A Remote Laboratory in Engineering Measurement

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***Abstract*—Online engineering practice is offering nowadays new potentials for training of measurement technologies and experimental procedures. In a laboratory mainly devoted to Instrumentation for Measurement by hands-on activity in engineering fields, students and engineering professionals are using, at present, online experiments in a blended-learning approach. A set of experiments has been designed and developed as well as some virtual simulators. The experiments integrated in a Moodle platform are using a web-server system based on LabVIEW 7.1, linked to them by data acquisition interface cards, a video server, and a booking system developed as an extension of the Moodle platform. This paper reports a particular setup specially designed for remotely measuring and determining mechanical material properties and its combination with the design of a highly interactive user interface. The user may remotely conduct the experiment, getting numerical, graphical, and live video output information and receiving e-mailed experimental results.**

***Index Terms*—Online engineering, remote laboratories, web- and computer-based learning.**

I. Introduction

EXPERIMENTAL teaching and learning of Instrumentation for Measurement issues [1] has been often regarded with special attention as an essential complement to the abstraction of concepts and of defined methodologies and procedures, like in many others engineering areas [2]–[5]. Several experiments have been developed in the Instrumentation for Measurement area specifically regarding metrological concepts and measuring methodologies such as a calibration procedure of a temperature system, the straightness evaluation of a surface on a given direction, the measurement and evaluation of urban microclimatic conditions (sun radiation intensity, pressure, temperature, humidity, wind velocity, and direction), level measurement and control in a closed loop system of two water tanks, digital and analog light actuation, and a system for mechanical material characterization. All the experiments are available at http://remotelab.fe.up.pt/.

A Michelson Interferometer will be soon available as an example of system traceability to the SI unit of length [6] in metrological laboratories. For this particular experiment, a remote and a virtual system have been developed.

Responding to a request from industry for the determination of the Young's modulus of an aluminum specimen, the Lab team has realized how important it could be to design a system for that purpose and to make it available online for student training, for the part-time students normally with more restrictive timetable and for engineering professionals. Moreover, considering that in several engineering courses students deal with, among other subjects, the use of resistance strain gauges for measuring strains and confirming Hooke's law or determining elastic properties of a material, e.g., Young's modulus and Poisson ratio, an online experiment was developed.

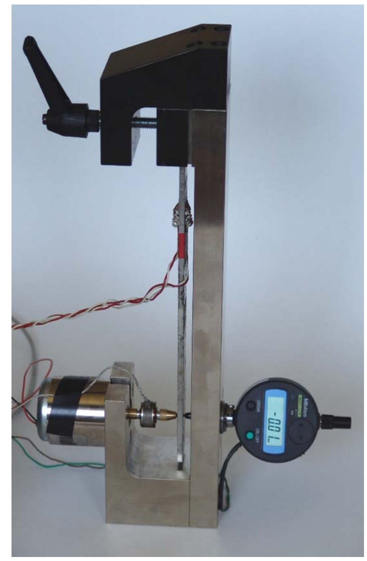

Fig. 1. Experimental setup.

The setup shown in Fig. 1 was specially conceived, designed, and instrumented to allow the students to remotely access it for verifying Hooke's law, becoming familiar with an experimental methodology used for measuring Young's modulus and, finally, to get training in processing data obtained from the test result file automatically sent by the application to the student e-mail address, if it has been introduced in the user interface.

In a blended-learning approach, the system can be used before a real laboratory session for preparing hands-on activity [7], [8].

Later, in the laboratory, the student may face a similar system for those measuring purposes. He/she may be asked to prepare a cantilever beam and then instrument it with resistance strain gauges, connect the sensors bonded on the beam to the commonly associated instrumentation—an energized Wheatstone bridge—and perform several tests by applying a set of discrete loads [9]. The student shall produce a spreadsheet with the different applied load values and the corresponding strains determined from the corresponding unbalanced bridge values, and process, analyze, and discuss the respective data during the laboratory session. Finally, he/she may be able to review a similar procedure by repeating it remotely every time

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he/she wishes to rework that issue, using the available remote access system now referred. Moreover, exploring the system, the student should be able to realize why, even using a similar method, it conducts to Young's modulus values differing between them up to 7%. The software application for conducting the experiment was carefully designed in order to highlight this experimental deviation.

