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A REMOTE ACCESS HAPTIC EXPERIMENT FOR MECHANICAL MATERIAL CHARACTERIZATION

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Abstract: Experimental laboratories are important educational and training resources. They offer hands-on activity which helps to grasp concepts and compensates from volatile and abstract forms of knowledge.
On-line laboratories have been developed during the last decade all over the world for supporting e-learning on the experimental field. Experiments have been either based on computer simulations of real experiments, or developed using software and hardware for user remote access to real experimental set-ups.
This work describes how to couple together haptic devices for remote interaction on an experimental set-up dedicated to test material mechanical characteristics.

Keywords: human-machine interface, force control, human perception, interaction mechanisms, sensors, control education, laboratory education.

1. INTRODUCTION

Virtual reality (VR) and the systems using its techniques have a very recent history and so are its applications as well as its social benefits. VR provides a 3D environment to the users for complete exploration and interaction as if they were really immersed in them. To this end VR systems use specific devices to stimulate the users senses, as vision, hearing and touch (Netto et al., 2003). Stereoscopic visualization is one of the most common features found in VR systems due to the relevance of vision on the general human cognitive process (Ackerman, 2002). On the other hand, the use of haptic devices could increase the user involvement and immersion level (Dargahi and Najarian, 2005). However, the use of haptic devices is not yet very popular in remote experimentation for educational purposes in engineering areas.

At present three types of laboratories may be considered: hands-on, virtual (simulated) and remote (Benetazzo, 2000; Corter et al., 2004; Ma and Nickerson, 2006). In the first, students practice hands-on in a collaborative way; they interact with the equipment and with each other. A virtual laboratory does not exist physically; the students perform their experiments by interacting with a virtual system created by a software application running on a computer. The produced environment where the components are manipulated may be of 2D or 3D type. In a virtual laboratory the students interact, in group or individually, with the virtual experiment. Finally, in a remote laboratory the students interact remotely, in group or individually, with the real equipment. In a remote experiment they cannot touch the experiment and, sometimes, they may not even interact between them (if the remote access is performed individually). If live video is available they will be able to observe the experiment. The interaction between the users and on-line laboratories comes under one of three forms:

a) real to virtual – real devices are used to modify virtual environments; in this case the user does not actuate a real object, but experiments himself the effect of his commands on the object;
b) virtual to real – the user interacts with a real equipment through a user interface in a computer;
c) real to real – the user manipulates real devices and his actions are transmitted to the real equipment remotely available.

The experiment described in Restivo et al. (2006a) is an example of virtual to real communication. A client interacts with a user friendly interface in a computer, and his actions are transmitted through the internet as digital information for controlling remote equipment. The results are visualized by the user, through data and live video imaging displayed on the graphical user interface.

Many discussions have taken place on the use of the three types of labs listed above for the learning/teaching process. According to Ma and Nickerson (2006), the evaluation of their effectiveness has been weakly explored. Other authors claim the same level of effectiveness for the use of those three types of labs (Corter et al., 2004). In the authors opinion the suitable approach, if possible, is based on a blended learning system.

It is recognized that the use of force and tactile feedback improves the effectiveness and safety of certain tasks. In telemedicine, for example, it is known to improve the physician actions. This technology may also be used in physician training (Dargahi and Najarian, 2005; Moraes e Machado, 2008). However, its use has not been so far significant in the science or engineering training field.

This work describes how coupling together the use of a haptic device for remotely actuating an experimental set-up dedicated to test material mechanical characteristics, improves the learning process through a more realistic interaction.

2. HAPTIC SYSTEMS

The cognitive mechanism used by the human being to explore and identify the world, its components and objects is extremely complex. For example, the sense of touch is used to identify the object shapes, their density and texture. The gathering of information of an object or part of it is mentally developed by combining touch and kinesthetic data related with the spatial and time distribution of the sensed forces.

A haptic device is a human/machine interface able to stimulate the user sense of touch. It may be used to interact with either real or virtual environments. In the first case, the haptic device has usually the master role in a master/slave force feedback application (e.g., tele-manipulation or tele-operation). On the second case, the haptic device interacts with a software application (e.g., video-games or simulators). Usually, vision and hearing information are associated to the haptic systems to significantly improve the realism of a simulation (Buttolo, 1997; Robles-De-La-Torre, 2006).

The main difference between a haptic interaction and the interaction using other devices (for example, a mouse) is related to the bidirectional communication present in the first case. This bidirectional communication permits to impose actions to a system and to receive the corresponding reactions using the same physical interface.

The majority of haptic devices transmit sensations to hands and fingers, because they are mainly used in manipulation tasks. Therefore, the mechanical structure of a haptic device is as important as its technical specifications, such as the number of input and output degrees of freedom (dof) and force capability. Those features will define the appropriateness of such a device for a specific application.

