CHAPTER X

Haptic Technologies in the framework of Training Systems: from Simulators to Innovative Multimodal Virtual Environment Systems

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ABSTRACT

Haptic technologies are complex robotic systems devoted to replicate force and tactile stimuli on human body parts such as hands, arms or feet during interaction procedures in Virtual Environments or in Tele-operation conditions. The application of different types of Haptic Interfaces for training purposes are presented in the specific frameworks of simulators, simulator-based training systems, multimodal training and shared multimodal training systems. The importance of integrating Haptics technologies in future innovative Virtual Environment based training systems is evaluated in light of their effective contribution to specific tasks in which paradigms involving contact functionalities are required.

Keywords: Haptics, Skills, Multimodality, Virtual Reality

INTRODUCTION

Today haptic technologies represent a relevant area of the robotics research and find their natural and largest applications in the fields of Virtual Environments (VE) and Tele-operation. Haptic systems are designed to convey contact information to parts of the human operator's body (hands, arms, feet, etc.) in response to specific manipulative or exploratory actions performed in VE or in remote real scenarios. From this general functionality, the term "Haptic Interface" (HI) has been utilized in the course of the recent years (Hayward, 2004).

In general terms, the common functionality of a haptic interface or of a force feedback device is that of being able to generate forces at the level of the human limb where these forces are required or simulated. Usually these places are the palm's surface of the human hand when manipulative operations must be controlled, or other parts of the human body, such as the anterior or posterior aspects of the trunk in the case of whole body motion haptic interfaces.

The design of haptic interfaces represents an innovative area of research per se, since, although haptic interfaces are very similar to serial or parallel robots, their design must address specific issues that are very different from the functional specifications of conventional robots. In particular, the main features characterizing a haptic interface are the following (Barbieri, 1991): *transparency, fidelity and natural movemen*t of the user's hand or body.

To exert forces on the human limbs, when the user intends to manipulate objects in the remote or virtual operational space, as far as the interaction with the haptic interface is concerned, two possible operative conditions are possible in the control space: in the first the HI is always maintained in contact with the user's limb during the control of the operation, in the second, instead, the HI enters in contact with the user's limb only at the instant of time in which the generation of forces is required.

The first category comprehends the large majority of present haptic interfaces, i.e. robotic devices that are external with respect to the user's body and that are usually grasped at their end-effector during the whole duration of the interaction task. A particular type of "Always in Contact" devices, named external always in contact, refers to those systems whose end-effector is shaped as the effective tool they intend to emulate, i.e. laparoscopic masters, stylus-like appendices, etc. Implicitly, exoskeletons systems, although possessing different characteristics from the general Always in Contact devices, belong to this first category.

The second category represents a completely different concept of haptic interface: here the robotic system is controlled to follow the user's hand or limb at a certain distance except when a contact force is required given the specific hand position and orientation at the specific instant of time. At that exact instant of time, the "Encountered Type" haptic interface is controlled in order to enter in contact with the human limb and generating the required force vector.

A particular type of haptic interface, so far not largely developed in the scientific literature but with a promising development in the near future for training purposes, is the so-called "Whole-Body Motion Haptic Interface", which functionality is that of being able to generate forces of large magnitude on specific locations of the user's body, in particular the trunk or the back (Checcacci, 2003). Among the applications allowed by this type of interface we can mention the tele-operation of humanoid robots in dangerous environments.

HAPTIC SYSTEMS FOR VE APPLICATIONS

A complete haptic system is far more complex than the pure mechanisms which topology has been described above. By analyzing the complete hardware and software technologies subtending the system "haptic interface" utilized for controlling the physical interaction with VE, we will discover that the electromechanical system represents only a small part of the complete system. As depicted in Fig. 1 (right), a complete haptic system requires the implementation of several software components capable of insuring all the functionalities that allow the user to realistically interact with the virtual entities represented in the VE (e.g. virtual objects, etc.).

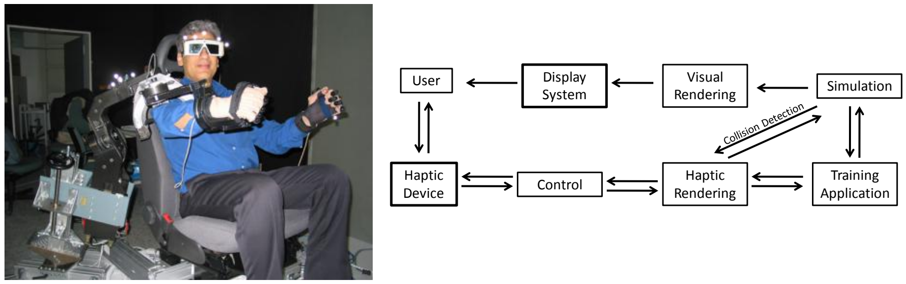

Figure 1 Example of Exoskeleton System for driving simulation (left) and diagram of complete Haptic System (right). In the diagram the user interacts with the system by means of two hardware elements for haptics and visual feedback. The Control module drives the haptic interface actuators under the computation performed by the Haptic Rendering module. The simulation manages the overall behavior of the virtual objects depending and provides contact information to the Haptic Rendering, for feedback, and status to the Training Application.