The blended-learning approach can be considered as a well-structured methodology for helping the student to get a deep know-how of that experimental methodology and its experimental limitations. Moreover, the present example demonstrates clearly how a simple hands-on experiment becomes a complex and expensive automated system just to make it available online. This aspect has been as well highlighted to the students to illustrate an automated solution of a simple system.

The above example was explored in different perspectives. However, remote and virtual experiments should be regarded on others insights, as well.

Remote (and virtual) experiments should be accepted as new possibilities for under equipped laboratories, or just for sharing resources and so reducing costs [10]–[12]. In fact, for many years, hands-on activities have been the monopoly of well-structured experimental university laboratories, and now the web access makes resources available anywhere, anytime. By sharing them, they contribute to reduce possible gaps between educational institutions regarding practical knowledge, and to promote student-student interaction, particularly if considering underdeveloped countries. In any case, a setup raises its cost to be available online, but being available, for everyone, everywhere, standing alone 24 h a day, seven days a week, without having to multiply setup replicas, will decrease its investment.

Considering some of the highlights pointed out by Bologna recommendations on the enhancements of engineering education, the access to remote experiments may also help to improve students' autonomy, inciting them to acquire the ability to exercise the experiments by themselves, and so contributing to stimulate "student centered learning."

In any perspective, it is clear that we are facing the pedagogical value from the use of the computer and the web-based educational tools, and the examples come everyday from many different areas [13]–[16].

In any case, this type of technical facilities has to be very well balanced because the real laboratory activity has a fundamental importance on the engineering background—"a remote laboratory acts as an interface between users and real equipments," [17]–[22]. In an opposite point of view, a remote laboratory or even a virtual experimental replica are valuable tools impossible to replace only with nice pictures, good videos on demand, or expensive Finite Element Analysis packages or any other modeling software for engineering applications [7].

The first remote laboratory appeared in the early 1990s. Since then and essentially since 2002, the use of technology has been presenting several approaches. One of the most universal is based on the software with web server functionality named Laboratory Virtual Instrument Engineering Workbench (LabVIEW). As typical of data acquisition software, it communicates through the hardware interfaces with the instrumented experiment. Another powerful solution is based on the use

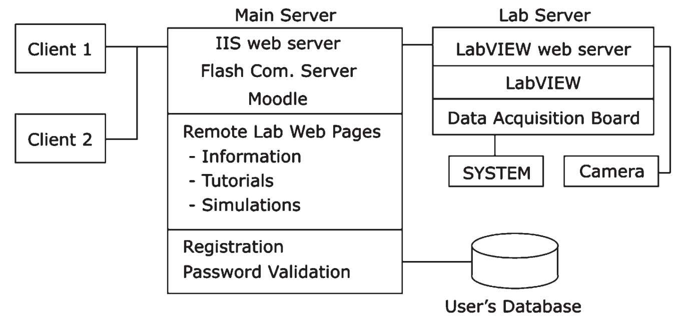

Fig. 2. System architecture.

of web services. Between those two main approaches, many others, some of hybrid type, are also used. In the present case, LabVIEW is the software used both for data acquisition and as web server. Currently, the authors are testing new solutions developed within new experiments not so complex, based on freeware. They offer very low cost and power consumption, lighter user-friendly interface, better stability and compatibility, and an easier architecture.

This paper reports one particular experiment and its exploration. It uses the Moodle platform for a self-contained learning object and integrates a booking application between this platform and the LabVIEW user interface. This free access experiment can also be launched from an e-book recently edited in the authors' native language plus English version [23]. These are the novel features of this paper.

