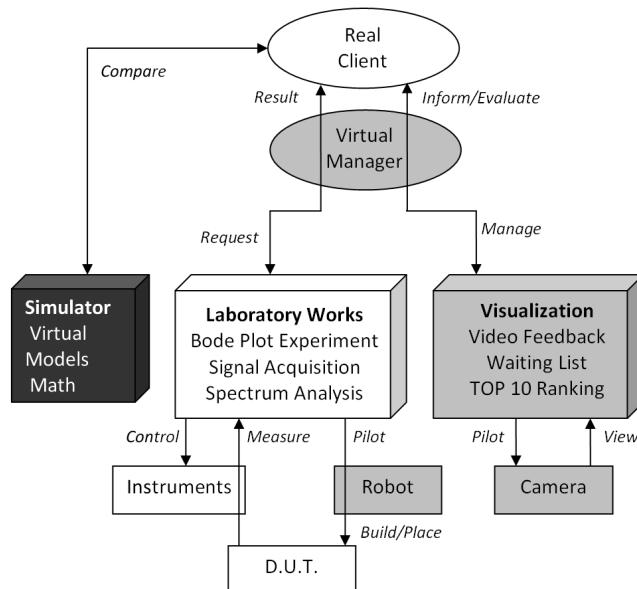


Fig. 7. Application block-diagram: the blocks in gray correspond to functions that are added to get a remote lab, starting from a hands-on lab (blocks in white).

and three main VIs listed below, that are built and controlled with NI-LabVIEW software. Their remote

front panels are embedded into HTML pages accessible through LabVIEW webserver. These VIs are loaded in active memory on the server for running (VI open).

- **LaboratoryWorks** is the main VI of the remote lab. It enables to select the type of experiment (GPIB-Bode plots or DAQ-Signal spectrum analyses) and the type of filter (passive, active, low-pass, highpass, bandpass etc.). It allows to control the instruments and the robotic arm to build the DUT, to make measurements, to recover data graphs and to participate to the Top 10 ranking. The client has full control over this VI.
- **Visualization** gives a feedback on the remote lab. The client can observe this VI. It includes three functions: **VideoFeedback** uses an image acquisition toolbox for video capture and image processing in real-time. Each image is compared to some reference sub-images representative of the various instruments in use (front panel of oscilloscope, multimeter etc.) A template matching algorithm, applied on color and shape information in each image captured at video-rate, enables the user to focus selectively and zoom on each of the devices. Thus, a remote user can see the instruments front panels evolving with time. **TOP10** is a function to display the ranking in a “hall of fame” (best answers to measurement requests). **WaitList** is a function to display the waiting queue of users that are requesting the activity on instruments.
- **Simulator** is a 3rd VI accessible via the LMS. It is the main VI of the virtual lab (as opposed to the remote lab) that only offers numerical simulations of the various DUTs. It gives students the opportunity to make comparisons between simulation results and actual measures. Since it does not communicate with any instrument, there is no waiting queue to manage: many users can run simulations in the same time. By selecting “re-entrant execution” in the VI options, LabVIEW can duplicate the simulation VI to get as many VI-clones as needed without conflict.
- **Virtual Manager** is a set of VIs in charge of the lab management. It ensures 3 main functions.
 - (i) Storage: it stores data of each experiment (username, timer, experiment selection, Top 10 answers) into a MySQL database (currently not linked with the LMS database);
 - (ii) Scheduling: it manages the waiting queue of connected clients. It uses a specific tool (Remote Panel Connection Manager) for the management of remote front panel connections. There is no sophisticated scheduling mechanism nor concurrency problem, since a user is allowed 5 minutes only, and a first-in first-out solution is adopted (no time slot reservation). In the meanwhile, a

waiting user can switch to other activities proposed inside the LMS as described in section 4.3, or watch what his colleague having current control is doing, and optionally communicate with him if he wants to collaborate in real-time (using LMS tools, chat, forum etc.)

(iii) Initialization and Security: it reinitializes the system (interface and robot) to its default state, each time an experiment ends, or if another user takes the control of the LaboratoryWorks VI. Six variables are used for that purpose: user name, VI name requested by user, user status (waiting, viewing or controlling), starting time, ellapsed/remaining time before closure, plus a global variable that is a flag to track any user change (bit for re-initialization).

3.3.3 Client Side Interface

The installation on the client machine requires to download and install only one plugin: the LabVIEW RunTime Engine. This plugin allows to execute the remote front panel object code embedded in a HTML page.

To run the lab, the client logs into the webcampus of the university. It is based on the LMS platform Chamilo which is standard-compatible with other LMS thanks to automatic export facility of SCORM data (we intend to use Moodle instead since it offers dedicated modules for plugging weblabs).

