Haptic devices on medical training applications, a brief review

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Abstract. Current computer systems rely heavily on the senses of sight and hearing, making aside all other senses. Haptic devices, however, covers partial deficiency but also allows user to perceive tactile sensations. There are several developments in both hardware and software, showing various solutions. The tools used range from simple mathematical analysis, to issues of inference based on probabilistic models. Solutions use different types of haptic devices, some made or adapted by researchers and others that are already commercially available. This paper is a brief review of some applications of haptic devices in the field of medical training and professional use. A review of the state of art developments with haptic devices is described and opportunity areas in research are addressed to further develop a formal dissertation proposal.

Keywords: Haptic devices; virtual training environments; medical training; suture training system.

1 Introduction

In the field of medical training, like in many others knowledge areas, experience is a significant part of the learning process. However, even under the guidance of an expert a mistake can cause severe discomfort or death of the patient. Nowadays, it is required to update and reform the teaching and learning practices in this area; for instance, law reform and advocacy for human and animal rights have changed the way students are trained. Originally animals such as dogs, mice or rats were used to train new physicians. More recently mannequins to teach various techniques and surgical procedures are used. In the last two decades there has been an increment in the use of virtual environments (VE) that can simulate risky situations providing feedback to users. The interaction between humans and machines has focused mainly on visual and auditory issues without considering the sense of touch; the level of sensation has been relegated as tactile devices such as mouses, keyboards or touch screens used exclusively as hardware devices that enter information. In order to extend the usage of this hardware, haptic tools interfaces were developed allowing computer equipment to send tactile sensations to the user. In the field of experimental psychology and physiology, the word haptic is used to describe the ability to perceive the environment through active exploration, using our hands, and feeling an object to perceive its shape and its properties according of the material the object is made up[1]. Haptic or haptics are words generally used to refer to all the feelings related to touch, including the ability to detect the position and movement of the limbs. More generally, haptics is commonly used today to refer to the science of touch in real and VE [1]. The idea of using touch as a means of communication comes from the years 1985 and 1999 [2], when it was considered that the channels of communication could be improved on the basis of combining various simple patterns and like a mouse to glide pixel by pixel on a graphic display. This raised the possibility of sending information to the user via a touch device as a mouse makes, thus, it is possible to send pixel by pixel to the haptic device information of shapes, depths and textures. This mechanism sometimes is called *haptic display* [2].

There are various studies that proposed the incorporation of haptic devices in virtual learning environments to improve the perception and performance of students [3][4]. Some applications can be found in medicine training. The incorporation of haptic devices in virtual learning environments represents new challenges for both electronics and computer science.

This paper is organized as follows: Section 2 defines haptic devices, describes the operation principles their classification and presents examples of commercial devices. Section 3 describes medical applications using haptic devices. Section 4 presents a summary of generic APIs to work with haptic devices. Finally, Section 5 is devoted to the discussion over research opportunity areas.

2 Haptic Devices

On this section we are going to describe the operation principles of haptic devices, their classification and some examples of commercial devices.

2.1 Description and operating principles

Haptic devices have been used in different areas and therefore are of different kinds of them. To get started, a haptic device can be defined as one that allows us to perceive tactile sensations from computer equipment interacting with it. A haptic device is said to be *under-actuated* when its number of actuators is smaller than its number of sensors, when a haptic device has the same number of sensors and actuators, it is said to be *fully-actuated* device. When there is a device with only sensors but no actuators, it is called *unactuated* device [5]. It is easier to develop under-actuated devices than fully actuated. Nevertheless there are many techniques to compensate for this disadvantage [5].

An ideal haptic device would be one in which a user could not distinguish between an object to be playing in the real world or virtual world [8], hard surfaces such as walls, would feel the same hardness in real life, the corners would be perceived even with sharp edges and the user would be able to distinguish surfaces with different textures. A real haptic device has a certain amount of friction, which add noise to the system, but in the long term and in extreme cases, can fatigue the user. In addition, the device itself has some inertia, which is not a problem if the user moves slowly, but doing so quickly, the inertia of the system can generate an undesirable sensation, similar to be dragging extra weight and can also limit the maximum speed at which the device responds.

A real device must be properly balanced, in order to compensate different external forces, including gravity, likewise, must have mechanisms that provide sufficient reaction to stimuli and a sense of sufficient effort to simulate hard surfaces. [8] The resolution must be high, in order to provide as much detail as possible of the textures in the VE. The workspace of the haptic device must be large enough in order to simulate real workspace.

