Improving Interaction in Remote Laboratories Using Haptic Devices

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Abstract—**Laboratories are an important educational resource to provide experimental exploration. For distance learning, several labs have been developed and can be used over the Internet for remote experiments. A remote experiment can performed in a virtual environment, in a virtual replica of a real lab or even in a real lab monitored by cameras. The goal of this paper is to present a way to improve the interaction in remote experiments by the use of haptic devices.**

Index Terms—**Haptic devices, remote laboratory, virtual laboratory.**

I. Introduction

Virtual Reality (VR) and the systems based on it have a very recent history. The main idea behind VR is to provide a 3D environment were users can explore and interact in a synthetic world and feel immersed on it. In order to reach that, VR systems use specific devices to stimulate the user senses, as vision, audition and tact [13]. Stereoscopic visualization is one of the most common features found in VR systems. For this, each scene is generated from two horizontally separated points of view to provide depth perception by the use of a visualization device. Recently, haptic devices have been used to enlarge and improve the possibilities of VR applications. They provide a better immersion in a virtual reality environment, but their use is not common in educational systems on the Web, as remote laboratories.

In the literature it is possible to find three kinds of laboratories: hands-on, simulated, and remote laboratories [10]. In the traditional hands-on laboratories, students can access physically the lab and interact with real things. The students can see and feel the experiments while interacting with other students. In the remote lab, the students can access the real lab by the Web and interact with real things, but they cannot feel the experiments and interaction with other students can be difficult. In the simulated laboratories, the students access a virtual lab by the Web and interact with virtual things. As in the remote labs, they cannot feel the experiments and cannot interact with other students.

Besides the fact that it is accepted that lab-based courses are an important component of scientific education, there are several discussions about if technology can really promote or improve students' learning or if the technology inhibits learning. According to Ma and Nickerson [10], the relative effectiveness of remote and simulated laboratories compared with traditional hands-on labs is seldom explored. Some papers discuss this question and advocate the equivalence between hands-on, remote and simulated laboratories [6, 10]. At this point, no studies were found in the literature about remote or simulated labs which provide haptic interaction for students. It is known in telemedicine that the use of tactile feedback improves the effectiveness and safety of physician actions [7]. In this paper the use of haptic devices is proposed to improve learning through more realistic interactions in remote and simulated laboratories.

II. Virtual Laboratories

Virtual laboratories are related to laboratories that can be accessed at distance. They are virtual environments in which students can work with tools and resources unavailable or only available remotely. It can happen because the tools and resources are specific or are located in a distant place [2]. In this kind of laboratory, students with theoretical basis can practice experiments and improve their knowledge. In this case, the term "virtual" can be used to do reference to a learning environment that exist and is distant or to a completely simulated learning environment that can be used through the Internet.

There are two types of virtual laboratories: simulated and remote. A simulated laboratory does not exist and is composed by a computer environment in which the student can interact with virtual objects and execute experiments. This environment can be and provide a two-dimensional (2D) or three-dimensional (3D) representation of components. The 2D representation has flat graphical elements that can be manipulated. The 3D representation offers 3D elements that can be manipulated in the space and can simulate a real laboratory. In simulated laboratories the student actions do not affect real objects. In opposite way, the remote laboratories are real spaces that can be remotely modified by users. In this kind of virtual laboratory, the students see the remote laboratory through cameras and can modify their components by the manipulation of graphical elements through interaction devices. In the remote laboratory, computers establish the communication with real components that can be tele-commanded. The cameras provide the visualization of the remote laboratory and allows students to observe the results of their experiments.

The communication between user and virtual laboratory can be divided in three types: real to virtual, real to real and virtual to real. The communication real to virtual occurs in simulated laboratories and real devices are used to affect virtual environments. User's actions did not affect real object, but users can simulate experiments and observe their results in the virtual environment. The communication real to real and virtual to real occurs in remote laboratories. In both types, the user's actions change a real environment. The main difference concerns in the type of environment observed by the user. In the real to real communication the user manipulates real devices and his actions are transmitted to other real device remotely connected. In the virtual to real the user manipulates virtual devices and it affect a real device remotely connected. On example of virtual to real communication was presented by [14] in which changes performed in a virtual environment are transmitted to a remote oscilloscope and can be observed through images provided by a camera located in the remote environment.

III. Haptics

The complete mechanism of cognition used by human beings to explore and identify an environment, its components and its objects is quite complex. In this context, the touch is used to explore objects features as their shape, hardness and texture. This exploration is performed through the combination of tactile and kinesthetic sensations which can be related to spatial and time distribution of forces in a part of the body. When this exploration is associated to computers it is necessary the use of haptic systems to allow haptic interaction. When associated to visual displays, haptic systems greatly improve the realism of simulations [14].