The remote labwork is one of the various activities proposed online to the students, among others like content delivery, quiz, test, simulator, demo, tutorial, help, survey, forum etc. It is simply accessed by pointing to a specific URL address, that is physically in the labserver directly connected to the equipments. Fig. 2 shows a typical interface seen by a client, *i.e.*, a remote student, when asking for plotting Bode curves to characterize the transfer function of active filters. The user builds his own circuit by piloting the robotic arm, makes measurements in real-time, exploits graphs thanks to cursors and markers, optionally takes part in the Top 10, has a visual feedback of the lab through a camera, and gets information about the waiting list of users with a time-counter, so that he knows exactly when he will be served. In the meanwhile, he can switch to other activities proposed in the pedagogical scenario described in section 4.3. A videotutorial of the use of the remote lab is available at [34].

3.3.4 Robotic Arm for Component Placement

Instead of virtual wiring, LaboREM gives the opportunity to build the circuit using an old fashioned robotic arm (Fig. 8). The circuits under test are active filters consisting of OpAmps, resistors and capacitors only (no inductance). Thus, a simple solution for easily placing components is to equip them with magnets, so that the right place and good connection contact are achieved, without needing high spatial

precision or big mechanical effort. This minimizes the risk of misplacement: tests conducted in 2013 give a reliability higher than 99.5%. Fig. 8 shows the two-step action: first, grasp one component from the bank of components; then, move and drop it down on the receiver board connected to the breadboard where OpAmps are already in place. In addition to

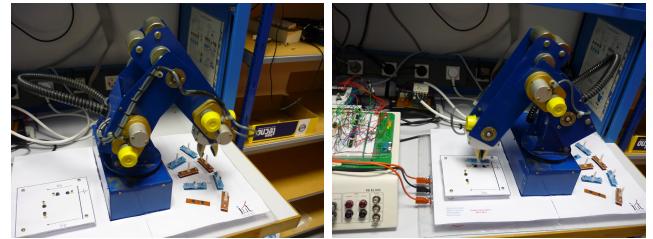


Fig. 8. Robot in action for (i) choosing and (ii) placing components equipped with magnets.

the robot-built filters, there are 8 precabled passive and active filters on the breadboard, so that the student can choose either to build his own filter, or to use precabled ones among high-pass, low-pass, band-pass, rejection, plus one extra unknown filter to be uncovered. Choosing the filter is simply done in the client interface by selecting the type of filter and component values (in the minimal version of the prototype, components can be chosen among 8 values: 4 resistors, 4 capacitors). Note that in case of failure of the robot placement, the client can switch to precabled filters instead, that do not require the robot use.

4 SCENARIO FOR E-LEARNING

4.1 Prerequisites and Objectives

The curriculum content for the technological diploma in industrial engineering is composed of various technical modules, ENA being dedicated to analog electronics. Prerequisites are the basics in mathematics and electricity. The objective is to learn active filters. In the remote lab, the student has the choice between various filters: some of them are known (SallenKey, Wien etc.), or can be built by the student himself; others are unknown and should be identified during the lab session.

4.2 Game-like strategy

It is well-known that the motivation of students practicing e-learning may not only be modeled and measured, but also fostered, with the proper use of an LMS (ARCS model [35]: attention, relevancy, confidence and satisfaction). In addition, the use of games may contribute in enhancing motivation, yet it is unclear to which extent instructional games directly affect learning outcomes [36], [37]. Games are characterized by 6 key-dimensions [38]: fantasy, clear rules and goals, sensory stimuli, challenge, mystery and

control. The game process involves a repeated loop of three successive steps: user judgment, behavior and feedback. The objective of adopting a game-like approach in learning is to prompt the student to repeat the activity, like when playing a game over and over (addictive process). In the proposed approach, the 6 game dimensions are taken into account as follows: mystery (unknown filter to uncover), sensory stimuli (visual feedback and robotic motion), challenge (Top 10), control (choice of DUT), rules (limited time and number of trials), goals (clear learning objectives with three difficulty levels to choose from), fantasy (freedom to conceive one's own circuit). Depending on the filters chosen for study, and on the exactness of answers, the student accumulates more or less points during his "travel" and may take place in the "hall of fame". If he discovers what the unknown filter is, he has reached the final objective of the "quest". If he fails, he may choose to backtrack and try again (limited repetitions). All the game scenario is managed by the LMS, apart from Top 10 and robot activities that are directly handled by the lab.

4.3 Pedagogical Scenario

A polylinear learning path is implemented in the LMS as a "treasure hunt", that is adapted to the competence level and motivation of the student. Competence and motivation are measured with an automatic assessment procedure (quizzes, tests and surveys). Depending on the level, a flag (red, orange or green) is generated to orientate the student towards the best path and with the best workload according to the student's profile and current study mood.

