Simulation and Training with Haptic Feedback – A Review

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Abstract

Recent advances in haptic technology have broadened the applicability spectrum of haptic devices and the potential of prototype development for commerce. This article provides a review of the available haptic technologies and associated hardware/ software characteristics. We compare haptic devices from the hardware perspective. We present the main features of existing haptic APIs as well as the trend in haptic applications development. We examine several case studies to demonstrate the effectiveness of haptic devices.

Keywords: haptic devices, virtual reality, simulation and training

1. Introduction

The word "haptics" derives from the Greek *haptesthai*, meaning "*to touch*" (Wall, 2004). Haptics is the science enabling tactile sensation in computer applications for simulation and training purposes. The user can receive three types of touch sensations through a haptic device: force feedback, tactile feedback, and proprioception (from latin "proprius", meaning "one's own" and perception, the sense of the relative position of neighboring parts of our body).

Haptic devices apply small forces through a mechanical linkage (e.g. a stylus in the user's hand) (Lamoureux, 2005). Devices such as the haptic glove (Sensable Technologies) allow the user to feel the shape and form of virtual objects, while others, such as the Screen Rover (www.abledata.com), enable visually impaired users to access computers almost as easily as users without visual impairments.

Our presentation is organized as follows. In section 2 we categorize haptic applications based on their application domain. In section 3 we present a brief history of haptic research. Sections 4 and 5 examine haptic devices and their characteristics. Section 6 explores several Application Programming Interfaces (APIs), and in section 7 we investigate the effectiveness of haptic augmentation through several case studies.

2. Application Domains

The rapid growth of academic interest in haptic systems is stimulated by the decreased cost of haptic hardware and the growing interest in haptic applications in the private sector. Several haptic application domains follow.

2.1. General Education

Research in psychology proves that students have different styles of learning, based on their cognitive development and abilities. Many learners understand and memorize better when movement and touch are involved. Focused only on visual and auditory learning, the traditional school can be inefficient for this category of students. The classic method of teaching can be defective even for the visual and auditory learners as they often memorize the phenomenon or process without understanding its underlying mechanisms. Students can have a deeper understanding of the concepts when haptic feedback is incorporated into the learning material.

The HaptEK16 simulator (Hamza-Lup, 2008) facilitates student understanding of difficult concepts (e.g. hydraulics) and has the potential to augment or replace traditional laboratory instruction with an interactive interface offering enhanced motivation, retention and intellectual stimulation.

2.2. Medicine

One of the most active application domains for haptics in medicine is laparoscopic surgery training. Additionally, surgeons at remote locations may use haptic applications to practice surgical procedures. Several research groups worldwide currently have surgical simulation applications. In one demonstration a “surgeon” located in Australia guided a ”trainee” in Sweden in an operation to remove the gall bladder, using an Internet link between Australia and Sweden (Satava, 1998).

The advancements in medical modeling and Virtual Reality enable medical training in a safer and more cost-efficient manner. A study by Chui (Chui, 2006) analyzes a surgical simulator for training students to perform spinal cement vertebroplasty. In this biomechanical model a haptic device is employed to capture the movement of the user’s hand, and the Cybergrasp™ device provides force feedback to the user’s finger during the insertion of the needle into the bone. The Haptic Cow simulator (Baille, 2005) is another haptic application designed for veterinary students performing fertility examinations. During training, the students palpate virtual internal organs via a haptic device that is positioned inside a fibreglass half-cow model.

2.3. Assistance for Visually Impaired

Haptics-enabled systems can aid blind and visually impaired users at using computers or playing games (Brewster, 2001; Basdogan and Ho, 2002). For instance, Yu et al (Yu, 2003) developed a low-cost web-based tool which can be used by blind people to design virtual graphs without the help of a sighted person. The automatic graph generation works like the graph-plotting tool in Microsoft Excel that plots a graph according to the selected data. Based on the data inserted by the user, the tool renders a graph on the computer screen. Blind users can then explore the graph through Logitech’s

WingMan Force Feedback mouse with audio feedback. The interactive drawing gives blind users the opportunity to draw graphs manually.

