Experimenting through the Web a Linear Variable Differential Transformer

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Abstract—**Aiming for teaching/learning support in sciences and engineering areas, the Remote Experimentation concept (an E-learning subset) has grown in last years with the development of several infrastructures that enable doing practical experiments from anywhere and anytime, using a simple PC connected to the Internet. Nevertheless, given its valuable contribution to the teaching/learning process, the development of more infrastructures should continue, in order to make available more solutions able to improve courseware contents and motivate students for learning. The work presented in this paper contributes for that purpose, in the specific area of industrial automation. After a brief introduction to the Remote Experimentation concept, we describe a remote accessible lab infrastructure that enables users to conduct real experiments with an important and widely used transducer in industrial automation, named Linear Variable Differential Transformer.**

Index Terms—**Remote Experimentation, Distance Learning, Remote Lab, LVDT.**

I. INTRODUCTION

The increasing demand for culture and knowledge, imposed by the society, alerted the educational community for the need to design creative ways to motivate and facilitate people for the learning/teaching process. Personal Computers (PCs) and the Internet have been playing an important role in this topic, by promoting the deliver of pedagogical contents, like documents, demonstrations, images and others, to all, independently of their social conditions or geographical restrictions. However, in recent years, these static contents are being complemented with dynamic ones, provided by E-learning environments (Virtual Learning Environments, VLE), which include components that allow students and teachers to interact in the same way as they do in a teaching room. These environments provide multimedia contents, administrative, learning, and assessment management tools, supported by communication platforms that allow interaction among users (e.g. chat rooms, forums, etc.)[1] [1].

Spite the fact E-learning is already a reality in our society, the pedagogical contents are being continuously expanded in engineering and sciences areas, where requirements suggest to follow the common rule that it is better to 'learn by doing'. Some experts argue simulations could fulfill this requirement. However, these can hardly contemplate unpredictable situations encountered when there is an interaction with real experiments. Besides, there are many specific and complex tasks impossible or very difficult to replicate with software simulation tools where, in such cases, it is less expensive to place the all experiment online (through the Web) in opposition to develop a simulation model, from the scratch. Therefore, in situations where simulations can not fulfill the specific requirements of a real experiment, or when cost figures suggest providing access to real equipment rather than simulating it, the 'learn by doing' rule should be satisfied by the Remote Experimentation (RE) concept, as suggested by several past and ongoing projects (e.g. PEARL [2], MARVEL [3], RExNet [4], PROLEARN [5]). Notice however that simulations still play a fundamental role in situations where the cost of implementing a remote experiment is high or when replication is needed. Another aspect is when the experiment includes the use of critical equipment that can be damaged by an erroneous use. In such scenarios, simulating the experiment in a first phase allows the user to acquire the necessary skills that will then allow him/her to control the remote equipment in a safer way. Other scenarios include the combined use of real equipment with simulation models, in a technique named as mixed-reality [6].

RE aims to supply real experiments able to be accessed and controlled from anywhere, by anyone, and at anytime, using a simple PC connected to the Internet [7]. In a general perspective, several aspects have been studied to identify the benefits of RE to education & training, as illustrated by figure 1.
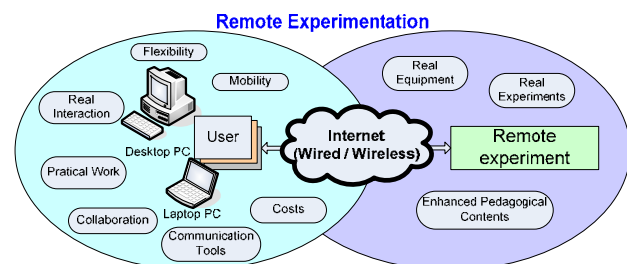

Figure 1. Remote Experimentation scenario

In an educational perspective, RE is considered to be a complement and not a substitute of a lab session since not all tasks can be done remotely (e.g. it is not feasible to remotely mount an electronic circuit, which impairs students from acquiring the required ability to handle electronic components and assembling them) [8]. Moreover, mobility and flexibility provided to students and teachers in their tasks are improved, since a remote