At present, only few of the above types of haptic interfaces are utilized in the framework of simulators or training systems design. In order to describe how haptic devices or, more general, haptic systems are exploited for training, it is worth to analyze the functionalities required to a haptic interface in the large spectrum of simulators and training systems.

TRAINING SYSTEMS

The use of digital technologies in the framework of training methodologies is largely increasing due to the recent exploitation of specific components of VE. We can distinguish between:

1. Training on Simulators
2. Simulator-Assisted Training
3. Multimodal Training Systems
4. Simulator-Based Training

Training on Simulators

Vehicle or flight simulators are aimed at recreating the same operating conditions as those encountered by the user in a real operation. In fact, the development of such simulators systems was based on Thorndike theory of "similarity" stating that "Learning is the result of associations forming between stimuli and responses" (Thorndike, 1921).

In these cases the user is located in the replica of a real cockpit and is asked to execute the same control operation as during a real operation. The user then interacts with physical commands, sometimes exact replicas of the same levers or buttons, etc., he/she would find on a real vehicle. Motion-based simulators are able to acquire such commands, as generated through real primary controls by the user, and perform adequate movements of the cockpit by replicating an approximation of velocity and accelerations trajectories as the real vehicle.

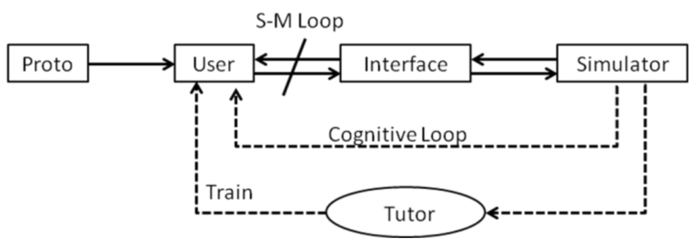

Figure 2 Simulator Block Diagram. On the left the training (Proto)col provided to the User that has a Sensori-Motor (S-M) loop with the Interface. At the same time the Simulator is connected to the User by means of the interface or directly to the User by means of the Cognitive Loop. Finally the human Tutor supervises the whole process.

The use of a real cockpit, integrating real physical primary controls, implicitly allows the user's sensation of contact with the primary controls to be exactly the same as in a real vehicle (Angerilli, 2001). Visual information is provided by computer graphics images generated in real-time by graphical workstation.

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Figure 3 Specialized haptic device for providing force feedback in driving simulator. These systems provide a flexible and realistic force feedback. Compare them with the general haptic interface used in Fig. 1 left.

Another example of the use of haptic devices in simulators relates to surgery applications, in which training can be performed by utilizing VE systems in which the novice surgeon can exercise in the surgical operation by directly interacting with a mock-up of the human body part. Haptic interfaces, mimicking the surgical tools, at least for the part where grasping is performed, are used to transmit the forces of contact between the tip of the surgical tool and the body's tissue (Raspolli, 2003 and Okamura, 2009). In terms of flexibility, i.e. the capability to reconfigure the system for different vehicles or applications, simulators systems of this kind are very poor. In order to augment the flexibility of simulators systems, VE technologies can intervene by virtualizing the cockpit and all primary commands. In this framework a virtual model of the internal parts of the vehicle can be used and visualized on an immersive visualization system, e.g. a CAVE. As far as sensations of contact with primary commands is concerned, this can be achieved through the use of haptic controls, i.e. haptic interfaces possessing the same appearance and external shape as the real primary commands, but controlled by the computer in order to generate the required level of contact and operative forces to the user for the achievement of a realistic behavior. The same approach is used nowadays for the control commands inside different types of vehicles and it is called drive-by-wire, although in drive-by-wire cases there is no force or tactile feedback as in the haptic controls.

Simulator-Assisted Training

An higher level of interaction and a more sophisticated level of assist in the training protocol can be obtained by inserting a logical module that allows the interpretation of the user's commands and, based on that, be able to adequately modify the training protocol even in real-time.