A detailed description of the game-like scenario may be found in [8]. The scenario is based on four concepts, as in e-games: levels, lives, points, and time. Four counters are used for the evaluation of student's activity: a timer, a counter for highest level achieved (difficulty level), a counter for number of lives used (number of trials), a counter for scoring (marks obtained to online quizzes and final exam). This allows to estimate a participation index and a performance index which are parameters taken into account as in [19] for driving motivation in auto-regulated distance e-learning. The scenario outlined in Fig. 9 gives an overview of the global labwork activity with the objective to be achieved along due time. The various colors code the difficulty level.

A typical scenario contains: (i) videopresentation of the lab and of experiments; (ii) test on prerequisites; (iii) first remote labwork (Lab1 on passive filters) with three levels of difficulty; (iv) lesson about active filters (online documents); (v) formative test; (vi) second and third remote labworks (Lab2 on Bode plots, Lab3 on signals and spectra analysis); (vii) comparison with simulator (virtual lab); (viii) final summative test with upload of work report; (ix) satisfaction survey.

Fig. 10 is a snapshot of the screen seen by a client when asking for the remote lab within the LMS: he can download a preformatted text-file for writing the report to answer the questions (left button), click on "Travaux Pratiques" (middle button) to run real experiment, or run the simulator (right button). The traffic light indicates the best difficulty level to choose from, depending on previous answers to quizzes. The student can also review a tutorial that explains the use of the lab by playing a video (bottom movie).

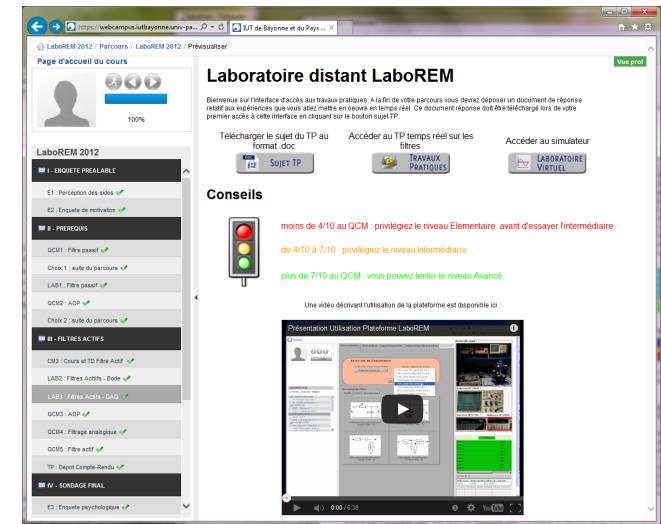


Fig. 10. LMS interface seen by the client when requesting access to remote lab experiment.

4.4 Student Motivation

In 2011, a group of 29 undergraduate students in industrial engineering was tested. At first, an *a priori* survey about their intrinsic motivation¹ showed that their main motivation was acquisition of knowledge (mean score of about 3.8/5), long before their position with respect to others (mean score of about 2/5). Maybe the distance activity explains partly this result. To enhance external motivation, a Top 10 list was added in 2013, that gives in real-time the best score achieved in the measurement activity. Moreover, the robotic arm was also added (with a videotutorial presenting its use). This proved to increase external motivation by a factor of about 20%. Indeed, Tab.2 gives the average values for intrinsic and extrinsic motivation measured from pre- and post-inquiries² (before and after the lab activity) in 2011, 2012 and 2013. It also shows (in bold) the increments between 2012 and 2013.

1. The definition may be found in [39]. Sample assertions for measuring motivation are, among 20 sentences: "It is important for me to learn"; "It is important for me to look like being proficient"; "I am motivated by this remote learning activity"; "I am motivated by the final mark I will obtain for this labwork" etc.

2. Note that Pre- and Post-inquiry values are not directly comparable since they are based on two different types of questionnaire; moreover, in 2011, there was no Post-inquiry available.