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[1] Moodle is an example of a freeware VLE, available at
http://moodle.org/.

lab is available 24 hours per day, during 7 days a week allowing them to access it, from their home, from the school or from any other place. The potential benefits to certain courses, given the diminishing time for presential lectures defended by the Bologna agreement (applicable to the European Higher Education Area) [9], are obvious, as remote experiments allow the incorporation of practical subjects without physical and time restrictions. Using a remote experiment to support those lectures will deeply enhance the students' understanding, since it facilitates practicing the learned theoretical subjects. In addition, the use of synchronous communication tools (e.g. videoconference) to support remote experiments can overcome possible social isolation problems (due to the excessive use of PCs) and, at the same time, promote a wide collaboration among different people (e.g. experts previously unknown to each other). Collaboration among teachers will also be increased, since each one may share his/her knowledge, contributing also, for better courseware contents. Equipment costs and the lack of places to accommodate laboratories (a reality in some institutions) are overcome with RE, since it is possible to deliver a lab session with small requirements of both space and equipment. Moreover, RE presents some advantages for people with special needs: i) doing a real experiment does not require moving to the lab, and ii) the access to RE interfaces may be done through applications specially designed for people with special needs (e.g. people with vision or hearing impairments).

But RE is not confined to a school perspective, because remotely controlling any infrastructure is also a very interesting solution for companies, where workers are casual students that require rapid explanations in specific work situations (e.g. a worker is mounting an equipment and is not certain about its behavior - then, remotely testing that equipment could help him/her accomplishing his/her task). In this situation, the use of a remote experiment may contribute to reduce mistakes, time and costs. Like in a school perspective, RE also contributes to companies, since globalization demands training workers for knowledge update. This situation, together with less available time, places RE as a valuable choice to give practical support for specific subjects, allowing practical training, anytime, from anywhere.

Even with several remote experiments already available, the RE concept should be further explored in next years, by developing more applications that can benefit the educational & training community, in several subjects. Therefore, this paper presents another contribution in the electronic instrumentation area, namely a remote experiment focusing on an electronic transducer named Linear Variable Differential Transformer (LVDT). The following section starts with a brief presentation of the LVDT transducer, explaining the basic functional principals and its importance in industrial automation. Section 3 focuses on the remote experiment, presenting the entire developed remote infrastructure, subdivided in its physical and logical modules. Before concluding the paper, the remote experiment with the LVDT is contextualized in a particular course lectured at the Polytechnic Institute of Porto - School of Engineering - (ISEP).

II. LEARNING GOAL: HOW DOES AN LVDT WORK?

Many electronic applications present in our everyday life would not be functional without transducers, namely without their ability to measure physical quantities. Transducers are used in automation for the process and manufacturing industry, including: robotics, experimental engineering, cars, agriculture, medical equipment and others. There are several transducers in the market, with a different operating mode and characteristics. Teaching a particular transducer should not be limited to the theory, because there are so many characteristics that influence their operating mode, some of them impossible to preview and/or very difficult to analyze. Thus, simulation models do not guarantee a good understanding, being fundamental to verify its aspects in a lab environment.

Being one of the most interesting transducers available to measure displacements in several industrial applications (e.g. in the active suspension systems of cars, in civil engineering by the dynamic measurement of fatigue in large structural components used in suspension bridges, and others), the LVDT was a natural choice to be implemented in the remote infrastructure. To the best of our knowledge there is currently no remote experiment available with an LVDT, although one may find several others based on temperature transducers [10].

