HAPTIC INTERACTION IN MEDICAL VIRTUAL ENVIRONMENTS

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1. INTRODUCTION

Human perception combines information from various sensors, including visual, aural, haptic, and olfactory, in order to perceive the environment. Virtual reality applications aim to immerse the user into a virtual environment by providing artificial input to its interaction sensors (i.e., eyes, ears, hands). The visual and aural inputs are the most important factors in human-computer interaction (HCI). However, virtual reality applications will remain far from being realistic without providing to the user the sense of touch. The use of haptics augments the standard audio-visual HCI by offering to the user an alternative way of interaction with the VE.

One of the major application branches of haptic-enabled virtual environments is medicine. In the following, the most important medical application areas are briefly presented and described.

1. Echography examination is a noninvasive technique in which the observation and examination of the organs such as the heart, liver, and spleen are achieved permitting the evaluation of the fetus for normal development as well as the blood flow through specific vessels. In many places, such as small hospitals and health centers, it is possible that echography-related equipment exists, but there are no experts able to perform the examinations. Typical cases include many small medical centers, isolated sites, or rescue vehicles, which do not have the appropriate well-trained sonographer to perform the initial echography for the evaluation of the emergency level (1).

2. Training systems for blind and visually impaired people are based on interaction in real situations; usually with the assistance of nonblind trainers. Navigation of the blind users in real-world situations exposes them to real danger and increases the possibilities of ending to undesired situations such as accidents. Typical examples include applications that allow blind people to access 3D information such as maps (2), or navigate in realistic environments using a virtual cane (2,3).

3. Further, most phobia treatment techniques require the patient to be somehow exposed to the phobia object either physically (real life, in vivo exposure) or mentally (visualization or imaginary exposure). The physical exposure environment is difficult to be achieved because it often requires the presence of both the therapist and the phobic person, outside of the therapist's office, which results in increased cost and time for the therapy, possible public embarrassment concerns, loss of confidentiality, and risk of potential physical harm (4).

In this chapter cases where diagnosis, treatment, and rehabilitation of patients can be improved by the use of haptic-enabled virtual environments will be discussed. A brief introduction into VEs and their components is presented in the sequel.

The chapter is organized as follows. The following paragraph briefly presents the aspects of haptic virtual environments. Then, factors that affect haptic interaction are described and methodologies used for the generation of force feedback in medical applications are analyzed. The next section presents a number of haptic-enabled interfaces that are used in medical applications. A number of cases where medical treatment or training is improved using haptic-enabled interfaces is presented in the last section.

1.1. Haptic Virtual Environment

The term virtual environment (VE) describes an environment that is fully or partially simulated by a computer. Most VEs offer primarily visual experiences, displayed either on a computer screen or through special stereoscopic displays. However, a VE may include sensory information concerning any of the other human senses (i.e., hearing, touch, taste, and smell).

Haptics is the study of how to couple the human sense of touch with a computer-generated world. Lack of the sense of touch in virtual reality systems and simulations causes several problems concerning the provided realism and immersion of the user in the virtual environment (VE). For example, if a user tries to grab a virtual cup, no nonvisual way exists to let the user know that the cup is in contact with the user’s virtual hand. Also, no mechanism exists to keep the virtual hand from passing through the cup (5). Haptic technologies attempt to solve these problems. They can be subdivided into two main subfields: those that provide force (kinaesthetic) and those that offer tactile feedback.

Force feedback techniques deal with devices that interact with the muscles and tendons that give the human a sensation of a force being applied. These devices mainly consist of robotic manipulators that push back against a user with the forces that correspond to the environment that the virtual effector is in.

Tactile feedback techniques deal with the devices that interact with the nerve endings in the skin, which indicate heat, pressure, and texture. These devices typically have been used to indicate whether the user is in contact with a virtual object. Other tactile feedback devices have been used to simulate the texture of a virtual object.