II. System Architecture

The system architecture is shown in Fig. 2.

The Microsoft Internet Information Services main web server contains all the information on the available experiments (system description, how to use it, access to the experiment, final report) and a database for authentication purposes. After system validation of registered users, the user may schedule the experiment using a hypertext preprocessor application integrated in the Moodle platform. This computer also runs a video web server—Macromedia Flash Server Communication, for webcam video delivering. Some experiments with heavier image requirements use more expensive cameras (in the present case Axis, Panasonic, Trendnet) via a Linux video server. These IP network cameras usually provide the image in motion JPEG or MPEG4 codecs directly to the web page of the experiment.

In the laboratory, each experiment has its own web server supplied by National Instruments LabVIEW. Once authorized, the user accesses this computer directly and the system setup through an I/O data acquisition card (USB or PCI).

III. Determining Mechanical Material Characteristics

Several methods may be used for determining the Young's modulus of a specimen [24]. One of them is based on the traditional methodology of a beam-type specimen submitted to a bending test. The beam-type specimen, of constant rectangular cross section, was prepared and instrumented with two resistance strain gauges, symmetrically bonded, respectively,

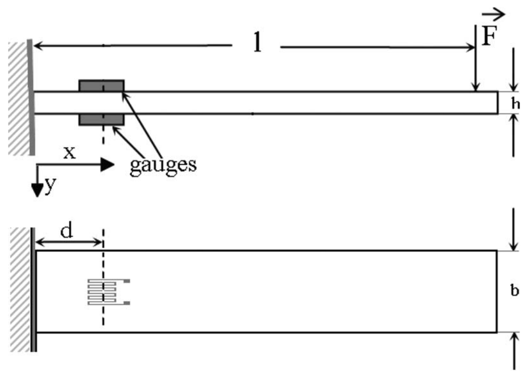

Fig. 3. Cantilever beam test setup.

on the top and bottom surfaces of the beam and oriented along its longitudinal axis.

The specimen was then used in a simple cantilever beam mounting test system. The electrical strain gauges were integrated in a half Wheatstone bridge circuit configuration. The load is applied near the free end of the beam, at a distance l from the fixed end, and d is the distance from the fixed end to the geometric center of the strain gauge grid (Fig. 3).

For many materials loaded within a moderate stress range in a uniaxial tension test, the relation between the stress along the x-direction (σ_x) and the corresponding longitudinal strain (ε_x) can be established by Hooke's law

$$\varepsilon_x = \sigma_x / E. \tag{1}$$

The bending moment produced by the load F applied at a distance l from the fixed end causes a longitudinal strain, ε_x, on the beam at the geometric center of the strain gauge grid

$$\varepsilon_x = 6F(l-d)/(Ebh^2). \tag{2}$$

Hence, the deflection δ on the surface of the cantilever beam, along the x-direction, is given by

$$\delta(x) = y(x) = \left[6Fx^2/(Ebh^3)\right] \cdot (l - x/3). \tag{3}$$

IV. Design of Mechanical Setup

Special care in the design of the supporting base was considered. COSMOSWorks Designer for SolidWorks software package was used for displacement analysis (Fig. 4).

All main parts were manufactured in C 45 E carbon steel and designed for stiffness. The maximum angular deflection of the mounting surface of the voice coil actuator (described in the following section) leads to a variation in the specimen loading point below 2 μm. Both this mounting surface and the specimen fixture surface were machined to be kept parallel to each other and allow an application of load perpendicular to the specimen surface.

In order to prevent the specimen mid plane undesirable rotation, a guided clamp was considered which positions itself on the base support with stringent tolerances; thus, the load application point is made to coincide with the mid plane of the beam.