2.4. Military Simulations and Training

Haptic-enabled VR simulations across a network allow people in different locations to participate in military training exercises (Gun and Mettenmeyer, 2002). At the Army's National Automotive Center, the Simulation Throughout the Life Cycle program used haptics to test military ground vehicles under simulated battlefield conditions. For example, they simulated an environment where workers at remote locations can collaborate in reconfiguring a vehicle chassis with different weapons using instrumented force-feedback gloves to manipulate the 3D components.

Haptic applications can be used to safely train aircraft and other complicated machinery operators. Flight training simulators are safer when teaching potentially dangerous tasks, such as taxiing down a runway (Menéndez and Bernard, 2001).

2.5. Architecture and Graphic Arts

Haptics may be applied to designing virtual art exhibits, concert rooms, museums, and even individual or co-operative virtual sculpturing projects across the Internet (Brewster, 2001; Handshake VR News, 2004).

Novint™ Technologies developed an architectural walkthrough for Sandia National Laboratories that allows users to load detailed architectural models and explore their design using Novint's e-Touch technology. Haptic technology allows users to receive haptic feedback while feeling the digital models, or picking up and placing objects such as chairs.

2.6. Entertainment

Haptics naturally fits in video games and simulators by enabling the user to feel and manipulate virtual solids, fluids, tools, and avatars (Handshake VR News, 2004). One example is a stock XBox controller (Basdogan and Ho, 2002) powered by Immersion's force feedback technology. Players of "Star Wars" game have the opportunity to experience a heavy recoil effect when firing a rocket launcher and the rapid-fire vibrations from a machine gun.

3. Haptics Research

Haptic research originates with the work of Heinrich Weber (Prytherch, 2002), a 19th century professor at the University of Leipzig. In 1987 Lederman and Klatzky (Klatzky, 1985), summarized four basic procedures for haptic exploration, each one eliciting a different set of object characteristics:

- *lateral motion* (stroking) provides information about the surface texture of the object;
- *pressure* gives information about how firm the material is;
- *contour* following elicits information on the form of the object;
- *enclosure* reflects the volume of the object.

The development of several haptic devices in the early 1990s facilitated important experiments that involve human tactile perception, and improved the understanding of haptic human-computer interaction.

The increasing number of researchers in the haptics domain in the late 1990s contributed to the appearance of a specialized Internet magazine. *Haptics-e* published haptics-related technical discussions and articles. Since the foundation of *Haptics-e* (2000) and Haptics International Society (2003), numerous conferences, symposiums, and publications were organized, indicating the expansion of the haptics research community.

4. Haptic Devices and Hardware Characteristics

In this section we present the most novel haptic devices and we categorize the hardware device characteristics by comparing information from various manufacturers.

As we mentioned earlier, blind users can then explore the graphs through Logitech's WingMan Force Feedback mouse (figure 1) with audio feedback. Another successful initiative pursued by SensAble Technologies is their line of PHANTOM® devices. PHANTOM® Omni™ (figure 2a) is a six-degree-of-freedom portable device with a compact footprint and a removable rubber stylus. An alternative tool is the PHANTOM® Desktop™ (figure 2b), which is similar to the PHANTOM® Omni™, but provides better precision positioning control and higher fidelity force feedback output.

The Mimic Mantis has a different design compared to other haptic devices: this tension-based device incorporates an on-board processor for faster computation of forces, allowing the haptics software to be embedded directly into the device. The user interacts with the system through an integrated keyboard and a two-button grip, which can be changed to satisfy the application requirements.

The wireless CyberGlove® II from Immersion Corporation (figure 3) is a fully instrumented glove that provides up to 22 high-accuracy joint-angle measurements. It uses proprietary resistive bend-sensing technology to accurately transform hand and finger motions into real-time digital joint-angle data. Each of the incorporated sensors is extremely thin and flexible, being virtually undetectable in the lightweight elastic glove.