The LVDT operating mode is based on the variation of the mutual inductance between a primary winding and each one of two secondary windings when a ferromagnetic core moves inside it. When the primary winding is supplied by a sinusoidal waveform (with specific amplitude and frequency), the voltages induced in each secondary windings are also sinusoidal waveforms and equal, when the core is in its central position. When the core moves, one of the two secondary winding voltages increases and the other decreases by the same amount. This analysis requires a signal conditioning circuit to transform those sinusoidal waveforms into a continuous one, representing the core displacement. Figure 2 presents a general circuit diagram that allows using the LVDT in any industrial application.
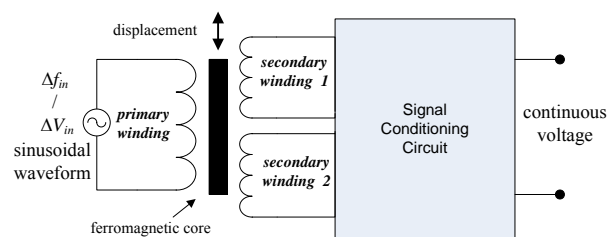

Figure 2. LVDT circuit diagram

The LVDT importance in industrial automation is justified by some of its characteristics, namely:

- theoretical infinite resolution;
- almost unlimited lifetime and high reliability, justified by a negligible friction between the core and the windings;
- electrical isolation between primary and secondary windings that facilitates electronic circuit design;
- high repeatability, sensitivity and linearity;
- easy detection of the core directional displacements;
- and a broad dynamic response.

However, teaching about the LVDT operating mode can not be limited to an analytical functional analysis because of its random aspects, such as: i) a variation in the frequency promotes changes in the sensitivity; ii) the load (placed in the secondary windings) influences the output; iii) temperature interference, and others.

Based on those characteristics, practical experimentation is very important for understanding the LVDT's operating mode. Considering all the previous aspects, we decided to implement the remote infrastructure described in the next section, which allows remotely controlling an LVDT and exploring its features and its operating mode.

III. THE REMOTE INFRASTRUCTURE

Providing remote access to the LVDT started with the specification and later implementation of a lab infrastructure able to be controlled through a PC connected to the Internet. This infrastructure was designed in accordance to the results provided by an analysis of the LVDT's functionality, which indicated the use of an independent Signal Conditioning Circuit (SCC)[2]. With this approach, the SCC was implemented in a Printed Circuit Board (PCB) able to be remotely reconfigured and monitored in some specific points, allowing a deeper user interaction.

As a primary requirement, we identified the ability to control the LVDT's core displacement. All those displacements are monitored by a WebCam, which allows seeing if user's action causes any impact in the remote infrastructure. The SCC/PCB was designed with several light indicators monitored by a second WebCam. All these solutions, which will be further analyzed in the next subsections, were implemented focusing an approach to a real lab, given the user ability to reconfigure and test different points of the circuit and, at the same time, see what he/she is really doing. Since lab work is usually done in teams, the infrastructure also includes a videoconference tool, allowing real-time interaction among users. All the referred functionalities were implemented in the remote infrastructure depicted in the block diagram of figure 3, which illustrates its physical and logical modules.
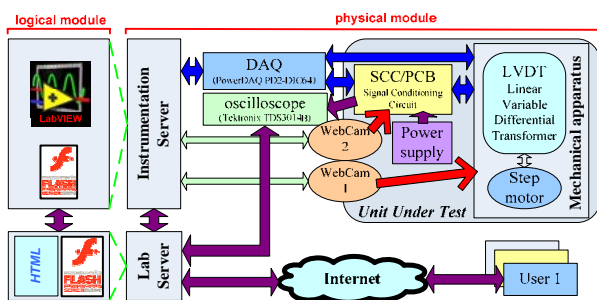

Figure 3. Block diagram of the implemented infrastructure

A. Physical module

The physical module contains the Unit Under Test (UUT), the two WebCams, a Data Acquisition Board (DAQ) [11], and a four channel oscilloscope [12] to

visualize the signals present at the SCC/PCB and two Servers (the Lab Server and the Instrumentation Server). The DAQ and the oscilloscope provide the interface between the UUT and the servers that make available the experiment to remote users. The UUT contains the mechanical apparatus, which includes the LVDT [13] and a step motor that controls the LVDT's core displacement, and the SCC/PCB used to handle the voltages received from the second windings, plus an external power supply. For monitor purposes, we used two WebCams: the first directed to the mechanical apparatus, allowing to observe the displacements of the LVDT's core (with a resolution of one millimeter provided by a ruler) and the second directed to the light indicators that provide visual feedback on users' actions performed on the SCC/PCB.