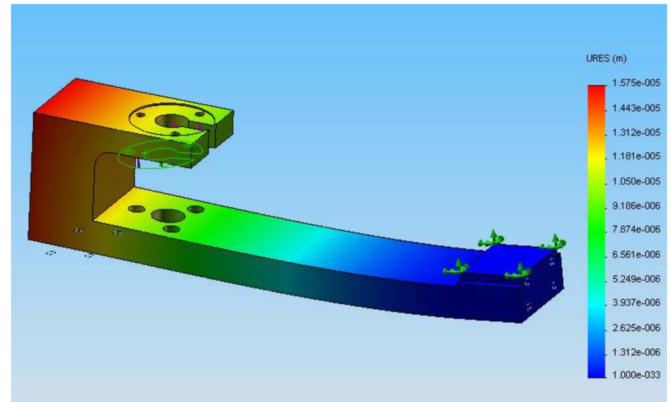

Fig. 4. Finite Element Method analysis for the supporting base.

The large clamping area and the positive stop provided by the clamping column both for the specimen and the guiding plate also guarantee that the cantilever fixture is correct.

This stop also ensures that the specimen and thus the distance between strain gauges fixing points and the beam fixture is always the same.

Loading contact with the specimen is achieved by means of a hardened steel ball (4 mm in diameter) in order to minimize variation of the load application point.

On the same axis of the voice coil actuator, a mounting hole provides an accurate position for a digital dial indicator specially design support.

Finally, all nonworking surfaces of the apparatus were nickel plated.

V. Remotely Determining Mechanical Material Characteristics

A cantilever beam, instrumented with resistance strain gauges, is loaded by a linear motor of voice coil type (Densitron VM5050-250) which is closed-loop force controlled (driver card Maxon LSC 30/2). A miniature load cell (Honeywell—Sensotec 31 plus a signal conditioning from Honeywell/Sensotec DA-05) is arranged in series with the motor shaft and measures loads in a range from 0 up to 24.5 N. A digital dial indicator (Mitutoyo 543-681B) measures the deflection at the load application point. A modular half Wheatstone bridge transmitter (from PRelectronics 2261) is used for measuring strains by reading its current output $(4 \div 20\ \text{mA})$. The digital dial indicator communicates with the controlling application, developed in LabVIEW 7.1 on the local PC, by an RS232C interface. The remaining system hardware communicates through an USB card 6009, from National Instruments. Alternatively, it could, as well, be used Matlab (from MathWorks) to acquire the sensors data and to generate the control signals, using the data acquisition toolbox [25]–[27]. However, LabVIEW (from National Instruments) makes things easier, by providing an embedded web server. Thus, publishing a *Virtual Instrument* application is achieved by simply saving it as HTML file and starting the web server. Additionally, since National Instruments produces also hardware, full compatibility and performance of the data acquisition board can easily be achieved. The low-cost USB-6009 data acquisition

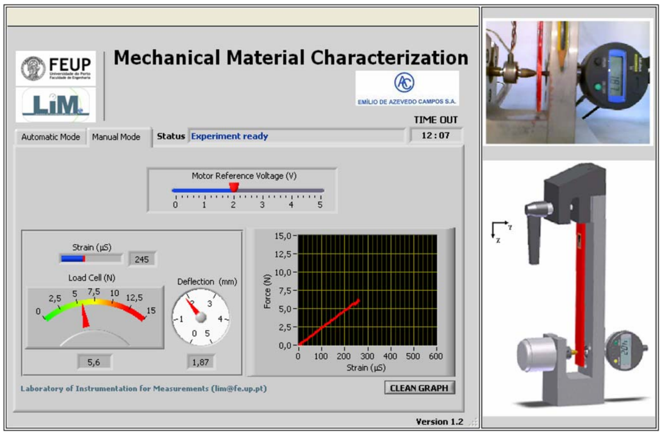

Fig. 5. User interface: manual mode.

board is an excellent "value for money" choice, by providing multiple analog input (8, 14 bit), analog output (2, 12 bit), and 12 digital I/O.