Haptic-enabled VE is a VE, which includes the sensory information concerning the sense of touch. Such environments have been used in the past to assist medical branches such as echography examination, phobia treat-
2. HUMAN FACTORS IN HAPTIC INTERFACES

Humans with poor or no visibility use their hands in exploring environments. Humans are very good at identifying 3D objects placed in their hands, but are not as able to identify 2D objects (6). In 2D exploration, such as exploring raised surfaces on a plane, humans use a set of exploratory procedures as observed by Lederman et al. (7). In order to design and develop haptic interfaces in a virtual environment, it is important to ensure the safety of the user as well as to study the limitations of human perception to forces and tactile feedback. In the following, the characteristics of human haptic perception abilities will be discussed.

2.1. Anatomy and Physiology

In order to correctly design a haptic interface for a human, the anatomy and physiology of the body must be taken into consideration. In force feedback, the proportions and strengths of average joints must be considered. As the hands are most often used for haptic interfaces, the properties of the hand should be considered when designing a new interface. In tactile feedback, the interface must track several variables of the human sense of touch. The fingers are one of the most sensitive parts of the surface of the skin, with up to 135 sensors per square centimeter at the fingertip (8). Also, the finger is sensitive to up to 10,000 Hz vibrations when sensing textures, and is most sensitive at approximately 230 Hz. The fingers also cannot distinguish between two force signals above 320 Hz; they are just sensed as vibrations. Forces on individual fingers should be less than 30-50 N total. For the average user, the index finger can exert 7 N, middle finger 6 N, and ring fingers 4.5 N without experiencing discomfort or fatigue (8).

Humans are very adept at determining if a force is real or simulated. In an experiment conducted by Eberhand et al. (9), a device was used to determine how humans reacted when they sensed that an object they were holding began to slip. The device consisted of a solenoid attached to a metal plate, which was allowed to slide when the solenoid was turned off. None of the subjects were tricked into believing that the object was actually slipping. They all noted that "something was wrong with the object," but none commented that the object behaved as if it were slippery.

Studies show that a strong link exists between the sensations felt by a human hand, such as an object slipping, and the motions the hand was going through to acquire that knowledge, such as holding an experimental apparatus (10). The human haptic system is made up of two subsystems, the motor subsystem and the sensory subsystem. A strong link exists between the two systems. Unlike the visual system, it is not only important what the sensory system detects, but what motions were used to gain that information.

Another important factor in virtual reality systems is the situation when a visual cue and a haptic cue are in contradiction. The visual cue typically overpowers the haptic cue. This fact could help solve "the stiff wall problem," which is as follows. It is very difficult to create a machine that will correctly simulate the meeting of a virtual object with a hard immovable object. To overcome this problem, the user is presented with visual feedback, which presents that he has reached a hard surface, which gives the impression to the user that the virtual wall is rigid, even though the haptic interface does not give the force of a hard, stiff surface, but rather a linear Hooke's law approximation.

2.2. Safety Issues

In attempting to portray physical forces, robotic systems, which are much stronger than the finger joints, must be designed to account for the flexion and extension strengths and flexibility of the human joints. If an interface for the "average user" is being considered, it should be considered that the size of the hand affects the extension of the fingers and the flexion range. A hand that is larger than the average user will not be able to flex its finger as designed and could be injured by the interface (11,12). Also, the user must be able to overpower the system, because the user must feel like being in control and cannot be injured by the device if its control system fails (9).

3. HAPTIC FEEDBACK GENERATION

In this chapter, the evaluation methodologies to calculate force and tactile feedback will be described. Specifically, force feedback calculation from rigid and deformable objects as well as the implementation of haptic texture and friction used in most cases of haptic-enabled applications will be analyzed. Moreover, methodologies used to represent the haptic texture of objects in order to increase the simulation realism will be described. Such cases include texture representation by recording and playing back the haptic properties of soft tissues for minimally invasive surgical simulations and training (13). Other haptic texture representation techniques are used in the case of "HapticIO" project (14), as well as for the simulation of rehabilitation applications for blind users (15). Friction is another important property in haptic VR simulations. Lack of friction causes objects in the VE to be very slippery and hard to interact with. In the case of rehabilitation applications, friction is used to allow the user to feel the object. In surgical simulation friction is used to allow realistic interaction with the virtual organ (16). Both friction and texture are important in haptic applications because they increase the realism of the environment and improve the performance of the users. Medical teleoperation systems that use haptic for assessment or treatment of patients require the use of synchronization techniques concerning the workspace scaling and data transfer time delay (17).