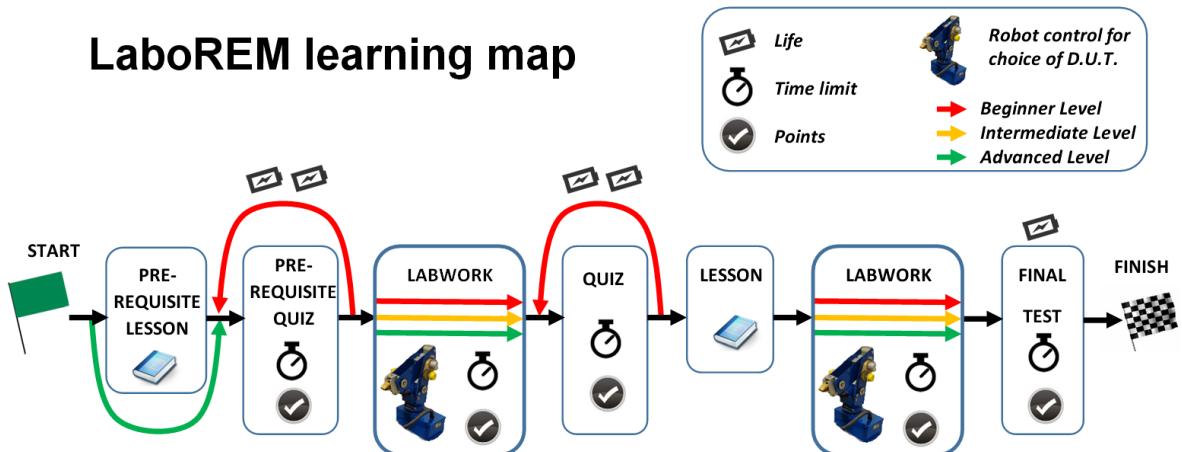


Fig. 9. Learning map as a treasure hunt with various steps (implemented as activities in the LMS): start, lesson (documentation and help), quiz (evaluation and test), remote lab control, finish.

TABLE 2

Student motivation (on a 5-point Likert scale)

year (# students)	Intrinsic		Extrinsic	
Pre-Inquiry	mean	incr.	mean	incr.
2011 (29 stud.)	3.73		2.06	
2012 (22 stud.)	3.89		1.95	
2013 (25 stud.)	4.18	+0.29	2.42	+0.47
Post-Inquiry	mean	incr.	mean	incr.
2012 (22 stud.)	3.1		2.55	
2013 (25 stud.)	3.5	+0.4	3.1	+0.55

The LMS delivers all the traces for each student: number of accesses, time spent, number of trials, performance achieved, difficulty level reached, answers given to quiz (Fig.11). Four observations are taken into account for statistical analysis of pedagogical achievement: score (and number of trials) on a formative test, duration (and number) of document access, duration (and number) of lab activities, score on summative test. During a session, five variables are recorded: the self-perception of competence (Boolean V_1), the score to a formative test (integer V_2), the choice of proper remedial path (Boolean V_3), the duration of remedial activity (time in seconds V_4 that depends statistically on V_3), the score to a summative test (integer V_5). The student motivation by the game-like scenario is also estimated *a posteriori* from a satisfaction survey ("Post-Inquiry"). Note that all those variables are recorded from the traces inside the LMS only, but not from the remote lab which is quite independent (since it is not compliant yet with SCORM or IMS standards, as suggested in [40]). Whereas the dependency between V_2 and V_5 is not statistically significant on our test group (Wilcoxon test), the dependency between V_1 and V_5 is statistically significant. This shows that motivation (through self-perception of competence) is highly correlated to the performance achieved at the final test. Namely, 85% of students that feel competent succeed in their activity. It is therefore very important

Fig. 11. Typical traces of student activity delivered by the LMS: steps, status, points, time spent, details.

to estimate and control motivation. Indeed, motivation may be increased by many factors like competitiveness, flexibility, autonomy [41]. Worth to mention is the fact that the students that most participated in the Top 10 questions were not necessarily the “best” of our students (in terms of academic marks).

5 PLATFORM EVALUATION

To assess the quality and interest of a remote lab, both a technical evaluation and a pedagogical evaluation must be conducted. We conducted four runs of LaboREM: in 2009 (2 groups: 13+19=32 students), 2011 (2 groups: 18+29=47 students), 2012 (22 students) and 2013 (25 students) respectively. The first runs took place in a classroom equipped with PCs at the university (intranet access), whereas the two last ones were done by each student at home (Internet access, possibly with wifi wireless connection).

Each time, two anonymous questionnaires are used for the surveys: a detailed questionnaire with about 70 questions, some of them are given in Tab. 3 (answers on a 5-point Likert scale) and a global satisfaction survey scoring ten main issues reported in Tab. 4 (marks on a 20-point scale). The average satisfaction is about 13.5/20 for the last session (25 students in 2013). The previous sessions (about 100 students between 2009 and 2012) gave mean scores ranging between 12 and 13.5 (20/20 being the best and 0/20 being the worst).