The difference between haptic interaction and other interaction devices is its bi-directional communication feature. It gives the reception and sending information capability to a single interface (device). The haptic interaction happens through haptic systems, composed by the pair: device and control software.

In these devices, the touch sensation is provided by actuators, responsible by the display of the touch properties. Most haptic devices focus on presenting stimuli to the hands or fingers mainly because these are the body parts more frequently used to manipulate virtual environments. The haptic devices can be divided in two main groups: base-attached or base-free. The base-attached haptic devices are attached to a stable and fixed base. The base-free haptic devices do not have a fixed base and offer more freedom to the user if observed their space of action. The group in which a device is inserted is less important than its features, as the number of degrees of freedom allowed by the device and the amount of force which can be exerted by it. These features will allow determining if the device is appropriate for a specific application. As example, an application which presents planar movements demands 2DOF (degrees of freedom) devices. By the other hand, an application with a 3D environment for touch of 3D objects will demand a 3DOF haptic device.

Haptic interaction at distance can be divided into three types: static, when users can only touch the objects; collaborative, when users can touch and change, not simultaneously, objects in the environment; and cooperative, when users can touch and change objects in the environment at the same time [5]. In a remote application, a replica of the simulated objects is provided to the user and constantly updated. Once haptic devices basically provide tact and touch through spring force calculus, only force and direction are transmitted and all calculations are performed locally in the user application. This approach decreases network traffic and improves the application performance. Since one of the main difficulties related to haptics use at distance is the network latency, the static and collaborative approaches are more indicated to provide a faster response for remote user interaction because they do not need to prevent collision among users.

IV. Remote Experiments

The Laboratory of Instrumentation for Measurement (LIM) at FEUP has been devoting particular attention to the "hands on" activity of mechanical engineering students as well as other postgraduate activities and even to student introduction to research activities. The laboratory is mainly devoted to system sensorization, measurements and meteorological procedures, system automation and to the use of new information and communication technologies (ICT).

Concerning the use of ICT in the classroom, LIM has dedicated special attention to the production of thematic e-learning courses as well as to the development of remote and virtual laboratory components, always on a blended learning base [14]. In what concerns the remote and virtual laboratory components, they have been used for complementing student knowledge on experimental tasks or as a side task prior to or following real lab sessions for consolidating and promoting experimental activity.

An example of remote experiment is presented in Figure 1: a cantilever beam instrumented with resistance strain gauges is loaded by a linear motor [15]. The system may be used remotely for automatically measuring force, strain and deflection and it may also be actuated in a manual mode for monitoring the cantilever beam system performance to any value of the applied load, on the working range. The application for remote access is developed on LabVIEW 7.1. Figure 1 shows the user interface available for remote actuation. On its upper right corner a real time video permits the real system visualization.

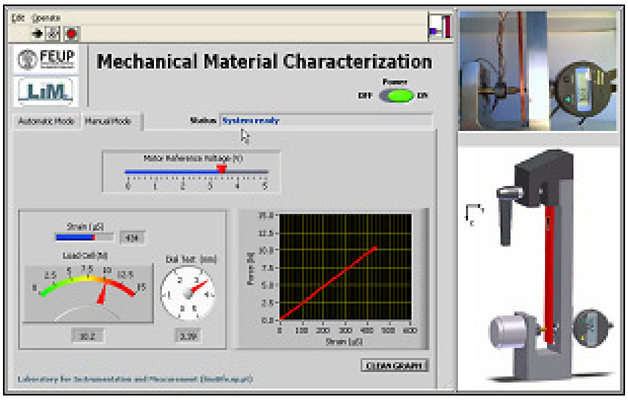

Figure 1 – Remote user interface.

V. Haptics in Virtual Laboratories

Haptics in virtual laboratories allow the education in areas in which the touch is required for the correct understanding of concepts, as physical phenomena, variation of frequencies, medical procedures, engineering, virtual museums, etc. Then, their demand will depend on the kind of laboratory.

In virtual laboratories, the use of haptics is relevant if the application is able to recognize the user movements and can provide haptic feedback. As previously mentioned in Section II, virtual laboratories can be simulated or remote. In simulated laboratories a virtual environment can be manipulated and in a remote laboratory a real environment is commanded at distance.