In the following, details will be provided for all aforementioned properties that influence the haptic feedback generation in medical VEs.
3.1. Force Feedback

Force feedback from rigid objects is usually calculated using a spring force model. The force applied to the user is perpendicular to the object surface and is calculated using the following formula.

\[ F = k \cdot d, \]  

(1)

where \( k \) is the spring constant that depends on the physical properties of the simulated object and \( d \) is the penetration depth of the probe into the object.

For deformable objects, the force feedback is calculated directly from the deformation properties of the model.

4. HAPTIC TEXTURE REPRESENTATION METHODOLOGIES

In human sensing and manipulation of objects, the perception of surface texture is fundamental for both accurate identification and perceptual realism. The identification of everyday objects depends crucially on texture information. Therefore, haptic texture rendering and material properties are important in order to create flexible simulations capable of suggesting soft silk velvet, rough cotton denim, or silk satin. As with graphical textures, a major design constraint for haptic textures is the generation of a sufficiently “realistic” texture. All objects have a surface roughness, which manifests itself as small forces when objects slide under load against each other. Simulating this roughness using haptics enriches the interaction between a user and a virtual world. Thus, designers of haptic displays for virtual environments or telerobotic applications have attempted to provide textural information to users when conveying aspects of virtual objects, and have developed a variety of algorithms and hardware that can present a convincing simulation of surface textural features.

4.1. Texture Sampling Methods

Fritz in his thesis (18) presented two implementation techniques for texture sampling: the lattice texture and the local space texture methods. Generating the texture on a uniformly spaced integer lattice provides a means for spatial filtering and introducing neighborhood dependencies of the samples on the lattice. The local space technique takes advantage of the local nature of haptics and requires only two samples: the current one and either the previous or next sample. This method is versatile and fast, but texture repeatability is not guaranteed and filtering can only be accomplished based on the single distance parameter.

4.2. Implementation of Random Textures

In Fritz and Barner (19), synthetic texture generation achieved through the use of stochastic modeling techniques to produce random and pseudorandom texture patterns. These models are based on techniques used in computer graphics textures generation and textured image analysis and modeling. The features of a texture are described through its power spectrum, where modifications of the spectrum produce various textures. Finally, filtering is used to shape the power spectrum of the texture primitive, while keeping the high-frequency power sufficiently low. The technique discussed in this paper, and the preliminary results obtained, show that a wide variety of textures can be simulated through the use of simple random and pseudorandom models and linear filters. Filtering not only provides texture variation by modifying the power spectrum, but also helps to keep the texture force signal from causing instability problems in a haptic interface. These textures may not represent real textures, but are suitable for data visualization where the important feature is perceptible differences.

4.3. Implementation of Real Texture

The goal of real texture implementation is to model the properties of the material and to use them in order to create realistic texture feeling. Minsky’s (20) pioneering work on synthetic texture rendering uses a 2D force feedback joystick. Specifically, a technique is proposed for creating a class of textures and small features on the surfaces based on their geometry, which allows an automatic pipeline from a height map of small surface features to a haptic display of the surface. This method is used to implement synthetic lateral-force gradient texture, assuming a spring model of force and triangle wave texture. Using this system, called Sandpaper, she created haptic simulations of mechanical systems, solid materials, real-world surface textures, nonphysical materials, some haptic representations of medical imagery, and a user interface prototype. This method of creating simulations of textured surfaces led to objectively realistic surface simulations.