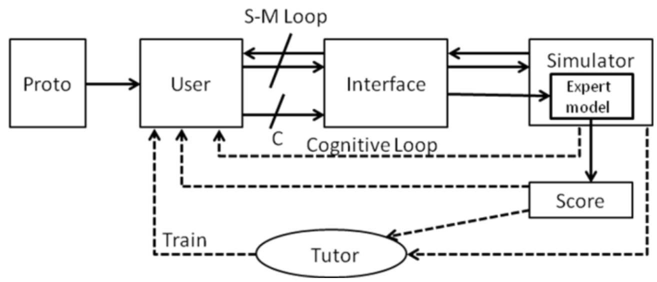

Figure 4 Simulator Assisted Training,
where the Expert Model is used only for the scoring

Different examples of this type of training systems can be found in literature: for example rehabilitation of upper limbs (Frisoli, 2007), training writing based on reactive robots (Avizzano, 2002) and cobots (Faulring, 2004).

Multimodal Training Systems

The training utilizing Multimodal Training Systems (Fig. 5) differs from Simulator-Assisted Training since the information derived from the simulator system is in this case utilized by the User for self-assessment and by the Tutor in order to modify the training protocol. The Project SKILLS (Bergamasco, 2006) exploits such a training methodology for each of the developed demonstrator systems, for instance (La Garde, 2009 and Ruffaldi, 2009).

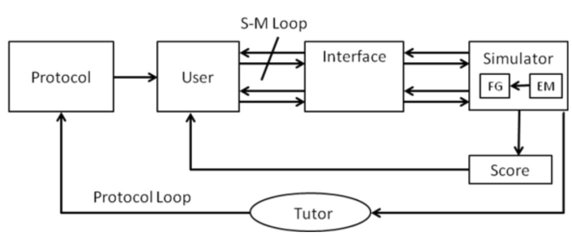

Figure 5 Multimodal Training System,
where the Expert Model is used for the Feedback Generation

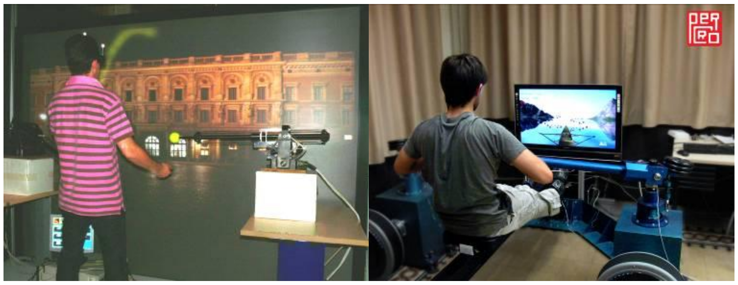

Figure 6 Two examples of systems for training based on the multimodal training schema. On the left the Haptic Juggling with co-located feedback, and on the right the Rowing System providing realistic water feedback.

Simulator-Based Training

In a Simulator-Based Training system, the tutor is substituted by a Learning Model that, based on performance data generated by the simulator, is able to automatically modify the training protocol according to specific performance parameters (Fig. 7).

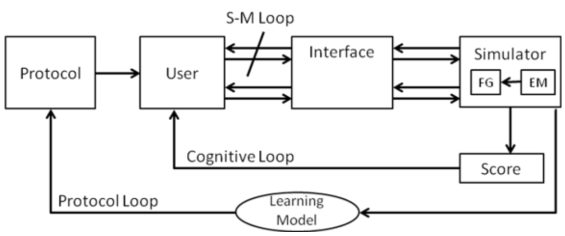

Figure 7 Schematic of the Simulator-Based Training in which both the Cognitive Loop and the Protocol Loop are computed and tuned by the system

CONCLUSIONS

The use of Haptic Interfaces in different cases of Training Systems has been presented. As seen in the case of Simulator-Assisted Training systems, haptic interfaces can play an important role for increasing the level of flexibility of the system when there are operating conditions in which the user must physically interact or operate with primary commands. In fact, Haptic Interfaces can easily simulate the presence of different virtual controls, such as gear-shift, steering wheels or handles, thus allowing the use of the same simulator systems as a training system on several vehicles.

On the other hand the use of Haptic Interface can also enhance the level of functionality of the simulator systems, as seen in the case of Multimodal Training Systems. Here the Haptic system can generate a large spectrum of contact or kinesthetic feedback to the human operator, thus allowing a more sophisticated tuning of the Training Protocol. This has been achieved in the framework of the SKILLS project, in which e.g. Haptic Interfaces have been utilized for the implementation of the resistance force on the oars in the rowing scenario, and for replicating contact conditions on the human hands during juggling operations in VE.

We believe that further sophistications in the developments of Haptic Interfaces, both at the level of electro-mechanical hardware as well as of control algorithms, can surely increase the exploitation of haptic feedback for training purposes.

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