3. HAPTIC SYSTEMS FOR REMOTE LABORATORIES

Remote laboratories allow the user to access and interact with real distant systems. The use of haptic devices in remote laboratories seeks to improve the interaction quality. The sensed force resulting from remote interaction with the real objects will improve the mental model elaborated by the user.

Only one user at a time may fully interact with the experiment, as it happens in a traditional real lab. The communication scheme is based on a client-server structure, in which the server is connected to the real equipment and the client is running in the user computer.

The use of haptic systems in a remote laboratory may occur indirectly or directly. In the first case the user changes environment parameters with a local haptic device which induces changes on a remote one that interacts with the remote equipment. This is similar to a typical master/slave force feedback tele-manipulation system. On the second case the user acts on a local haptic device and his actions modify a remote equipment. In this case the remote equipment includes sensors and actuators. The actuators will interpret the data received from the haptic actions and modify accordingly the remote equipment state. The sensors sensorize the remote equipment behaviour and return the corresponding information to the user through the haptic device.

4. REMOTE EXPERIMENT FOR DISTANCE LEARNING

The Laboratory of Instrumentation for Measurement (LIM) is mainly devoted to the hands-on activity of Mechanical Engineering students at the Faculty of Engineering of the University of Porto, Portugal. This laboratory also supports other training activities, at under- and post-graduate level, in various engineering fields as well as several R&D projects. Its main areas of interest are related with sensorization, measurement, systems automation, metrological procedures, virtual instrumentation and employment of ICTs in the classroom involving, for example, the development of remote and virtual laboratory components (Restivo et al., 2007).

The remote and virtual experiments have been used in a blended learning base, for consolidating the conceptual knowledge from theoretical sessions and for enlarging the experimental access to hands-on activities within the lab (Susana et al., 2007).

An example of a remote experiment is shown in figure 1 (Restivo et al., 2006b). A cantilever beam instrumented with resistance strain gauges is loaded by a linear motor. This experiment was 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 the test data results, e-mailed by the application to the user.

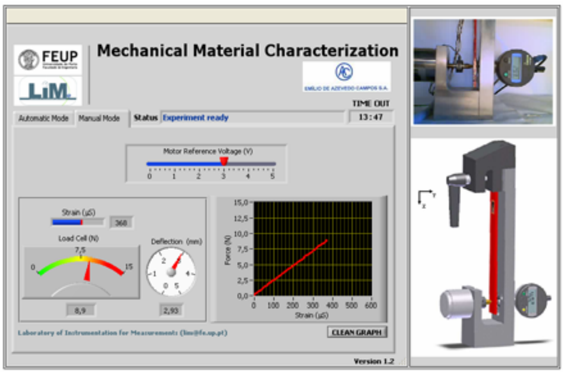

Fig. 1. User interface for remote actuation of a real experiment.

This experiment, as well as others developed at LIM, aim at improving the students knowledge and their soft skills.

Additionally, if more institutions invest on sharing these materials available anywhere, anytime, in an autonomous mode of use, the cost/benefit ratio will increase. Teachers should take a special care for avoiding the development of similar systems. In spite of it new complement development will be welcome.

It is obvious that realism is an important item for the relevance and utility of remote laboratories. The integration of haptic devices with remote laboratories will definitely enhance the realism of the remote experiments and will permit to adapt them as learning tools for users with special needs.

The authors are aware of the current high cost of haptic devices but they believe that further developments will bring new possibilities.

5. INTEGRATION OF HAPTIC SYSTEMS IN ON-LINE EXPERIMENTS

The remote experiment represented in figure 1 has been modified in order to increase the realism of the interaction between the user and the experimental set-up. The free end of the cantilever metal beam is remotely actuated through the user interface. This interface has three main areas: data, live video and the set-up picture. The live video is focused on the most interesting area of the set-up for providing the user with visual observation of his actions. By selecting the manual mode of actuation, the user may apply to the metal beam through the horizontal slider any force level in the available range (input data area). The user gets information on the applied load value, on the strain on the area sensorized with electrical strain gauges and on the deflection value at the point where the force is applied by the linear motor (output data); he also gets the graphical evolution of force versus strain.

As in a traditional lab only one user may actuate the experiment. But if the experiment is remotely executed by a student group, the results may be discussed by the group elements.

The step ahead for this specific application is focused on improving the realism of the interaction by offering to the user a deeper exploration of the experiment, leading to a better mental model construction. The interface must therefore provide:

a) intuitive interaction;
b) detailed exploration;
c) visualization.

For intuitive interaction the user should apply forces and get their feedback through a haptic device. For detailed exploration he should touch and examine the equipment, complementing the visual information from the live video. The video and graphical data should be used for displaying the information but the user should actuate the experiment only through the haptic device. The real-time force feedback perception is an important challenge for the user haptic device manipulation. Figure 2 presents the simplified diagram of the new proposed experiment. The added and the modified functionalities are represented within the green and red rectangular shapes, respectively.