5. FRICTION REPRESENTATION METHODOLOGIES

Friction is an important feature in the implementation of virtual worlds that use haptic interaction. Several physical models such as Coulomb’s friction law or Dahl’s friction law describe physical properties of friction. Lack of friction in virtual world makes objects seem sleepy and thus hard to recognize or use. Studies on the implementation of the theoretical friction models in the virtual environment have been proposed so as to give more realistic haptic feedback. The most common friction model is the static–kinetic friction model:

\[ F_f = \begin{cases} \min \left( \frac{F_p}{|\mu_s|}, \frac{F_n}{|\mu_k|} \right)^2 \text{ static} \\ \left( \frac{|F_p|}{|\mu_k|}, \frac{|F_n|}{|\mu_s|} \right)^2 \text{ kinetic} \end{cases}, \]

(2)

where \( F_f \) is the friction force, \( \mu_s \) is the static friction coefficient, \( \mu_k \) is the kinetic friction coefficient, \( F_p \) is the perpendicular force between the two surfaces, \( v \) is a unit vector with direction opposite to the velocity of the object, and \( F_n \) is the tangential applied force to the object. Although the model is relatively simple, several problems exists concerning implementation of friction to haptic interfaces because of the discontinuity of the function when changing from the static to kinetic model and vice versa.
For this reason, several approaches have been proposed using as a base Coulomb’s or other models in order to provide friction to haptic-enabled VEs.

The models described in Refs. 21–23 discuss the way of using Coulomb’s model with a haptic display. In Ref. 24, Dahl’s model is implemented for virtual haptic use. The viscous case is discussed in Refs. 22 and 25. Drag friction (22) is also examined for usage in haptic environments. Finally, many models of friction are studied in Ref. 26 and Karnopp’s model is suggested for usage with haptic displays.

The following table presents various friction representation methods proposed in the past:

<table>
<thead>
<tr>
<th>Model</th>
<th>Main Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coulomb’s Law – spring law</td>
<td>Implementation of the model gives smooth results.</td>
</tr>
<tr>
<td>Dahl’s friction model</td>
<td>Discrete calculation model, robust to noise accounts vector motion and forces (2D–3D) and neither drift or relaxes. The normal force is assumed to be constant.</td>
</tr>
<tr>
<td>”Textured” friction</td>
<td>Calculated using the formula,</td>
</tr>
<tr>
<td>Viscous model (variation)</td>
<td></td>
</tr>
<tr>
<td>Karnopp’s model (26)</td>
<td>A complete, recent study on using friction in a virtual world. Complete study about the stability conditions of the friction algorithm provided exists. It is hard to define friction parameters for materials.</td>
</tr>
<tr>
<td>Experimental model (29)</td>
<td>The friction used is not found by a function following a model but from previous experiments on the materials. Experiments are not made using the human finger-pad but materials.</td>
</tr>
<tr>
<td>Visions instead of friction</td>
<td>An experimental model based on measurements using Phantom. It works well only for stiff surfaces. Braille reading is possible using this method. Not realistic feeling. Can accurately describe friction behavior as observed in experiments or described in literature. The model calculation needs integration and no implementation exists for usage with haptic displays.</td>
</tr>
<tr>
<td>Integrated friction model</td>
<td></td>
</tr>
</tbody>
</table>

Friction hysteresis that is experimentally observed is described by the model. Model is oriented for controlling devices.

6. SCALING AND TIME DELAY IN HAPTIC-ENABLED SYSTEMS

Another important issue for haptic interaction in VEs is the workspace scaling. As proposed in Ref. 35, if scaling is applied only to the positions, and the forces felt by the human remain the same as measured, then the apparent stiffness of the environment changes because of the scaling factor $s$. The scaling factor is then defined by:

$$x_{\text{slave}} = s \cdot x_{\text{H}}.$$  \hspace{1cm} (3)