			
Figure 1. Logitech's WingMan™ mouse	*Figure 2a.* PHANTOM® Omni™	*Figure 2b.* PHANTOM® Desktop™	*Figure 3.* Cyber Glove II

Novint Technologies, Inc. introduces a 3D game controller haptic device, Novint Falcon, which (figure 4) enables users to control a game in three dimensions. The device has three arms that are gathered in a handgrip with programmable buttons. The position and the forces rendered by each arm are updated 1000 times per second to create a real life experience for the user.

Having developed a set of prototypes since 1997, Carnegie Mellon University proposed in March 2008 an innovative haptic device based on magnets. The device (figure 5), built into a bowl-shaped cavity in a desk, includes a levitating bar that, grasped by the user, makes the magnets exert force on the bar. Missing the mechanical linkages, the system responds instantly due to no latencies from mechanical force-feedback. The moving part of the device, which responds and exerts actions in six degrees of freedom, exhibits relatively high stiffness (25 N/mm at 1500 Hz) and allows appliance of forces up to 55N. The perception of very smooth movements of the bar (up to 5-10 microns) permits the feel of differences between textures and subtle effects of friction. The disadvantage of the system is the limited range of motion for the joystick: 25 mm in translation and 15-20 degrees in rotation.

Figure 4. Novint Falcon

Figure 5. Magnetic levitation (maglev)

The following characteristics, also known as performance measures, are common to all haptic devices (Wall, 2004):

- **Degrees of Freedom (DOF)** represent the set of independent displacements that specify completely the position of the body or system.
- **Workspace** refers to the area within which the joints of the device will permit the operator’s motion.
- **Position resolution** is the minimum detectable change in position possible within the workspace.
- **Continuous force** is the maximum force that the controller can exert over an extended period of time.
- **Maximum force/torque** is the maximum possible output of the device, determined by such factors as the power of the actuators and the efficiency of any gearing systems. Unlike continuous force, maximum force needs to be exerted only over a short period of time (e.g., a few milliseconds).
- **Maximum stiffness** of virtual surfaces depends on the peak force/torque, but is also related to the dynamic behaviour of the device, sensor resolution, and the sampling period of the controlling computer.
- **System latency** measures the time passed between the moment of changing the controller’s position and the moment when a resultant force can be calculated and

rendered by the device. Latency includes computation by the computer and therefore depends on the speed of the computer as well as the speed of the device.

- **Haptic update rate** is the inverse of system latency, measured in Hz.
- **Inertia** is the perceived mass of the device when it is in use. This should be as low as possible to minimize the impact of the device controller on rendered forces.

5. Haptic APIs

Several APIs have evolved for the development of haptic applications. They include SensAble OpenHaptics Toolkit, Reachin API, Immersion Corporation's API for automotive, and Sense Graphics' H3D API.

SensAble OpenHaptics Toolkit (www.sensable.com) enables software developers to add haptics and 3D navigation to a wide range of applications, from games and entertainment to simulation and visualization. The toolkit is familiar to graphics programmers because it is designed after the OpenGL API.

Reachin API (www.reachin.se) is a modern development platform that enables the development of sophisticated haptic 3D applications in the user's programming language of choice, such as C++, Python, or VRML (Virtual Reality Modeling Language). The API provides a base of pre-written code that allows for easy and rapid development of applications that target specific needs of the user. UK Haptics, a newly established medical software development company, agreed to use Reachin API as the core haptic technology platform for their Virtual Veins application. Virtual Veins is a medical simulation package for training medical staff in catheter insertion.