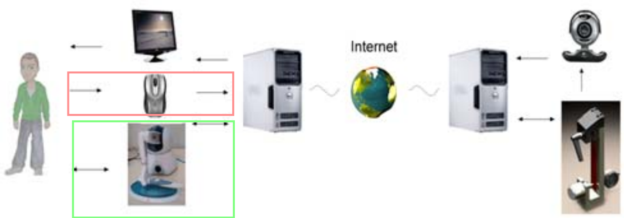

Fig. 2. Diagram of the remote experiment using a haptic device.

6. DEVELOPMENT

The client application running on the user computer was modified. Specific routines for communication with the haptic device were added, and a client input and output data stream was defined. The graphical user interface was redesigned and a 3D virtual model of the real equipment was developed (figure 3). In the server application, changes were also introduced on its design and on the data stream input/output.

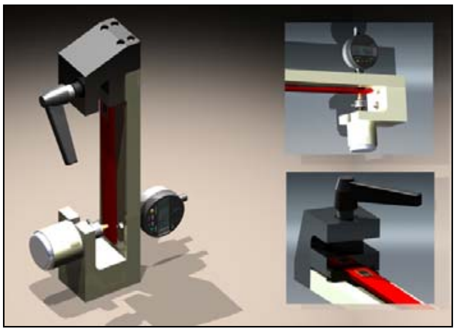

Fig. 3. Virtual 3D model of the real equipment.

As the haptic device used offers three degrees-of-freedom (dof) and the real set-up allows movements with only one dof, the integration of the haptic device in the remote experiment required a mapping from the haptic device workspace to the real set-up workspace (figure 4). The red circle in figure 4 represents the initial actuation point on the real cantilever beam. In the haptic environment this corresponds to having the haptic tip at a point in the x-y plane. If the haptic tip is moved away from the x-y plane the system understands it as if the user is pushing the cantilever beam.
The data streaming between client and server have been transmitted by sockets and they need to be adapted to include the information management of the haptic device. The haptic device produces data at 100 MHz rate, a normal sampling rate for this type of equipment. This created a problem for TCP (transmission control protocol) because sending and receiving data sockets require transmission confirmation.

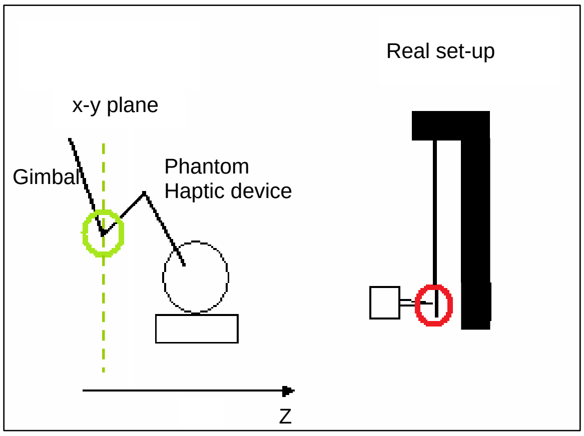

Fig. 4. Mapping from the haptic device workspace to the real set-up workspace.

For minimizing network traffic the position data before contact of the haptic device with the x-y plane was not transmitted. It was found that the information volume generated by the haptic device and sent by TCP protocol was creating significant communication delays compromising the experiment perception.
Another type of protocol had to be used – the UDP protocol (user datagram protocol). This protocol does not associate transmission authentication to the sending and receiving tasks, so the amount of network information could compensate for any possible data loss. A server response corresponding to the measured applied force is produced whenever the client receives a data package of device displacement.
At present the user interface has also been modified by replacing the picture of the equipment by its 3D interactive model, Figure 3. On the data area the same output values are displayed (strain, deflection and force).

6. RESULTS

The application was tested between a Brazilian university and a Portuguese university. The server application was in Portugal and the client one in Brazil. During the tests the mean network communication velocity was 60Kbps. The mean rate of package loss was of 10% and the mean delay between sending and receiving was around 2 s, using a common internet connection. These are mean values from 10 tests. In spite of the measured communication delay, the system exhibited good performance and stable behaviour.
The visual observation showed the delays to be of the order of those observed with the initial application without the haptic device.
Figure 5 presents the graphical window of the application developed in LabVIEW 7.1 software on the server PC. The remaining system hardware communicates through a National Instruments USB card 6009, from with the instrumentation of the real system. This window shows data on the communication process.