If scaling is performed only to the position, then:

$$K_u = \frac{f_{\text{Env}}}{Ax_{\text{slave}}} = s \cdot K_{\text{Env}}.$$  \hspace{1cm} (4)

where $K_u$ is the stiffness felt at the operator side, $f_{\text{Env}}$ is the force measured, $Ax_{\text{slave}}$ is the actual displacement, and $K_{\text{Env}}$ is the stiffness of the environment. In order to avoid changes in stiffness, the force feedback vector can be calculated using the formula,

$$f_{\text{H}} = K_p (x_{\text{H}} - x_{\text{slave}} / S) + K_f f_{\text{Env}} / S,$$  \hspace{1cm} (5)

where $f_{\text{H}}$ is the force vector sent to the haptic device, $K_p$ represents a virtual coupling (8) between the master and the slave system, $x_{\text{H}}$ is the position of the haptic device probe, $x_{\text{slave}}$ is the position of the remote robot probe, $s$ is the scaling factor, $K_f$ is a control parameter (normally equal to one), which can be tuned down if communication delay affects the stability of the system, and $f_{\text{Env}}$ is the measured force vector. The first part of the sum is hysteresis force. The hysteresis force provided to the users does not exist in the real world. The reason of its existence is to avoid having different positions between the probe in the virtual and the real world.

7. HAPTIC INTERACTION DEVICES

Today, there is a large number of haptic equipment are available in the market. This section will refer to a selection of general-purpose haptic devices, which were or are used in medical applications as well as a number of haptic devices specially developed to be used for medical purposes.

The PHANToM (http://www.sensable.com) is a high-end force feedback device from SensAble Technologies. It has six degrees of freedom for reading the position of the probe and three or six degrees of freedom concerning the feedback, depending on the model.
The CyberGlove (http://www.immersion.com) is a lightweight glove with flexible sensors. The sensors measure the position of the fingers and the wrist. Two models of the glove exist for either hand: the 18-sensor and the 22-sensor glove. The 18-sensor glove features two-bend sensors on each finger, sensors measuring thumb crossover, palm arch wrist flexion, and abduction. The 22-sensor model adds sensors to measure the flexion of the distal joints of the fingers. The CyberTouch is a tactile feedback option for CyberGlove. Six vibrotactile stimulators, one for each finger and one for the palm, that can be programmed independently construct the CyberTouch. The array of stimulators can generate simple sensations such as pulses or sustained vibration. The CyberGrasp Haptic interface is a force-reflecting exoskeleton that fits over CyberGlove. The grasp forces are exerted via a network of tendons that are routed to the fingertips. The device exerts grasp forces that are roughly perpendicular to the fingertips throughout the range of motion. Forces can be specified individually.

CathSim AccuTouch system is a device specifically designed for the training of nursing and phlebotomy students. The device allows health-care professionals to gain experience using the device instead of performing the procedure on patients. The device combines cognitive and motor skills training into an integrated learning experience. Various types of patients are simulated and the system is even able to create complications. The student is able to feel the needle and catheter insertion into the skin and vein lumen.

Endoscopy AccuTouch Simulator includes three types of endoscopic procedures: flexible bronchoscopy and upper and lower gastrointestinal flexible endoscopy. It is a computer-based system for teaching and assessing motor skills and cognitive knowledge, enabling novices and experienced physicians to practice in a safe environment. The systems uses real-time computer graphics, including anatomic models developed from actual patient data and a robotic interface device. Force feedback is provided through the flexible scope to emulate the actual feel of a procedure.

The Endovascular AccuTouch Simulator allows clinicians to practice endovascular procedures such as PTCA, stenting, and cardiac pacing. Endovascular procedures require careful attention to interpretation of the fluoroscopic image as well as the subtle feel transmitted through guide wires, catheters, and other interventional devices. The Endovascular AccuTouch System, which duplicates the look and feel of the actual procedure, provides clinicians the ability to develop their skills, prior to performing the procedure on a patient and to return to maintain their skills.

Hysteroscopy AccuTouch System is a simulation platform for hysteroscopy procedures. The system provides an immersive haptic-enabled virtual environment for cognitive and motor skills training. The system allows physicians to experience the appropriate resistance, while navigating through cervical canal and uterus. Digital simulations of real-life procedures, complications, and tool/tissue interaction let clinicians learn hysteroscopy procedures in a realistic, risk-free environment.