According to figure 4, the SCC/PCB has two parts: part 1 consists in a wave generator plus switch 1; part 2 has two switches (2 and 3) and two half-wave rectifiers used to transform sinusoidal waveforms (received from the windings) into one continuous voltage, which level represents the displacement made by the LVDT's core.
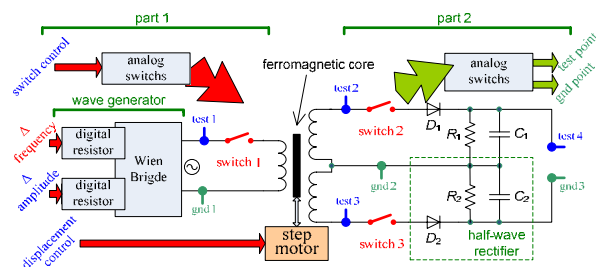

Figure 4. Block diagram of the UUT used in the remote infrastructure

A Wien Bridge generates a sinusoidal waveform with amplitude and frequency able to be remotely modified by changing the value of two variable digital resistors [14]. By remotely turning ON switch 1, this wave generator connects to the primary winding of the LVDT. The user may also measure the sinusoidal waveform using one oscilloscope channel connected between point test 1 and reference gnd 1, both available at the SCC/PCB.

The two secondary windings are connected to two half-wave rectifiers, each one composed by a diode, a resistor and a capacitor ($D_{1,2}$, $R_{1,2}$ and $C_{1,2}$), which give to the user the ability to change the output signal by turning ON/OFF switch 2 and switch 3. In order to deeply understand the signals present at the SCC/PCB, two more points (test 2 and test 3) and a reference (gnd 2), allow measuring the signal before rectification. After the half-wave rectifiers, the user can measure the rectified signal between point test 4 and reference gnd 3, which is an either positive or negative continuous signal representing the physical displacement made by the ferromagnetic core of the LVDT. To measure the signals in the referred points of the circuit with another instrument (e.g. a multimeter), we decided to make available another two points: a common test point and a common reference gnd. These points can be switched to the available test points (test 1, test 2, test 3 or test 4) and to the available references (gnd 1, gnd 2 or gnd 3), as illustrated in the schematic of figure 5.

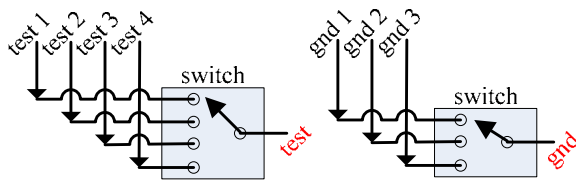[2] There are several circuits comprising both the LVDT and the SCC.

Figure 5. Switches configuration of the SCC/PCB for using another measuring instrument

Since remotely controlling any infrastructure promotes delays and, thus, some uncertainty about if some action was really accomplished, we placed a set of light indicators, at the SCC/PCB, that are monitored through WebCam 2. Figure 6 displays an image of the remote infrastructure emphasizing the ruler placed near by the LVDT (indicates core's displacements) and the SCC/PCB with the set of light indicators. Each light indicator, when ON, represents a specific configuration, made remotely, namely (described from left to right):

- <u>three yellow lights:</u> indicate the selected reference point (see figure 5);
- <u>four green lights:</u> indicate the selected point (test 1, test 2, test 3 or test 4) connected to the common test point (see figure 5);
- <u>two red lights:</u> indicate if there is a signal at the primary or at the second windings;
- <u>three other green lights:</u> indicate which switches are ON.