TABLE 3

Sample questions and their scoring from the 2011 student survey to evaluate the application (Likert scale: 5 = “strongly agree”, 1 = “strongly disagree”)

I like to be able to do the labwork anytime and from anywhere	4.4
I like to be able to choose the level adapted to my own competencies	4.4
I understand the objective of the labwork	4.3
I feel the number of exercises is enough	4.3
I like the liberty of action in this activity	4.2
I need to speak (collaborate) with my colleagues or a tutor	4.1
I need much effort for interaction	2.8
I find the interface too complicated	2.6
I find the scenario too complicated	2.5
I like the easy connection and the response time	2.4

From the evaluation in Tab.4, the following facts may be assessed. First, passing from the classroom in 2011 (with a tutor) to the home in 2012 (student alone) led to a sharp fall in the marks (student less confident, less motivated). Improving the application in 2013 (mainly by the use of robotic arm and Top 10) clearly increased student motivation and hence satisfaction, leading to the same average mark as in 2011. Second, the improvement each year of the quality of online

TABLE 4
Students answers (with marks ranging from 0 to 20)

Year (# students)	2009 (13)	2011 (18)	2011 (29)	2012 (22)	2013 (25)
Evaluated issue	in classroom				at home
Comfort of interaction	12.8	11.6	13.9	12.3	13
Technical quality of platform	14.1	12.6	13.7	12.8	13.5
Game like scenario	13.9	14.9	13.5	10.4	13.4
Pedagogical efficiency	13.8	13.1	12.9	10.3	12.6
Remote control of devices	13	12.7	14.2	11.7	14.1
No space-time constraints	12.5	14.2	13.9	13.1	12.4
Collaborative work	12.6	14.3	14.5	13.4	15.2
Autonomy	13.8	13.7	13.7	12.3	14.2
Preparation, Docs and Prerequisites	10.9	12.6	13.4	14	14.5
Overall satisfaction	12.6	12.5	12.1	10.7	13.3
Average Mark	13	13.2	13.6	12.1	13.6

documentation for help and preparation to prerequisites is rewarding: the students’ marks reflect this fact by constantly increasing. Then, two issues are very positive from the students point of view: collaborative learning, autonomous activity. This is particularly true for undergraduate students (mostly teenagers). The issue of pedagogical efficiency must be investigated further: we intend to conduct experiments with two separate groups of students from the same year, one doing hands-on lab, the other doing remote lab and compare their academic results before drawing any firm conclusion.

Apart from those quantitative surveys, the students have also the opportunity to leave free comments about the application. From their point of view, two issues are clearly the keys for success: technical quality and prerequisites. Indeed, bugs should never happen in distance e-learning (leaving the student alone with a problem) and the work should be well prepared and documented in order to yield an effective activity (need of clear objectives). “More early explanation” before leaving the student alone in front of the computer may be required as reported in [42] that deals with remote control of photovoltaic panels at NASA center in California.

6 DISCUSSION AND FUTURE WORK

If motivation increase was clearly established (section 4.4), we do not claim that better learning outcomes, compared to hands-on, are clearly visible yet. This is in agreement with other research works on weblabs [43]. Nevertheless, this platform is one supplementary tool to help students in their studies, especially in an autonomous and student-centered

context, as recommended in Europe by the Bologna process. Moreover, this tool is exhibited each year as a demo during the “open doors day” of the university and proves to be very attractive for the visitors which are teenagers coming from high schools. It contributes to increase the number of students willing to undergo a STEM curriculum (science, technology, engineering, mathematics). This is a highly desirable educational impact since there is nowadays a shortage of science and technology students.

Altogether, the results of the e-learning experiments conducted here show that, for 75% of the student group under test, the self perception of efficiency and/or the proper choice of remedial strategy (use of online help) is highly correlated with their success in learning. However, for the remaining 25% of the group under test, it is important to implement tools to enhance students’ motivation and hence performance. For that purpose, learning paths with polylinear flowcharts that can adapt to student’s proficiency level are relevant. Moreover, game-like scenarios help to counteract the possible demotivation in distance e-learning. The evaluation of the proposed method shows the same phenomenon and leads to the same conclusion as reported in [44] which deals with motivation setting in sports: a difficult but still achievable objective enhances the students’ motivation. The tutor (real or virtual) acts like a coach in sport games, so that students achieve the best they can (adaptive learning). The need is clear for a platform that estimates automatically the motivation and controls the regulation of workload for each student. Implementing a Top 10 feedback (“hall of fame”) to increase motivation while answering the quizzes proved to be very efficient. Indeed, competitiveness increases motivation, as shown in the surveys answered by students themselves.

The perspective of this work is manifold. From a technical point of view, a multi-server solution is of high interest, to give access to experiments in various remote labs, like the iLab shared architecture [45]. The network solution based on webservices for more portability [31] is implemented: it should now be evaluated and compared to the proprietary remote front panel protocol solution currently in use. With our university partner in Bucharest, Romania, we successfully tested 30 simultaneous connections in 2009. Now that the platform is deployed and operative, it can be shared with other universities, namely the 25 other Technological Institutes of industrial engineering in France, and with other interested academic partners in Latin America (the translation from French to Spanish is under work).

As regards pedagogical aspects, namely to improve the process of differentiated learning, a controller based on the Dempster-Shafer theory of evidence could be implemented to improve the estimate of the student state (motivation, proficiency, autonomy

etc.) and regulate in real-time the workload for each student.