According to used control, there are two kinds of haptic devices: impedance control and admittance control. They differ not only in the type of control, but also in the mechanical structure [10], both of them have pros and cons. In the case of impedance control, the paradigm is the following: The user moves the device, and the device responds with a force if a virtual object is found. This means displacement as input and reaction force as output and implies that the user will inevitably feel the mass and friction of the device. The impedance control devices are light and manageable, normally has direct current (DC) motors.

The admittance control is the inverse of impedance, in this type of control the paradigm is: The user exerts a force on the device and the device responds with a displacement proportional to it; this is, force as input and displacement as output. This type of control, always consider freedom in the mechanical design of the device, because the displacement and inertia can be reduced by servo mechanisms, this makes such mechanisms more robust than impedance controlled and are able to move with great strength and stiffness. It is preferred to use these devices in industrial applications such as flight simulators, but due to its complexity, there are few haptic devices with such control, as they usually are bulky and must be carefully designed to interact safely with humans because of its strength and stiffness. An example of these devices is the HapticMaster from FCS Control Systems company (now Mog Corporation [11]).

The main features of the haptic devices, for both impedance and admittance, are the following:

Workload or workspace: Corresponds to the dimension or volume that can reach the device in the physical space considering the three coordinate axes.

Resolution: Specifies the slightest movement can be detected or made by the haptic device, shown in sub-multiples of a meter or in dots per inch.

Force: The force that the device may assert, as a combination of actuators at a given point. Nominal force is the one the device works normally with peak force or maximum, is the one that device may occur over short periods of time.

Maximum speed: Represents the speed which device can move or be moved, considering that inertia must be compensated to achieve more optimal simulations.

2.2 Classification of haptic devices

As we mentioned before, there are several ways to classify haptic devices, depending on its application, degrees of freedom, performance, etc. Bello [6] organizes haptic devices in large groups, related to the application or the form of interaction, touch screens, exoskeletons and stationary devices, gloves and wearable devices, interaction point and devices for specific applications. According to its application, devices can be described as follows:

Programmable Keyboard: One of the earliest examples of the implementation of a feedback keyboard was the Clavier Rétroactif Modulaire Project (1990). This consists of a keyboard similar to a piano that provides force feedback computer-controlled in each of its 16 keys [2], which focuses on music research.

Exoskeletons: Exoskeleton devices were developed by Bergamasco et. al. (1992), incorporating several biomechanical observations of the human body [2]. In order to become functional, the researchers used different techniques to improve engine performance, reducing friction and adding sophisticated methods to guide the cables.

Gripping or grasping devices: One of the first devices designed for this purpose was developed by Howe in 1992 [7], the device has two degrees of freedom and was designed for two fingers. The user's fingers interact unilaterally with the device on the inner side of the banks, generating a precision grip.

Point Interaction: This device assumes that you only need one contact point to perceive virtual objects. An example of this family is The Phantom™ device, described below.

Increased mice: This type of mouse was described by Akamatsu [2], is generally a device shaped and sized like a computer mouse, but includes two haptic features: One is an electromagnetic brake to program the forces of friction and the other one is a transducer that provides vibro-tactile sensations.

Joystick: Adelstein and Rosen [2] show an example of a joystick with two degrees of freedom and force feedback, from there; other devices have been designed another similar joysticks.

Virtual reality devices: There are many devices for VR applications. Their origins date back to 1992 on a paper presented by Burdea [9], who show a series of pistons positioned in the fingers, so you have to oppose opening and closing the hand currently. The leading exponent of this technology is CyberGrasp from VRLOGIC[1], which provides force feedback on every finger and allows you to locate the hand position in three dimensions.

Isometric devices (or admittance controlled): There are few examples of such devices, but one of the most representatives is the Haptic Master from the FCS Control Systems company [11]. This consists of a robotic arm and a control unit that generates six degrees of freedom in a force feedback device that allows very considerable magnitude about hundred of Newtons.

In this job we focus in Learning Virtual Environments using haptic devices to train physicians. For this reason, in the next section it will be described the most common haptic devices used on VE medical applications.