Figure 6 also presents the four channel oscilloscope connected to the four test points (test 1, test 2, test 3 and test 4) and to a ground reference, a multimeter connected between the test and gnd common points[3] , and the DAQ screw terminal panel with 64 I/O ports, some of them used to control/monitor signals sent/received to/from the UUT (switches, light indicators, and the step motor used to displace the LVDT's core).
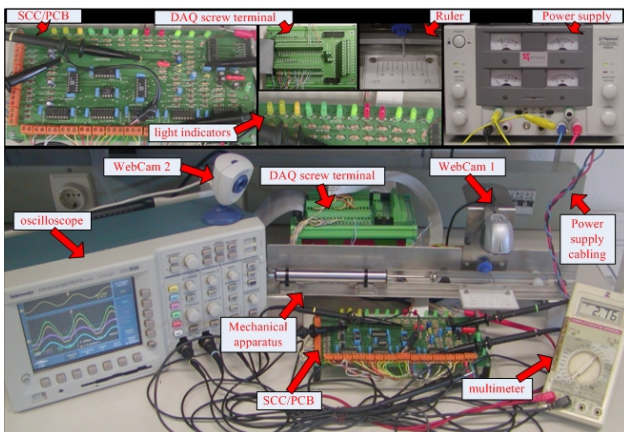

Figure 6. General view of the remote infrastructure

Besides processing all the control and monitor actions made at the remote infrastructure, the Instrumentation Server, located near by the UUT, has also the responsibility to control the two WebCams that facilitate

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[3] Although presented in the infrastructure, the multimeter interface is not available yet.

the observation of the remote experiment. Due to network organization and for distributing the processing power among the servers, the handling of remote accesses was directed to a web server (the Lab Server) that is directly connected to the Instrumentation Server through a private Ethernet connection.

All the referred control and monitor processes are handled by a software layer. Thus, the next subsection gives a detailed explanation of the used software, and the underlying architecture together with the remote interfaces presented to users for remotely controlling/monitoring the lab infrastructure.

B. Logical module

The software layer controls and monitors the implemented infrastructure while also providing the interface access to remote users. To implement a communication channel that allows a real-time interaction among users during lab experiments, we customized a videoconference tool. This tool aims to replicate a similar environment encountered in a real lab, given users the ability to interact like they do during a real experiment (chatting, talking and seeing each other) [15]. The oscilloscope required no user interface development, since it has already a web interface supplied by the manufacturer. Figure 7 presents the positioning of the several components that form the interface to the remote lab, namely in the top left is the videoconference, in the top right is the oscilloscope, in the bottom left is the LVDT and in the bottom right are the two WebCams' images.
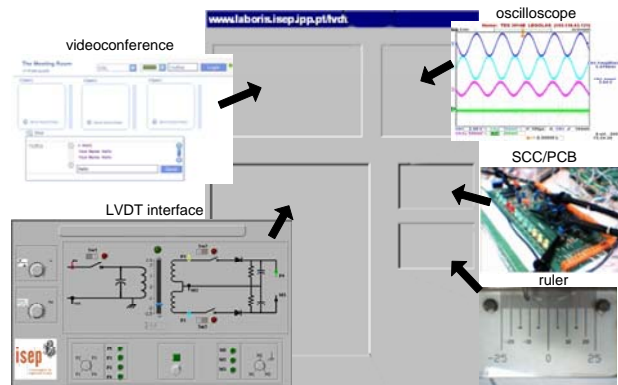

Figure 7. Web interface used to remotely control/observe the infrastructure

LabVIEW was the adopted programming language [16] for developing the LVDT's interface, since it follows a client-server architecture and is characterized by its simplicity for software development. This language is very easy to understand and allows implementing powerful software programs, together with remote interfaces able to be accessed through a web browser. It follows a thin client approach, which avoids previous software installations in the clients' PC to control the remote infrastructure (a plug-in needed to interpret LabVIEW programs [17] will be automatically installed at the first access). Although the user has to download the interface in each access to the infrastructure, the thin client approach always guaranties the most recent interface, avoiding users to care about new versions. Figure 8 illustrates a more detailed image of the LVDT's interface presented to remote users.
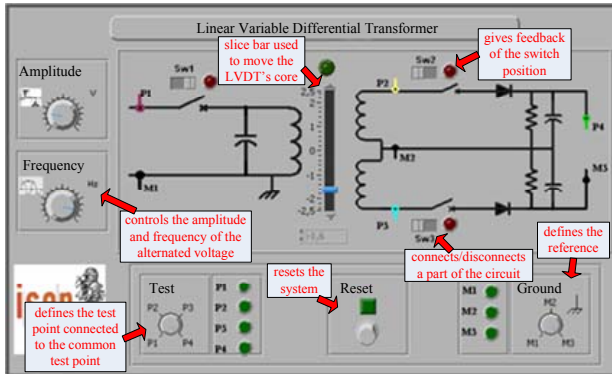
Figure 8. The remote interface used to control and monitor the UUT