We intend to switch to Moodle (instead of Chamilo and Dokeos LMS previously in use at our university). Indeed, it will make easier the design of adaptive learning paths and the plug-in of weblabs thanks to dedicated Moodle modules. We intend to make LaboREM fully compliant with SCORM or IMS standards as in [40] that deals with the complete integration of weblabs, based on web services, into an LMS by creating SCORM packages in a graphical way.

As regards image processing use, face expression analysis may be a good help to know the state of motivation of a student, as mentioned in [35]. To give the control of the camera to the client is attractive both for enhancing the student motivation and for addressing student requests for visualizing hardware settings or for closer collaboration through computer vision (cf. videoconferencing with a tutor) or even augmented reality purposes. In addition to the wide-angle camera that supervises all the scene, a minidrone equipped with a micro-camera could be used to fly over the lab at user’s request. Audio hints and sound should also be added since sensory stimuli are one of the 6 key dimensions that characterize games [38], and some students are more sensitive to the aural learning channel (cf. VARK cognitive model [46]).

Other applications of remote activities for delocalized research laboratories are under investigation, namely to control prototypes of plasma reactors for biomedical applications, and to pilot remotely renewable energy systems on the roof of the university buildings.

ACKNOWLEDGMENTS

The authors thank the Regional Council of Aquitaine, Bordeaux, France for financial support. They are also thankful to their former master students, Irina Talmaciu with the technical military academy of Bucharest, Romania, and Bernard Cauquil with the university of Toulouse-Le Mirail, France. Finally, they would like to thank two colleagues: Kevin Levron for his skills in programming that helped for network configuration and adaptation of the LMS to the specific needs of remote lab, and Christine Druon for correction of English flaws in the manuscript. They also thank the anonymous reviewers for their fruitful comments that helped to improve the paper.

REFERENCES

- [1] L. Gomes and S. Bogosyan, “Current trends in remote laboratories,” *IEEE Trans. on Industrial Electronics*, vol. 56, no. 12, pp. 4744–4756, Dec. 2009.
- [2] J. Garcia-Zubia and G. R. Alves, Eds., *Using Remote Labs in Education: two little ducks in remote experimentation*. Bilbao, Spain: University of Deusto, 2011, ISBN 978-84-9830-398-8.