The hardware solution implemented on this example also includes other functionalities relevant to remote usability and power saving. The hardware is prepared for energizing all the electrical system components whenever a remote actuation is requested. When the user requests application control, a light dependent resistor sensor will assess the current room light level. If required, the control system will then switch on the setup dedicated light. The digital dial indicator is normally powered by batteries and manually switched. Moreover, an internal special adaptation was done for enabling its power on/off as it would be normally done by pressing its particular button, each time the system is on/off.

Two modes for user interactivity have been implemented on the user friendly interface. In the manual mode, the user may impose any load value (within the available nominal range) and will observe, on the user interface at the local PC, the evolution of the applied load, as well as the corresponding strain and deflection values. The image of the loaded beam, from an USB webcam, is also available on the upper right corner of the user interface (Fig. 5) in a more expedite way than that of an embedded image on the LabVIEW user interface [28]. The webcam image is brought to the user by using the Macromedia Flash Communication Server. This application captures the image from the USB port and creates a video server that can be linked to a frame in a customized HTML web page.

In the present example, the page includes two additional frames, one for the virtual instrument front panel and the other for a drawing of the system on the right lower corner of the interface, providing the entire experimental setup image in a more clear way.

In the automatic mode (Fig. 6), the system performs an automatically predefined test.

The total load is applied in three increments. After completing the stabilization stage for each load increment, the corresponding force, strain, and deflection values are digitally recorded and the deformed cantilever shape is graphically presented. Moreover, a real-time video of the loaded beam is available on the upper right corner of the user interface and, on the bottom right, is presented the setup diagram.

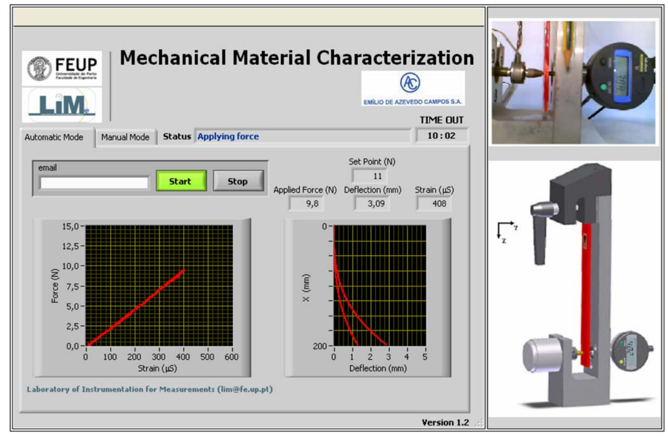

Fig. 6. User interface: automatic mode.

Fig. 7. Confirmation of the sent e-mail.

Test Results: Cantilever beam		
Date: Thursday, March 13, 2006		
Time: 21:25		
Load (N)	Strain (µS)	Deflection (mm)
4,02	162	1,25
8,9	375	2,91
13,8	592	4,59

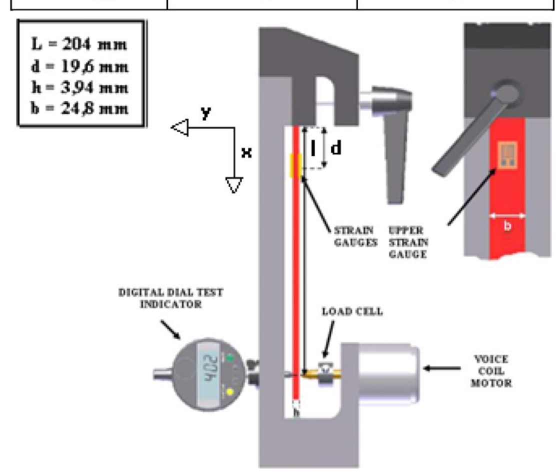

Fig. 8. Data available on the sent e-mail (experimental values and relevant geometry characteristics of the setup).

On the user interface, an e-mail address should be introduced for later automatic delivery of the recorded data file, notified on the interface *Status* at the end of the test (Fig. 7).

The user receives, by e-mail, the test results in a data file as well as information of the geometric parameters, as shown in Fig. 8.