2.3 Commercial devices used on medical applications

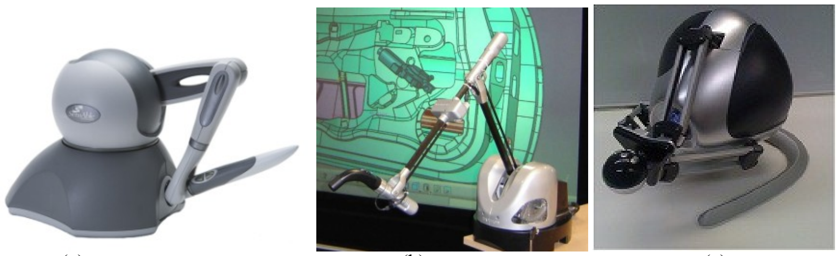
Following, a brief description for most commonly used haptic devices in VE for medical applications is presented.

Phantom Device: Originally developed by the Massachusetts Institute of Technology (MIT) [8], is a desktop device that provides an interface that shows strength between the user and the computer. It is controlled by an impedance control algorithm and there are currently several variants of this device, Phantom Omni (Figure 1a), Phantom Desktop, Premium Phantom and Phantom Premium 6DOF. Where the end-effector is a

[1] http://www.vrlogic.com/html/immersion/cybergrasp.html

stylus or a thimble, in which the user holds the stylus or insert his finger in the thimble. It consists of three DC motors connected to a broadcast and encoders for position coordinates x, y, z, torque engine is transmitted by a series of pre-tensioned cables that reduce the stiffness of the device because to its lightweight aluminum construction. The three axes coincide at one point, so it eliminates the torque at that point, this enables a single contact point in the virtual world, enhancing the sensation on VE. This device has been widely accepted and used by various researchers.

For applications development involving this device, SenSable has *OpenHaptics development platform toolkit* that works on Windows™, Linux and Mac OS™, using native OpenGL for graphical environment.



(a) (b) (c)

Fig. 1. (a) Phantom Omni device from Sensable Technologies [27], (b) Virtuose 6D35-45 [12], (c) Falcon device, Novint Technologies Inc. [13].

Virtuose 6D35-45: this is a device with 6 degrees of freedom (6DOF), shown in figure 1b it is designed specifically to work in VE. According to the manufacturer it is the only device in the market to have full feedback on the 6DOF. Operation freedom emulates a human arm, it is composed of two major joints fixed to a rotating base, the second segment ends with a "wrist", which can rotate on three concurrent axes and offers the possibility of exchange the end actuator to place different types of tools. It also has three buttons that can be used to interact with the GUI.

For the development of graphics applications, manufacturer offers three software solutions: Virtuose API, provides functionality for haptic devices; IPSI API, includes a solution for collision detection and Core PPI and IPP Human that allows the development of applications for physical interaction between humans and objects. All for Windows and Linux platforms, for the first two, the programming is done through C ++ language, while the latter, has its own visual programming interface. This device connects to computer via Ethernet interface and belongs to the classification of controlled impedance.

Falcon device: this device is manufactured by Novint Technologies Inc. (figure 1c) is primarily targeted for using with games. However, manufacturer provides as development kit a set of libraries for Windows platforms, using programming language Visual C ++. Graphic management is done through OpenGL to develop own applications. This device belongs to control impedance family, has 3DOF with a delta robot-type configuration, and it is possible to exchange the handle either with a sphere or a gun [13]. It is connected to the computer through a USB interface. The drivers are provided by the manufacturer, allowing communication and an effective update frequency between 800Hz and 1 kHz.

Table 1 shows a comparison of some features for haptic devices mentioned above.

Table 1. Comparative table of different haptic devices

Specification	Phantom Omni	Falcon	Virtuose 6D35-45
Workspace (mm)	160 x 120 x 70	101 x 101 x 101	150 x 150 x 150
Resolution (mm)	$\approx 55x10^{-3}$	$\approx 63.5x10^{-3}$	$6x10^{-3}$
Force feedback Nominal /peek	0.88 / 3.3 N	8.8 N	35 / 10 N
Control software	Open Haptics C++	Novint SDK C++	Virtuose API C++
Interface	IEEE1394 Firewire	USB 2.0	Ethernet
Degrees of freedom	6	3	6
Degrees of force feedback	3	3	6
Manufacturer	Sensable	Novint	Haption

3 Haptic devices in medical applications

In this section we present a summary of various studies that use haptic devices on VE for medical applications. There are developments in hardware and software, and some solutions include from simple mathematical analysis to inference issues based on probabilistic models. The use of haptic devices in medical simulations in the first instance intended to improve training applications and its used in a variety of specialties like palpation, needle insertion, suturing, laparoscopic surgery and so forth.