- [3] C. Pleul, C. Terkowsky, I. Jahnke, and A. E. Tekkaya, "Tele-operated laboratory experiments in engineering education. The uniaxial tensile test for material characterization in forming technology," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 16, pp. 323–347.
- [4] S. Dormido, J. Sanchez-Moreno, H. Vargas, L. de la Torre, and R. Heradio, "UNED labs: a network of virtual and remote laboratories," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 12, pp. 253–270.
- [5] P. Orduña, S. B. Uribe, N. H. Isaza, E. Sanristobal, M. Emaldi, A. P. Martin, K. DeLong, P. Bailey, D. L. de Ipiña, M. Castro, and J. Garcia-Zubia, "Generic integration of remote laboratories in learning and content management systems through federation protocols," in *43rd Annual Frontiers in Education Conf. (FIE 2013)*. Oklahoma, US: IEEE, 2013.
- [6] O. H. Graven, D. Samuelsen, and L. M. MacKinnon, "Computer-based role playing game environment for analogue electronics," *Int. J. of Online Engineering ijOE*, vol. 5, no. 1, pp. 27–33, 2009.
- [7] M. Steriu and F. Luthon, "Open architecture for signal processing lab distance learning," in *4th IEEE Digital Signal Processing Education Workshop (DSP'06)*, Jackson Lake Lodge, Wyoming, USA, Sep. 24–27 2006, pp. 305–310.
- [8] F. Luthon, A. Petre, D. Steriu, and A. Besleaga, "LaboRem: open lab for remote work," in *3rd Int. Conf. on Signals, Circuits and Systems (SCS'09)*. Jerba, Tunisia: IEEE, Nov. 2009, pp. 1–6.
- [9] I. Gustavsson, K. Nilsson, J. Zackrisson, J. Garcia-Zubia, U. Hernandez-Jayo, A. Nafalski, Z. Nedic, Ö. Gö, J. Machotka, M. I. Pettersson, T. Lag, and L. Håkansson, "On objectives of instructional laboratories, individual assessment, and use of collaborative remote laboratories," *IEEE Trans. on Learning Technologies*, vol. 2, no. 4, pp. 263–274, Oct-Dec. 2009.
- [10] M. Tawfik, E. Sanristobal, S. Martin, R. Gil, G. Diaz, J. Peire, M. Castro, K. Nilsson, J. Zackrisson, L. Håkansson, and I. Gustavsson, "Virtual instrument systems in reality (VISIR) for remote wiring and measurement of electronic circuits on breadboard," *IEEE Trans. on Learning Technologies*, vol. 6, no. 1, pp. 60–72, Jan. 2013.
- [11] I. Verginis, A. Gogoulou, E. Gouli, M. Boubouka, and M. Grigoriadou, "Enhancing learning in introductory computer science courses through SCALE: An empirical study," *IEEE Trans. on Education*, vol. 54, no. 1, pp. 1–13, Feb. 2011.
- [12] M. E. Auer and C. Gravier, "Guest editorial: The many facets of remote laboratories in online engineering education," *IEEE Trans. on Learning Technologies*, vol. 2, no. 4, pp. 260–262, Oct. 2009.
- [13] L. D. Feisel and A. J. Rosa, "The role of the laboratory in undergraduate engineering education," *J. of Engineering Education*, pp. 121–130, Jan. 2005.
- [14] T. Wolf, "Assessing student learning in a virtual laboratory environment," *IEEE Trans. on Education*, vol. 53, no. 2, pp. 216–222, May 2010.
- [15] J. V. Nickerson, J. E. Carter, S. K. Esche, and C. Chassapis, "A model for evaluating the effectiveness of remote engineering laboratories and simulations in education," *Computers & Education*, vol. 49, pp. 708–725, 2007.
- [16] J. Ma and J. V. Nickerson, "Hands-on, simulated, and remote laboratories: A comparative literature review," *ACM Computing Surveys*, vol. 38, no. 3, pp. 1–24, Sep. 2006, article 7.
- [17] J. Garcia-Zubia, P. Orduña, D. Lopez-de-Ipiña, and G. R. Alves, "Addressing software impact in the design of remote laboratories," *IEEE Trans. on Industrial Electronics*, vol. 56, no. 12, pp. 4757–4766, Dec. 2009.
- [18] S. Saighi, M. Billaud, D. Geoffroy, and T. Zimmer, "Electronics basics e-learning: From lectures to lab," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 9, pp. 199–210.
- [19] J. A. Mendez and E. J. Gonzalez, "Implementing motivational features in reactive blended learning: Application to an introductory control engineering course," *IEEE Trans. on Education*, vol. 54, no. 4, pp. 619–627, Nov. 2011.
- [20] N. Kostaras, M. Xenos, and A. N. Skodras, "Evaluating usability in a distance digital systems laboratory class," *IEEE Trans. on Education*, vol. 54, no. 2, pp. 308–313, May 2011.
- [21] S. Rapuano and F. Zoino, "A learning management system including laboratory experiments on measurement instrumentation," *IEEE Trans. on Instrumentation and Measurement*, vol. 55, no. 5, pp. 1757–1766, Oct. 2006.
- [22] M. A. Trenas, J. Ramos, E. D. Gutierrez, S. Romero, and F. Corbera, "Use of a new Moodle module for improving the teaching of a basic course on computer architecture," *IEEE Trans. on Education*, vol. 54, no. 2, pp. 222–228, May 2011.
- [23] M. Llamas-Nistal, M. Caeiro-Rodriguez, and M. Castro, "Use of e-learning functionalities and standards: The Spanish case," *IEEE Trans. on Education*, vol. 54, no. 4, pp. 540–549, Nov. 2011.
- [24] T. Augustin, C. Hockemeyer, M. D. Kickmeier-Rust, and D. Albert, "Individualized skill assessment in digital learning games: Basic definitions and mathematical formalism," *IEEE Trans. on Learning Technologies*, vol. 4, no. 2, pp. 138–148, April-June 2011.
- [25] E. Sanristobal, M. Castro, S. Martin, and M. Tawfik, "Remote labs as learning services in the educational arena," in *IEEE Global Engineering Education Conf. (EDUCON)*, Amman, Jordan, Apr. 2011, pp. 1189–1194.
- [26] E. G. Guimaraes, E. Cardozo, H. Moraes, and P. R. Coelho, "Design and implementation issues for modern remote laboratories," *IEEE Trans. on Learning Technologies*, vol. 4, no. 2, pp. 149–161, April-June 2011.
- [27] Z. Nedic, J. Machotka, and A. Nafalski, "Enriching student learning experiences in remote laboratories," in *2nd WIETE Annual Conf. on Engineering and Technology Education*, Pattaya, Thailand, Jan. 2011, pp. 9–14.
- [28] Z. Nedic and J. Machotka, "Remote laboratory NetLab for effective teaching of 1st year engineering students," *Int. Journal of Online Engineering ijOE*, vol. 3, no. 3, 2007.
- [29] K. DeLong, J. Harward, P. Bailey, and G. Kohse, "Online spectrometer experiments using the iLab shared architecture," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 5, pp. 121–134.
- [30] A. John, K. Gabriel, and K. Patrick, "Towards virtual laboratories: a survey of LabVIEW-based conduction of science experiments via the internet with an illustrative consideration of remote control of an oscilloscope," *Int. Journal of Current Research*, vol. 3, no. 6, pp. 123–127, Jun. 2011.
- [31] S. Dutta, S. Prakash, D. Estrada, and E. Pop, "A web-service and interface for remote electronic device characterization," *IEEE Trans. on Education*, vol. 54, no. 4, pp. 646–651, Nov. 2011.
- [32] I. Talmaciu, "Système de Formation en Ligne pour les Laboratoires Distant," IUT Bayonne, Anglet, France, M.Sc. dissertation, 2012.
- [33] J. Garcia-Zubia, D. Lopez-de-Ipiña, and P. Orduña, "Mobile devices and remote labs in engineering education," in *8th Int. Conf. Advanced Learning Technologies (ICALT'08)*, IEEE, Ed., Santander, Cantabria, Jul. 2008, pp. 620–622.
- [34] https://www.youtube.com/watch?feature=player_embedded&v=m7pyIr2ub54.
- [35] M. Muñoz-Organero, P. J. Muñoz-Merino, and C. D. Kloos, "Student behaviour and interaction patterns with an LMS as motivation predictors in e-learning settings," *IEEE Trans. on Education*, vol. 53, no. 3, pp. 463–470, Aug. 2010.
- [36] M. Pivec and P. Kearney, "Games for learning and learning from games," *Informatics*, vol. 31, pp. 419–423, 2007.
- [37] O. Dziabenko, J. Garcia-Zubia, and D. Lopez-de-Ipiña, "Remote experiments and online games: How to merge them," *Int. J. of Engineering Pedagogy (ijEP)*, vol. 1, no. 1, pp. 31–35, Apr. 2011.
- [38] R. Garris, R. Ahlers, and J. E. Driskell, "Games, motivation, and learning: A research and practice model," *Simulation & Gaming*, vol. 33, no. 4, pp. 441–467, Dec. 2002.
- [39] P. Carré, *De la Motivation à la Formation*. Paris: Ed. L'Harmattan, 2001.
- [40] E. Sanristobal, M. Castro, J. Harward, P. Bailey, K. DeLong, and J. Hardison, "Integration view of web labs and learning management systems," in *IEEE Education Engineering Conf. (EDUCON)*, Madrid, Spain, Apr. 2010, pp. 1409–1417.
- [41] R. Rengel, M. J. Martin, and B. G. Vasallo, "Supervised coursework as a way of improving motivation in the learning of digital electronics," *IEEE Trans. on Education*, vol. 55, no. 4, pp. 525–528, Nov. 2012.