The Laparoscopic Surgical Workstation is a hardware interface designed to simulate laparoscopic surgery. For optimum training, surgeons helped develop the high-strength and high-fidelity haptics necessary to render life-like simulation. This interface has two fully instrumented tools, providing the highest level of haptic feedback on the market today. This system enables developers, researchers, and educators to develop software for simulating laparoscopic abdominal procedures such as: cholecystectomy, tubal ligation, oophorectomy (ovariectomy), endometriosis treatment, and nissen fundoplication.

8. HAPTIC INTERACTION ENVIRONMENTS FOR MEDICAL APPLICATIONS

Several haptic-enabled VR systems have been developed to assist medical branches such as echography, cardiology, laparoscopic surgery, eye surgery, phobia treatment, rehabilitation, and minimal invasive surgery operations. In the following, some of these branches are indicatively presented so as to clarify the applicability of haptic interfaces in medical applications.

A remote robotic echography system is proposed in Ref. 1. The proposed system consists of the following two main parts: an environment for the display of the ultrasound image/video and the environmental video, providing the appropriate tools for allowing an expert to perform remote diagnosis using a haptic interface. The first part of the graphical user interface is the component for viewing, handling, and processing medical image/video files. A haptic-enabled VE for controlling and monitoring the remote mobile station, which includes a virtual reality 3D environment to provide the expert with visual and haptic feedback during the examination, is also provided, as shown in Fig. 1.

WISHKATS (Warwick, Imperial, Sheffield Haptic Knee Arthroscopy Training System) is a virtual reality training simulator being developed for knee arthroscopy. The required fidelity for such a simulator is a result of several interrelated factors such as the specific task examined, the experience of the user, the capabilities of the human perceptual system, and user acceptance. In Ref. 36, a human factors approach is described including consideration of theory, fieldwork, and experimental work to describe optimized fidelity with a focus on the production of innovative haptic feedback. Typically, haptics generation is constrained by device design and performance. WISHKATS design is being mediated by research to determine the necessary accuracy of a haptic device in terms of human perception. Fidelity will be tuned to the sensitivity of the human cognitive system for specific task performance (36).

It is obvious that training of surgeons in virtual environment will never substitute completely training on synthetic bones and on cadavers. However, it allows students to perform the initial routine work entirely in the haptic-enabled virtual environment (Fig. 2), saving cost and training time (37).
Haptic feedback, during minimally invasive operations, is provided by mechanical manipulators, which makes the implementation of simulated surgical instruments, which provide force feedback based on the available technology, feasible. Although the availability of force feedback during minimal invasive surgeries is relatively limited, force feedback is an essential component for the design of realistic simulation environments (14,16). The used interface consists of a mechano-electrical box, which is the artificial body, a set of minimal invasive surgery tools and switches that enable the control interactions with the simulation such as scene lighting and resetting. The doctors/trainees use the haptic-enabled surgery tools of the system to perform minimal invasive surgeries such as laparoscopic surgery (14). The system offers realistic haptic feedback by simulating the force feedback using deformable object/organ properties as well as friction and haptic texture through the KISMET (Kinematik Simulation, Monitoring and offline programming Environment for Telerobotics) (14).

Microsurgical tasks are another section where haptic technologies can be used. Eye surgery is one of the most demanding microsurgical tasks. The surgery requires both submillimeter precision and eye-hand coordination in a very small workspace. Researchers have developed eye surgical simulators, including the modeling of capsulorhexis procedure during cataract surgery (Fig. 3). The proposed prototype capsulorhexis simulator uses complex 3D graphical models along with a high-fidelity haptic force feedback device. The simulation of the capsulorhexis and the force feedback is based on a mathematical model of various tissue tear problem, which provides a training and learning environment using simulation techniques instead of actual patients (38,39).