A server application, installed in the Instrumentation Server, receives the users' remote connections and supplies/updates the illustrated interface, accessible through any Web browser (e.g. Internet Explorer). It allows users to control the amplitude and the frequency of the sinusoidal wave (generated by the Wien Bridge) that feeds the LVDT's primary winding, by changing the value of two knob buttons placed at the left[4] of the interface. The center of the interface presents the main circuit implemented in the SCC that allows controlling the three switches (sw1, sw2 and sw3) for connecting or disconnecting some parts of the circuit. Next to each button, is presented a light indicator that gives a real feedback of the SCC's switch conditions. Between the windings that represent the LVDT, there is a slice bar that allows users to change the position of its core, between +25 millimeters and -25 millimeters related to a central position. All these changes are monitored by WebCam 1. The test and reference points are also presented in the interface, and allow users' control using two knob buttons placed at the bottom of the interface. Selecting a specific option (M1, M2 or M3) implements a reference point for all the measurements made in the circuit. The test points (P1, P2, P3 and P4) will define the place where another instrument will be connected to the SCC[5] . There are light indicators next to each button that display the choice made by the user. Finally, and when the user detects any incoherence between the displacement made in the slice bar of the interface and the real displacement remotely made by the LVDT's core (by monitoring WebCam 2), he/she has the ability to reset the system by clicking in the reset button located at bottom center of the interface, which will place the LVDT's core in its central position (0 centimeters). This interface and the LabVIEW software were installed in the Instrumentation Server. All the remote users requests directed to the Lab Server, are redirected to the Instrumentation Server in a specific address, since LabVIEW integrates a Web server.

The videoconference tool also followed a client-server architecture supported by the software package named Flash Communication Server, which allows creating media streaming applications [18]. Together with this software we used the Macromedia Flash [19] to develop the interfaces for the videoconference tool and for the two WebCams that monitor the UUT. For distributing the

computing processing tasks, the Flash Communication Server was installed in both servers. In the Lab Server it was installed a software module that receives remote clients connections that intend to use the videoconference. In the Instrumentation Server were installed two applications that allow connecting the WebCams that monitor the UUT. The video captured on those WebCams is transferred back to the Flash Communication Server, located in the Lab Server that broadcasts the video images to all clients connected to the infrastructure. Since the Flash Communication Server requires high data rates for video broadcast (order of Mbytes per second), sometimes it is difficult to guarantee a good Quality-of-Service (QoS) in some networks. Therefore, we give to the user the ability to choose one of three possible interface's configurations based in his/her available bandwidth:

- Minimum: the user has access to the LVDT and oscilloscope interfaces (it requires a lower bandwidth);
- Medium: minimum configuration plus the image of the SCC/PCB given by WebCam 1 (it requires more bandwidth);
- High: the user has access to all the interfaces, namely LVDT, oscilloscope, Webcam 1 and Webcam 2, plus the videoconference (it requires an even higher bandwidth).

With this set of possibilities the user can control/monitor a remote lab with, almost, the same features encountered in a real lab, allowing a real-time interaction with an LVDT. However, to ascertain the usefulness of the implemented remote experiment it is necessary to test it in a real learning/teaching scenario.