- [42] D. A. O'Leary, J. Shattuck, and J. Kubby, "An online, interactive renewable energy laboratory," *IEEE Trans. on Education*, vol. 55, no. 4, pp. 559–565, Nov. 2012.
- [43] J. Henry and M. Ozkaya, "Engineering controls labs operated remotely," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 2, pp. 53–77.
- [44] E. A. Locke and G. P. Latham, "The application of goal setting to sports," *J. Psychology*, pp. 205–222, 1985.
- [45] V. J. Harward, J. A. del Alamo, S. R. Lerman, P. H. Bailey, and al., "The iLab Shared Architecture: A web services infrastructure to build communities of internet accessible laboratories," *Proc. of the IEEE*, vol. 96, no. 6, pp. 931–950, Jun. 2008.
- [46] R. Marcelino, J. B. Silva, A. V. Fidalgo, L. Schaeffer, and J. B. M. Alves, "Virtual 3D worlds and remote experimentation: A methodology proposal applied to engineering students," in *Using Remote Labs in Education*, J. Garcia-Zubia and G. R. Alves, Eds. Bilbao, Spain: Deusto Digital, 2011, ch. 17, pp. 349–374.



Franck Luthon received the electronics engineering degree in 1985, and the PhD degree in 1988, both from the National Polytechnical Institute INP, Grenoble, France, where he was assistant professor for ten years. Since 2000, he has been professor at the university of Pau, Bayonne, France. He founded and headed the industrial engineering department at the Technical University Institute IUT in Anglet, France. He created and is responsible for the Bachelor of Science

diploma in Industrial Ecology. His fields of interest are signal and image processing, electronic systems and learning technologies.



Benoît Larroque is assistant professor at the university of Pau, Bayonne, France. He received the PhD degree in automatic control from the National Polytechnical Institute INP, Toulouse, France, in 2008. He received the diploma in engineering from the Ecole Nationale d'Ingénieurs ENIT, Tarbes, France, in 2004. His research is currently focused on remote lab technologies and supervision.