On palpation a doctor presses on interest area with his fingers to locate reference points below the patient's skin and feel the presence or absence of anatomical features and/or physiological abnormalities. Direct contact patient/doctor is required for palpation and requires the simulation of force and tactile feedback. There are not commercial devices that perform this function, which has limited current solution for palpation simulation. There are different applications related to palpation, either using devices specially built for that purpose or using generic haptic devices like the Phantom. Examples of these types of application are: palpation of the knee [16], malignant tumors in head and neck [17] or use fingertips to felt abnormalities from a modified haptic device [18] (Figure 2).

Fig. 2. Palpation device combining force feedback from a Novint Falcon and tactile feedback at the fingertips from piezoelectric materials. [18]

There are several commercial applications for needle insertion; an example is The Mediseus Epidural simulator (Medic Vision) that includes force feedback. Simulation runs on a laptop, gives vocal response if the user makes mistakes and produces a report for the student [20].

On many interventional procedures, the initial step is the insertions of a needle o trocar as a guide for introduce another tool. Most current commercial simulators for minimally invasive surgery are built with the introducer already in place e.g. CathSim AccuTouch System [21]. It contains a needle carrier with 3 DOF and one degree of force feedback (DOFF). This one DOFF allowed the simulation of a needle passing trough different tissues. Suture simulating is another kind or needle insertions, there are several studies on the construction of a virtual suture simulator that allows to teach to future physicians different techniques for human tissue sutures, simulating different conditions and circumstances [22] [23] [3] [24] [25].

O'connor [3] probed that the use of haptic feedback improves performance of student learning and describes the difficulties of training in laparoscopic suturing. Also shows the complexity of the tasks and performs an experiment with different students where one group uses haptic feedback and another group does not.

On Brown [24], there are different ways to represent deformable objects, soft tissues, and several types of collisions needed to work with suture techniques. Also raises collisions that can be used for the realization of knots. However leaves open the implementation of the haptic device in these tasks.

Oshima [26] develop a training system for suture/ligature that provides quantitive information about the process of student learning and proposes a solution not entirely virtual. From a modified device for venipuncture, they built a device through synthetic leather that allows students to practice different kind of stitches. Students are evaluated by an imaging system that provides the teacher with an assessment of the job. A disadvantage of this system is the use of artificial skin, which must be changed for each operation. This training simulator is showed at figure 3.

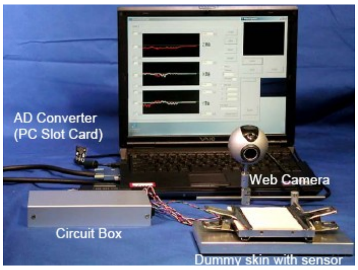


Fig. 3. Screenshot of the developed surgical skill training simulator at Waseda University. [26]

On applications involving virtual haptic devices, H. F. Shi [25] presents a model of knotted and sutures based on a Virtual Training Environment (VTE), throw an approximation of a real-time simulation of deformable linear objects (DLOs) with visual and force feedback. Special emphasis is placed on mechanical properties of a real thread such as stretching, compressing, bending and twisting, and these properties are considered in the propagation forces along the suture when the user pulls with one or both hands.

The user can practice basic suturing techniques in the simulator; the wounds are modeled on a spring mass system. Also, it simulates the instruments involved in the process, as well as collisions between soft tissue and the needle. One of the main contributions of this work is the use of the graphic processing unit (GPU) to perform calculations of deformable objects.

Regarding the need to simulate with high fidelity models not only visually, but also the haptic modeling, there has been several ways to get the best representation of human tissues. The two main solutions proposed are the mass-spring system (MSS) as in the previous case [25] and methods based on finite element models (FEM). However, due to the computational cost of latter, most authors decide for using the MSS like in case of L. L. Lian [23], from this model he shows a different way to represent human tissue. It also deals with collisions in the process and the behavior of a needle and thread and the forces involved on them.

Roger W. [22], describes a virtual simulator of simple wound suture, there are a needle holder attached to the haptic device, the graphics of needle holders, needle, sutures and virtual skin are displayed and updated in real time. The simulator incorporates several components such as real-time modeling of deformable skin, tissue and suture materials, and a real-time recording of state of activity during the job of suture, figure 4 shows this work.