A. Simulated laboratories

In simulated laboratories, the interaction occurs in an virtual environment and one or more users can use a same experiment. Applications for a single user allow the touch identification of textures, shapes, attraction forces and objects elasticity, as example. When more than one user is allowed in the environment, the application is added with objects that represent each user, also called avatars [1, 16]. The avatars allows identifying presence and proximity among the several users. However, the presence of several users in a same virtual environment demands a network dedicated or an Internet connection to perform what is named tele-haptics [17].

When sharing an experiment in a simulated laboratory, each student has his/her own environment as a replica of others environment. Thus, the refresh of the scene depends on the graphical refresh rate, low latency, large visual field, high interactivity and communication among the application users. All these features intend to provide to all users visual and haptic feedback about the actions of a particular user [8]. This kind of environment is called Shared Haptic Virtual Environment (SHVE).

There are three types of SHVE: static, collaborative and cooperative virtual simulation [5]. However there are several variations of each type if more senses are attached to the application, as audio and/or video. In a static virtual simulation each user can explore the virtual environment through the visualization and touch, but cannot modify it (Figure 2). In simulated laboratories, the static SHVE can be used to allows the identification of materials and their properties, as gravidity and elasticity. Then, the objects cannot be changed visually or haptically. However, it can occur in collaborative SHVE through tele-haptics unidirectional or bi-directional communication [14], in which one user manipulates the environment and all his/her actions can be received by all users, or all users manipulate and receive action feedback from each other.

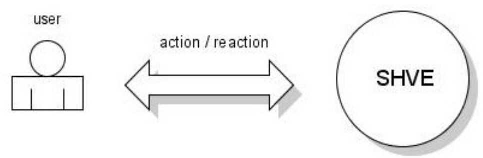

Figure 2: Static communication in a SHVE: users cannot modify the virtual environment.

Tele-haptics unidirectional communication one single user can manipulate or modify an object and it can be observed by all users that share the environment. These users are static and their actions do not affect the environment. It will occurs only in the bi-directional mode (Figure 3). In that kind of collaboration, a user per time can change the environment and his/her actions are transmitted to the others.

A cooperative SHVE is probably the more complex kind of SHVE. In this kind of application all users can interact at the same time in a single environment and their actions and modifications in the environment must be transmitted and observed by all users visually and haptically.

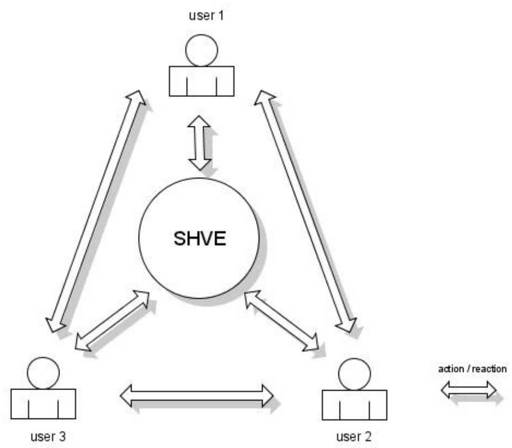

Figure 3: Bi-directional communication in a SHVE: users can modify the virtual environment and feel each other modification.

A virtual museum can be used to demonstrate applications of SHVE [11]. The static applications occurs when a single user navigate in the environment, touch and feel the objects to identify them without change their characteristics. The unidirectional communication can be observed when one user is a guide in the virtual museum and others must follow his/her movements. Thus, the guide cannot observe others actions. The bi-directional communication is when all visitors of the museum can touch, once per time, the environment and all other users must follow and feel his/her movements. When all users can move together in the museum, it is a cooperative SHVE.

Particularly, collaborative SHVEs have several application in education and can be used to teach at distance when a professor shows to one or more students how to perform a procedure [3, 9, 12].

B. Remote laboratories

Remote laboratories can be used to perform experiments using real but at distance devices. The use of haptics in these laboratories can improve student interaction once he/she can notice the forces and material properties related to objects or to the environment. In these cases, a user can remotely interact with a haptic device or can remotely control a specific device through a haptic device. In both cases, only one user can interact with the experiment, in a similar way to the real laboratories.

The use of haptics in remote laboratories can increase the realism of remote experiments. Examples are the study of gravidity and mass-spring forces. In theses cases, the user must have a haptic device and the communication with the remote laboratory must be bi-directional. It means that the communication application must be able to process the user movements and send a feedback according to his/her actions in the real environment.