The Immersion API (www.immersion.com) is a software library for creating and assigning haptic effects to interact with haptic devices such as rotary controllers. It provides the code necessary for developers to design and incorporate haptic effects into their applications. Leading auto manufacturer, BMW, has licensed Immersion's TouchSense technology to create the automotive industry's first intuitive information and control system called iDrive. The iDrive features a single control dial mounted on the central console, which allows a driver to have instant and total control of every comfort element in the car through their sense of touch.

H3D API is designed mainly for users who want to develop haptics applications from scratch, rather than for those who want to add haptics to existing applications. The main advantage of H3D API is that it makes it easy to manage graphics and haptics rendering. For this reason, H3D API is a vital extension to OpenHaptics. It allows users to focus their work on the behavior of the application and ignore the issues of haptics geometry rendering as well as synchronization of graphics and haptics. The API is also extended with scripting capabilities, allowing the user to perform rapid prototyping using the Python scripting language.

6. Effectiveness of Simulation and Training With Haptic Feedback

In a study Moody et al (Moody, 2002) demonstrated the effect of a force feedback system in the training and assessment of surgeons. The PHANToM desktop unit, run on Windows NT 4.0, was used together with a suturing simulation. After the task was

demonstrated and explained to each subject by the experimenter, each of the 20 participants performed two test sutures to familiarise themselves with the task and the experimental setting. Participants were then asked to form one suture across the skin excision, with the specifications provided by the experimenter. Results revealed that force feedback resulted in a reduction of the time taken to complete the stitch.

Cagatay Basdogan et al. (Basdogan, 2000) have conducted experiments to study the role of haptic feedback in performing collaborative tasks and in influencing the sense togetherness when working with a remote partner. For this purpose they designed a multimodal shared environment that included: one computer, two synchronized monitors, and two PHANToM devices. The 10 participants formed two groups. In one day one of the groups performed the task including only visual feedback, while for the other group visual and haptic feedback was included. In each of the 15 trials the participants collaborated with their partner to move a ring in virtual environment without touching a wire. The results of the experiment suggest a considerable enhancement of performance when the haptic feedback was present. The measurements also revealed that, depending on the age, the gender, and the level of computer usage of the participants, the haptic presence increased in some level the feeling of togetherness.

The study (Caroline, 2007) analyzes the effects of network delay on users that are working in a collaborative environment. Thirty participants took part in the study, performing the experiment in pairs. For observing the differences between the visual and haptic latency, the experimental task consisted of two parts: in the first part the users, positioned in a simple environment at some distance one from another, had to get close to one another relying on visual feedback; in the second part they had to move to a target, without loosing contact, relying on haptic feedback. Pairs of participants performed 12 experimental sessions with random level of latency added for every trial. The negative effects of the latency were slowed movement and an increased number of errors.

Virtual Haptic Back (VHB) Project (Williams, 2006) develops a series of haptic simulations of the human body parts, such as somatic dysfunctions, to help students learn the palpatory techniques. The project includes passive and active methods of study. The application has a multistage structure. The path and the movements of the expert performing the palpatory technique are recorded using PHANToM playback capabilities. The first stage allows students to follow the expert’s path, with no haptic feedback incorporated. In the second phase the haptic feedback is involved, and the student has to actively follow the correct path via visual cues. The results of the experiment show that the users from both groups improved their technique during the trials; however, the students from the group trained with passive trials performed significantly better then the other group.

As confirmed in the above case studies, the use of haptic feedback in simulation and training seems to improve the user’s experience and efficiency of performed procedures at a cost of a more complex system.

7. Conclusion

In this paper we provided a review of the available haptic technologies and associated hardware/software characteristics. Haptics is a fast-growing field with serious potential and a multitude of applications in entertainment, medicine, military and other fields. Several haptic APIs, stand out and enable faster development of haptic applications for simulation and training purposes.

The efficiency of simulation and training with haptic feedback is demonstrated for several application domains. However designing a training tool with haptic feedback increases the complexity and the real-time processing requirements of the application.

Significant progress has been made since the inception of the technology, and we believe that even more innovative haptic applications will be seen in the future.

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