Fig. 4. Screen shot of haptic suturing simulator [22]

Recording positions is one feature that is only possible with haptic devices and can be added to training, Cagatay [27] called this "haptic recording" and allows an instructor register through haptic devices and the appropriate software, the sensations perceived during a particular action, such as surgery and with this shows the student what to expect in the real world.

Cagatay also describes a laparoscopy training system, using two Phantom haptic devices. Software highlights special features, like collision detection; also, special emphasis is placed on "deformable object model" used to represent internal organs. Finite element model is necessary for this representation.

4 Software for haptic devices

There are several Application Program Interfaces (APIs) that can assist during the creation of VE, some created by the manufacturers themselves, such case is OpenHaptics from SensAble Company[2]. This toolkit allows developers to integrate haptics to existing third-party applications and development of new applications. OpenHaptics provides a new and extensible architecture that offers a framework for

[2] http://www.sensable.com/products-openhaptics-toolkit.htm

developing multi-layer applications, allows developers to program the rendering forces directly, offers control over the dynamic behavior of drivers and provides utilities and debugging aids. OpenHaptics works on Windows, Linux and Mac OS, but is limited only to the Phantom family devices, for the graphics is preferably designed to work with OpenGL, although it may work with DirectX or any other graphics library.

Another API is CHAI3D library [15], this includes graphic components, force feedback and control algorithms for haptic rendering. This is an open source library, it is written in C ++ mainly for academic use, it is easy to add extensions and supports several commercial haptic devices.

Haptik Library [28] is a library with an open source component-based architecture, which acts as a hardware abstraction layer, to provide uniform access to haptic devices. It does not contains graphic guidelines, algorithms related to physics or classes of complex architecture, but instead presents a set of interfaces that hide the differences of the devices to applications. This means that any dependence on a particular device is removed from the code and executable programs, ensuring that the application to work regardless of installed driver.

H3DAPI is open source software that uses OpenGL and X3D standards. Unify the management of haptics and graphics in a single scene. It is made to get independence in the management of different haptic devices and allows the integration of audio and stereographic displays.

5 Research opportunity areas

In previous articles there are different applications involving haptic devices in the field of medical training. However we can distinguish several opportunities for developing new applications. E.g. in suture despite the existence of several works, none of them can be seen that the procedure used by doctors to play virtually. Several studies have focused on virtual representation of the tissues and behavior of the thread and needle [25], other works allow virtual sutures including stereoscopic vision [22]. However the procedure presented is different from that one used by doctors in real operations, because simulators use only one hand and a single haptic device, while doctors uses both hands. This provides the opportunity to develop an application that allows integrating a haptic for each hand. Also, we can propose another one to allow contact with virtual objects in more than one point, possibly using a haptic glove.

Additionally, most medical applications including haptics are too specific e.g. laparoscopic applications are designed to work in a specific part of the body: knee, liver, gallbladder and so on. If users want to change the experiment, they must redo the application and change hardware. This left open research to generate some kind of architecture that easily supports application change, or at least a wider range of experiments. Also, is pending the job of developing applications to evaluate performance of student. The use of a smart tutor can help student to repeat work without presence of teacher.

6 Discussion and Conclusions

Current trends in research are allowing the development of virtual laboratories for learning and training in different areas including medicine. Because of the existence of low cost commercial haptic devices, nowadays is easier incorporate to serious applications this kind of devices. To build a medical training application with a haptic device, it is necessary to take in mind several considerations. Including if we want to build our own haptic device, use a commercial device or modify an existing one. Also, according to the application, it should be consider the number of degrees of freedom needed; the required computational would be provides, because both haptic and graphic require significant resources. Once elected the device, it should de consider whether it is necessary to work with their libraries or can use a generic API to help us more quickly and easily perform our work. Considering a medical application, the main question could be, is haptical representation as true as real touch? It is also necessary to add some functionality to evaluate user performance, in order to facilitate the learning or training process and reduce the costs involved.

Although there are several works in the medical field, the evaluation of their performance is so far subjective, as it is very difficult to assess whether a feeling is right or wrong, the best we can say about touch is "seems fine" and several tests are needed to establish statistically a generality.

Evaluation mechanisms will allow students to know about their performance even without the presence of an expert (teacher). These mechanisms can be implemented using artificial intelligence techniques such as neural networks or Bayesian networks to develop specialized intelligent tutoring systems.

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