IV. CONTEXTUALIZING THE LVDT'S EXPERIMENT

Our experiment intends to be a valuable choice to support the practical work required to teach the LVDT transducer in a specific lecture within a course named Instrumentation & Measurements (IM) of the Electrical and Computers Engineering degree offered at the Polytechnic Institute of Porto - School of Engineering (ISEP). Due to its importance in many areas of industrial automation (as referred in section 2), the LVDT should be well studied by experimenting it in a lab scenario. However, the available time to explore its features in a single IM lecture is very short, and allocating more lectures to its study would compromise the presentation/experimentation of other equally relevant transducers. Even with the practical support given to experiment the LVDT transducer, we have concluded that the available time is not enough for students to master this transducer or even acquiring an in-depth knowledge of it, which requires increasing the number of practical sessions. Moreover, the academic rules (that limit the number of teaching hours) together with the lack of places and teachers to accommodate/support the experiment and the previously referred compromise (lecturing time per transducer), makes that solution impracticable. Then, an alternative RE solution, like the one described, can overcome many of the problems pointed out, since it allows students to experiment the LVDT transducer without physical and time constraints.

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[4] Physically, these buttons change the value of the digital resistors referred in the previous section.

[5] Note that the SCC/PCB has already available four test points to connect the four oscilloscope channels.

To support the usage of the remote experiment we developed the Web site illustrated in figure 9, available from [20]. Developed with the Macromedia Flash, the Web site gives several useful links to support the execution of the remote experiment. It supplies general information about LVDTs transducers with videos and images, together with detailed technical information about the specific LVDT used in our remote infrastructure. Also available is a detailed technical report about the development of the presented remote infrastructure (in Portuguese), and an interface that allows users to choose one of the three possible interface configurations for controlling/monitoring the remote lab, as described at the end of the subsection 3.2 (Minimum, Medium and High). In attention to first time users, it is also available a video exemplifying all the actions made remotely to control/monitor the infrastructure, which facilitates their initial actions. Besides a general information about the Web site (date, authors, etc.), it is also available a lab guide (in Portuguese), divided in several topics, that helps users to run an experiment for learning the operation mode of both the LVDT and the SCC.
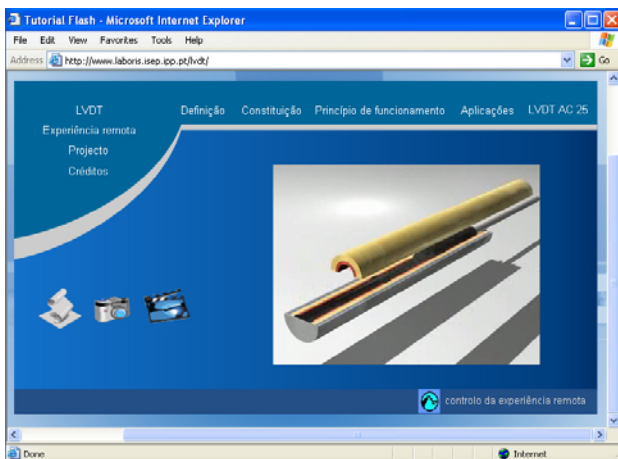

Figure 9: Web site developed to access the remote experiment

The remote experiment feasibility in an IM lecture context will be evaluated in future trials. Supported by the lab guide, students will run the LVDT's experiment in a real teaching scenario where we expect to gather results that may indicate future improvements in the remote infrastructure.

V.   CONCLUSION

The tendency to include the Remote Experimentation concept in the teaching/learning process in school and industry is still growing. The features supplied by RE brings it as an important complement to real labs since it provides a real-time remote interaction with real experiments together with communication tools that enable communications among users during an experiment, anytime from anywhere, reducing costs and increasing flexibility.

Based on several advantages brought by RE, this paper has described another remote infrastructure that allows a real-time interaction with an important transducer in the industrial automation area, named LVDT. The implemented infrastructure gives users the ability to interact with an LVDT, together with a Signal Conditioning Circuit, using a PC connected to the Internet. The adoption of a synchronous communication tool (videoconference) and a visual feedback of the remote experiment through WebCams, reduces the perceptual distance to presential learning scenarios, which, for sure, will encourage people to use the remote lab.

In the future, some minor improvements can be made to the remote infrastructure, namely: i) translate all the information of the Web site to English; ii) use a VLE to support the remote experiment; and iii) develop a more user-friendly interface for the oscilloscope, together with an interface for the multimeter. In addition to the previously referred improvements, future trial sessions will be run next semester in the context of the Instrumentation & Measurement course for undergraduate students, which may contribute for other future improvements in the remote infrastructure.

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