The student should process the data and produce the graphical presentation of strain and stress, which will give the Young's

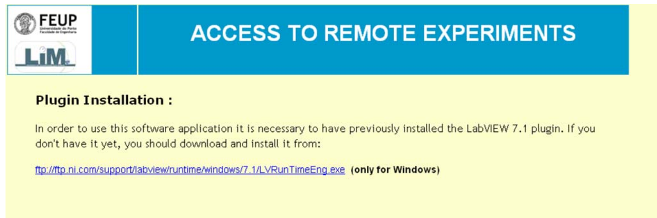

Fig. 9. Plug-in requirements.

modulus. If the student uses (3) for determining the deflection profile of the cantilever beam, along the x-direction, he/she will get graphical presentations as the ones visualized on the right-hand side graphic of the user interface (Fig. 6). In addition, the experimental results for the measured deflection at the load application point $(x = l)$ should be similar to the ones determined by the student.

The present setup has been designed for allowing easy beam substitution. Instrumented beams of different materials may be sequentially made available along the course semester for providing a more extended material characterization.

Another feature for teaching–learning objectives is achieved with a moderate hardware investment by including a second modular half Wheatstone bridge transmitter (PRelectronics 2261), using a beam instrumented with two strain gauges bonded at 90° to each other and adding a few facilities to the developed application. This additional hardware will make the system capable of providing not only data for the determination of Young's modulus but also for determining the Poisson ratio.

In fact, if the beam is instrumented with two strain gauges, one longitudinal and other transversal, the Poisson ratio will be available from the data of both strain gauges [(4)], and for Young's modulus determination, it will be used data from longitudinal one [(1)].

$$\varepsilon_z = -\upsilon \cdot \varepsilon_x. \tag{4}$$

Finally, the uncertainty associated to the experimental determination of Poisson ratio and Young's modulus may also be determined if the e-mail also includes the maximum admissible error of the equipment used for the beam dimensional measurements, the calibration data of the bridge transmitter and of miniaturized load cell, and the manufacturing data from strain gauges and from data acquisition cards. This type of training is of huge importance on measuring activities [24].

This remote experiment is available at the address http://remotelab.fe.up.pt/.

In the upper section of the web page is presented, following the laboratory identification, the information on the plug-ins recommended for accessing the set of "Remote Experiments" (Fig. 9).

The six remote experiments offered by this remote laboratory are accessed through the web page shown in Fig. 10.

When several users are trying to access the same experiment, only the first one will get control. The others will be warned that another user has gained control of the experiment. To deal more adequately with the situation, a booking system has been developed [29] (Fig. 11), as an extension of the Moodle platform.