The interaction with a remote laboratory can be performed through the modification of parameters that affect a remote device or directly by the manipulation of a haptic device. In the first case, the user modify environment parameters that affect a remote robotic device. Once modified, the remote device will be moved and it will be returned to the student that will be able to feel the movements through his/her haptic device. In the second case, the student moves the haptic devices and his/her actions automatically change a remote device. Then, all collision and forces related to the remote device environment will be returned to the student. Figure 1 presents an environment that can be used to imagine and explain both cases, then it was redraw as Figure 4. There are 3 main areas and in each one a different control of the experiment can be observed. The area 1 presents controls, the area 2 presents what could be a representation of the haptic device of the user, and the area 3 could be the real image of a remote device with haptic feedback capabilities. Then, if the user modify a parameter in Area 1 it will affect the remote device showed in Area 3 and the user could feel the modifications through his/her own haptic device, that could be graphically represented in area 2.

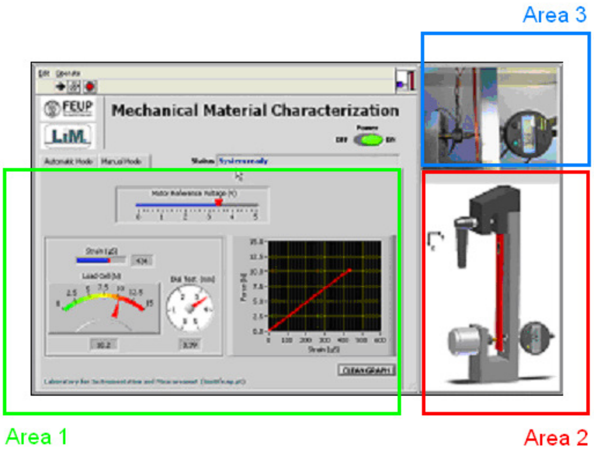

Figure 4 – Example of how a remote experiment could be set with haptics: student can modify area 1 parameters or can use a haptic device, represented in area 2, to modify the real instrument in area 3.

In remote laboratories the network latency is a critical factor and can affect the haptic control. It must be fast to allow the refresh of the haptic forces and transmit the movements between the student and the remote laboratory.

VI. Experiments With Haptics For Virtual Laboratories

The use of haptics to distance learning can improve experiments in which the material properties and forces related to the manipulation of objects are important factors to understand the experiment.

Initial works used a gigabit network connection to transmit interaction movements between users. For this, haptic devices had been installed in two different computers in a network. In this experiment a user manipulated the haptic device to touch the surface of a virtual sphere with physical properties to feel its roughness and hardness. His/her movements were transmitted and followed by another haptic device over the network and another user could also feel the object and perceive its properties. Figure 5 shows the haptic device used for this test. The application was composed by a visual sphere and a visual representation of the haptic device. However, a haptic scene was also rendered and was composed by a haptic sphere and a point which represented the haptic device. The haptic sphere presented a mass-spring material property. In this application was setup a client-server architecture in which one user guided other. Both users had a haptic device and the client had a copy of the scene.

Figure 5 – Haptic device used to feel a remote sphere.

In that application was observed that the network band is a decisive factor in the use of haptics in remote experiments. In a gigabit network no delays were observed in the transmission of the server movements. However, in a 10 megabit network delays were clearly observed and compromised the performance of the application. That application used the UDP protocol (User Datagram Protocol) to transmit the information through the network. This protocol is faster than the TCP (Transmission Control Protocol) because it does not required transmission confirmation. In fact, a haptic loop require 1000Hz frequency rate what demands fast communication. The haptic device used was the Phantom Omni (www.sensable.com).

The LabVIEW package was considered for the development of remote experiments. However, this software does not allow bi-directional transmission, what is necessary for haptic interactions. Additionally, several haptic devices require the use of a firewire or parallel port, what is not supported by LabVIEW interfaces. Due to this fact, the development of simulated experiences tends to be more easy because they do not demand the communication with real devices. However, the development of remote experiments can show real devices been manipulated as in hands on laboratories.

VII. Conclusions

This paper presented aspects related to the use of haptics in virtual laboratories. As bi-directional interfaces, their use is recommended in applications were the touch and forces related to a movement are an important factor in the learning process. However, it was possible to observe that several aspects must be considered when setting an experiment for virtual laboratories. It includes the number of users and if a virtual or a real environment will be used for the experiments.

For remote laboratories experiments, the student must have a haptic device and the application must be able to provide fast communication to guarantee a continuous and consistent update of the interaction.

A test of communication with haptics was performed and allows a remote device follow the movements of a server device. This application allowed a user feel the movement properties when guided by a remote user in a gigabit network.

Nowadays, the LabVIEW package cannot support the use of haptics. The authors intend to work in the development of new frameworks and applications able to create remote experiments able to control a device through haptics.

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