Besides, the medical assessment and surgery simulation applications haptic-enabled VEs are used in rehabilitation applications including applications for blind users and for patients with kinaesthetic problems. Specifically, a training system for the blind and the visually impaired is proposed in Ref. 2. The system allows blind people to interact in a haptic-enabled VE by using a virtual white cane. The system is designed so as to provide an alternative way to train blind users to use the cane. The main added value of the system compared with existing training systems is that the users can study various cases in a safe and controlled environment prior to practicing in the real world.
In the cane simulation application, the user navigates in 3D virtual environments, which represent existing outdoor or indoor places. The following figure illustrates blind users using a 5DOF haptic device to interact with the VR environment (Fig. 4). The user on the left tries to cross a road using the virtual cane. Haptic and audio feedback is provided whenever collision of the cane and any object of the scene is detected. The user on the left navigates in an indoor area representing an apartment.

Another important application is the examination of map models from visually impaired people. These models can be either indoor maps of apartments, public offices, and so on, or outdoor maps of cities neighborhoods, and so on. The maps of such applications are 3D representations of indoor as well as outdoor areas. In the following figures, a blind user is investigating the 3D map, which represents the structure of an apartment. Besides haptic, which is directly applied to the user’s hand, audio feedback is also used in order to inform the user about his/her exact position in the virtual environment (i.e., kitchen, living room) (Fig. 5).

Another approach that uses haptics for rehabilitation is the development of systems for kinaesthetic therapy. A haptic-enabled VE has been used for patients with motion coordination disorders of the upper limbs. The therapy environment is targeted to help patients who have lost precision/control of their arm-hand gestures (Fig. 6)(40).

As already mentioned, phobia treatment requires in many cases the exposure of the patient to the phobic object. Realistic VEs provide a compromise between real and imaginary exposure of the patient and minimize the potential risks of real exposure and the uncertainties of the imaginary exposure. Haptic interaction in VEs increases the immersion of the patient in the environment and reduces the overall treatment time (4).

8.1. Impact of VE Exposure Therapy

Besides applications for surgical simulation and telemedicine, haptic-enabled VEs provide an alternative means of training and interaction for special population categories like the visually impaired and for phobic persons. The major advantage lies in the fact that the user is never exposed to the danger (e.g., streets during cane simulation for the blind) or to the phobic object. This fact combined with the game-like nature of virtual reality immerses the user within the VE therapy, thus increasing its influence.
8.2. Financial Issues

Despite the efficiency of the afore-mentioned systems and tools in medical applications, today they remain far from being financially accessible for individual users because of their high cost. Possibly only organizations for special population categories (like schools for the blind) could afford such equipment for providing these services to their members. The cost for these services could also be distributed among user and health insurance companies with a percentage of 75% for the insurance companies and 25% for the users.

9. CONCLUSIONS

Haptic-enabled VEs provide powerful tools in the hands of doctors and medical researchers. During the latest years, numerous VR applications have been developed aiming to assist them. Indicative examples are cases such as surgery training, rehabilitation techniques, and cases where medical treatment and assessment is not possible. The use of haptic-enabled virtual environments is usually considered as an alternative solution in cases where assessment and treatment of patients is not possible.

Details concerning the implementation of haptic-enabled VEs including methodologies for the calculation of force and tactile feedback and haptic texture and friction modeling techniques were also provided in this chapter. Finally, a number of medical-related applications that use haptic-enabled VEs were presented in order to illustrate the applicability of haptics in medical applications.

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**READING LIST**

KEYWORDS

virtual reality, haptics, training, remote examination, force feedback, medical simulation.

ABSTRACT

In recent years, there has been a growing interest in developing force feedback interfaces that allow people to access information presented in 3D virtual reality environments (VEs). One of the major application fields is medicine. Several cases exist where standard medical treatment cannot be applied to patients for several reasons, such as distance from hospital, lack of specialized doctor, and lack of medical equipment. The use of haptic-enabled virtual environments provides an alternative solution in a variety of such cases, thus enabling assessment and treatment of patients. Furthermore, haptic-enabled virtual environments provide a nonhazardous means of treatment for several disorders like phobia treatment, where the patient has to be exposed to the phobia object. Training of disabled people, like the visually impaired, is another important application of haptic-enabled VEs. This chapter presents an extended description of haptic virtual environments and the major methodologies and techniques used in medical applications. Further, it demonstrates indicatively a number of applications in order to illustrate the applicability of VEs in several areas of medical treatment and training.