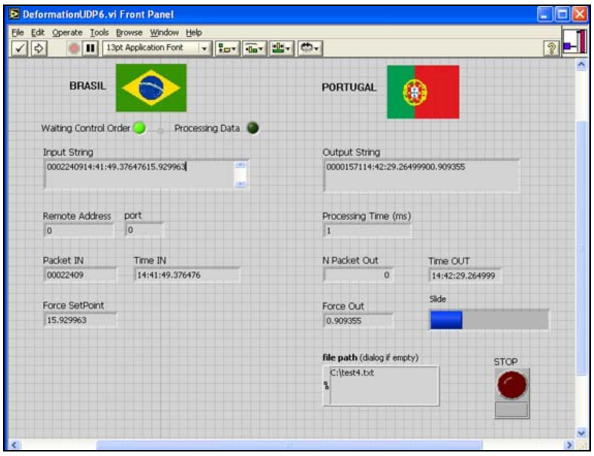

Fig. 5. Communication data user interface.

The new client interface was built using three graphical libraries: an API SDL (Simple DirectMedia Layer), in charge of the environment management, mouse events, keyboard and main panel (where images, information and graphical objects are shown); an API OpenGL (Open Graphics Library), responsible for the graphical processing for virtual representation of the equipment; and the OpenCV (Open Source Computer Vision) library, used for capturing video stream from an IP camera (Axis 210) using an http protocol and for image display within the interface. The integration of the communication application was programmed in C++ using the

OpenHaptics (www.sensable.com) library for integrating the haptic device. The client used a Phantom Omni haptic device.

7. CONCLUSION

In this work were presented results from the conception of a haptic system application developed as a tool for improving the learning/teaching activity in an engineering remote laboratory context. The results will be evaluated for use on distance learning tools.

The use of these systems is particularly important in experiments where the perception of the physical phenomena is important. The communication delays observed did not affect the experiment. The results from this work have reinforced the authors belief in the possibility of distance manipulation with haptic devices.

The haptic device used has 6 degrees of freedom for movement and three degrees of freedom for force-feedback. Common devices such as joysticks have enough functionalities for this type of application.

At present the interface is being expanded to incorporate a three dimensional model of the experimental set-up. Two cameras will be used for stereoscopic visualization and permitting the collaboration of several users exploring the same experiment.

REFERENCES

Ackerman, D. (2002). *A Natural History of the Senses*. Peter Smith Pub Inc.

Benetazzo, L., M. Bertocco, F. Ferraris, A. Ferrero, C. Offelli, M. Parvis and V. Piuri (2000). A Web-based distributed virtual education laboratory. *IEEE Transactions on Instrumention and Measurement*, **49**, pp. 349-356.

Buttolo, P., R. Oboe and B. Hannaford (1997). Architectures for Shared Haptic Virtual Environments, *Computers and Graphics*, **21**, pp. 421-429.

Corter, J. E., J. V. Nickerson, S. K. Esche and C. Chassapis (2004). *Remote versus hands-on labs: A comparative study*. Proc. 34th ASEE/IEEE Frontiers in Education Conference. Savannah, GA.

Dargahi, J. and S. Najarian (2005). Advances in tactile sensors design/manufacturing and its impact on robotics applications – a review. *Industrial Robot: An International Journal*, **32**, pp. 268-281.

Ma, J. and J. V. Nickerson (2006). Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review. *ACM Computing Surveys*, **38**.

Moraes, R. and L. Machado (2008). Fuzzy Bayes Rule for On-Line Training Assessment in Virtual Reality Simulators. *Journal of Multiple-Valued Logic and Soft Computing*, **14**, pp. 325-338.

Netto, A.V., L.S. Machado and M.C.F. Oliveira (2003). *Realidade Virtual – Fundamentos e Aplicações*. Visual Books.

Restivo, M. T., J. Mendes, A.M. Lopes, C.M. Silva, R. Magalhães and M.F. Chouzal (2006a). *E-Teaching Mechanical Material Characteristics*. Proceedings M2D'2006, 5th International Conference on Mechanics and Materials in Design, Porto, Portugal.

Restivo, M. T., J. Mendes, A.M. Lopes, C.M. Silva, R. Magalhães and M.F. Chouzal (2006b). E-Teaching Mechanical Material Characteristics. Proc. M2D'2006, 5th Int. Conf. on Mechanics and Materials in Design, Porto, Portugal.

Restivo, M.T., F.G. Almeida, M.F. Chouzal, J. Mendes and A.M. Lopes (2007). *Instrumentation for Measurement: a bilingual e-book*, Proceedings of ICECE'2007, Santos, Brazil.

Robles-De-La-Torre, G. (2006). The Importance of the Sense of Touch in Virtual and Real Environments. *IEEE MultiMedia*, **13**.

Susana, S., T. Restivo, E. Carrapatoso (2007). Remotely Accessed Experimental Systems, Proc. Int. Conf. on Remote Engineering and Virtual Instrumentation (REV), Porto, Portugal.