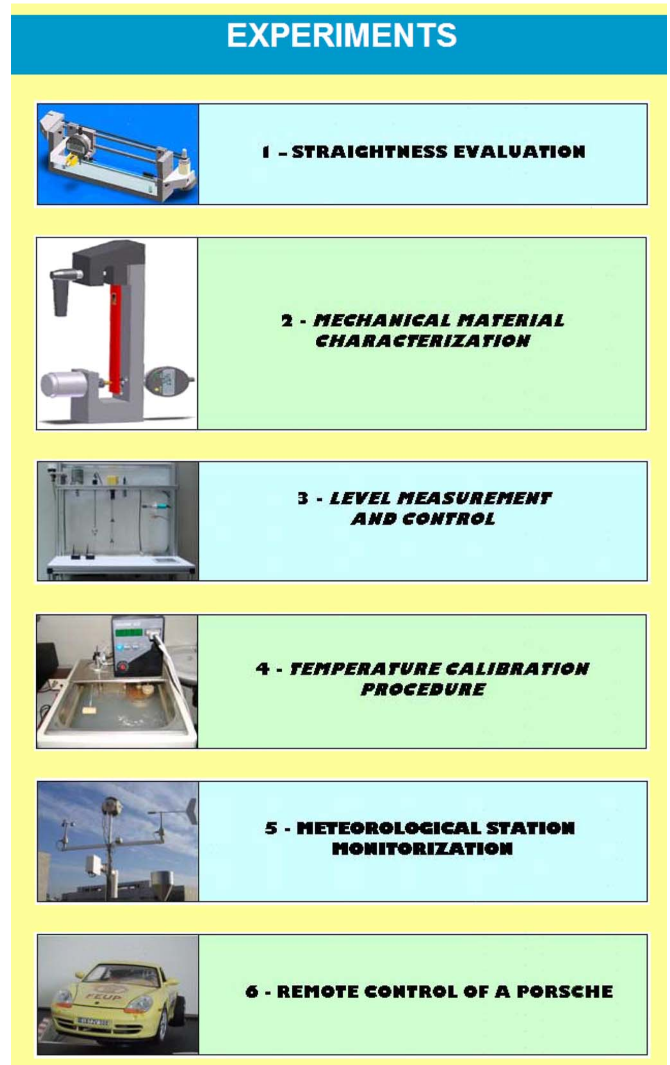

Fig. 10. Some of the available experiments.

At the moment, it provides 1-h time slots. If the user does not arrive within a predefined tolerance period, the Moodle extension will free the previously reserved time slot.

The use of Moodle brings additional advantages for storing tutorials on the subjects, as a short "Experiment Description," the "How to use the experiment," the access to the "Remote Experiment," and an "Evaluation topics" through the booking application (Fig. 12).

On the evaluation topics level, the user is asked to post answers to a few questions correlated with the experiment. These answers are used as a short final report later assessed by one of the teachers team.

VI. Remote Laboratory Evaluation

The pedagogical value of the online laboratories in engineering courses has been worked out by staff from the Schools of Education and Engineering. At the end of the course, a survey has been posted to the students in order to evaluate the impact

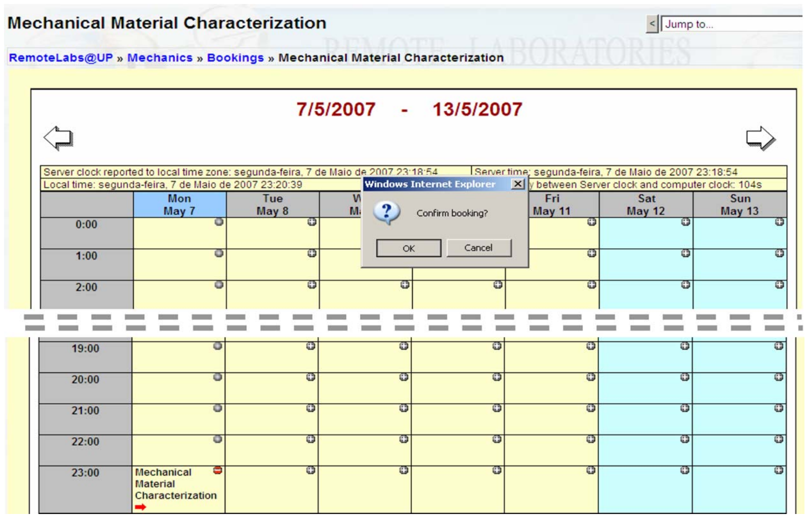

Fig. 11. Booking system user interface.

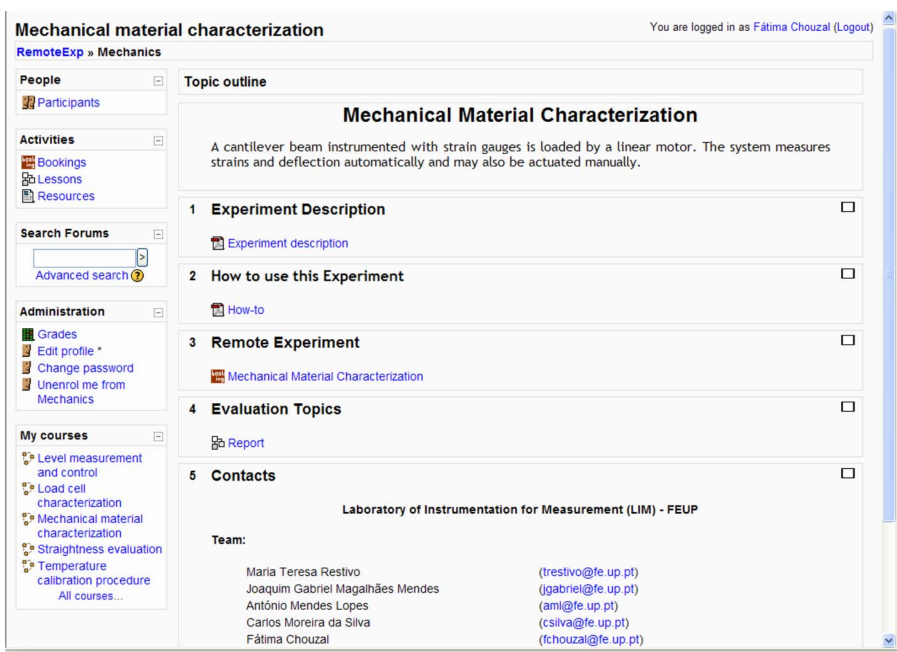

Fig. 12. Tutorials, experiment, evaluation topics, and contacts: all stored in the Moodle platform.

of the use of the remote laboratories. A questionnaire has been worked in a student sample of 63.

For each question, the student should select the adequate grade from very bad (grade 1) to excellent (grade 7). At the present time, it is possible to include some results based on the mean value grade for a set of selected questions (Table I). Some open student comments are also presented.

VII. Conclusion

The *Mechanical Material Characterization* remote experiment is integrated in the Moodle e-learning platform as well as a short description of the experiment and a guide tutorial in "How to use." A booking utility permits to book in advance the experiment and manages remote access.

All the remote experiments under development at the Lab fit within a blended learning context.

The system described in this paper proved to be of significant value for student training either before or after the laboratory session on mechanical material characterization. In the first situation, it permits us to prepare the hands-on activity observing the cantilever beam behavior, the measured strain level for loads imposed to a certain beam geometry, and the corresponding deflections. After the laboratory session, it offers the opportunity of reviewing all the above aspects using a system similar to the one mounted during the laboratory session, but with more sophisticated equipments.

Many works have been reported on the last decade and recently [3], [10], [12], [18], [20], [22], [25], [27], [30]–[32], but not much attention has been paid to the analysis and evolution of the remote and virtual experiences as teaching-learning tools for improving student performance [18], [33]. At present, the authors are involved in a project specially aiming the evaluation of "Labs-on-the-web" issues, which will bring

TABLE I
STUDENTS QUESTIONNAIRE RESULTS

Question	Mean value
Acquisition of new knowledge / concepts	5,51
Deeper learning of previous knowledge	5,56
Contribution for learning autonomy	5,43
E-learning contribution for better learning quality	5,68
Development of professional skills	5,10
Global evaluation of the remote experiments	5,25
Some relevant student open comments	
A more attractive way of delivering knowledge;	
A method that motivates a deeper learning;	
A useful resource to the learning subjects;	
An experimental component for the learning process;	
New opportunities for learning the subjects;	
A contribute for better mental perception of the subjects;	
New useful knowledge sources;	
Flexible temporal and spatial tools;	
Opportunity for using new technologies;	
The reduced interaction between the user and all the equipment can be not so impressive. But, the possibility of accessing the experiments from anywhere, anytime, is a big step!	

more advanced conclusions about systems flexibility, design, accessibility, and pedagogical relevance by using appropriate evaluation instruments.

A new project has been started, looking for a new version of the system. A haptic device will be used for actuating the system in order to increase the realism of the remote experiment [34] and its usability by people with special needs.

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