의료분야에서의 햅틱 피드백 응용

Applications of haptic feedbacks in medicine

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요약 의료 분야는 가상현실 (VR, Virtual Reality)의 주요한 응용 분야 중의 하나이다. 가상현실을 의료 분야에 응용하는 연구는 학제간 연구의 대표적인 사례로 간주되며, 컴퓨터 과학자나 공학자, 내과 및 외과의사, 의학 교육자나 학생, 군사 의료 전문가들이나 의생명 과학 전문가들이 참여하고 있다. 사용자들이 인지하는 몰입감의 경험을 기준으로 하여 사람과 컴퓨터의 상호 작용(HCI, Human Computer Interaction)을 향상시키기 위해서는, 햅틱(Haptic), 음성, 냄새 등 비전통적 상호 작용 방법이 탐구되어야 한다. 특히, 햅틱 피드백은 전통적 상호작용 방식인 시각 정보와 서로 긴밀하게 관계가 맺어진다. 시각 정보와 햅틱 피드백을 결합하게 되면, 사용자들은 몰입감을 좀더 강하게 느끼게 된다. 전세계적으로 햅틱 피드백은 오랫동안 연구되어 왔고, 햅틱 기반의 시스템도 많이 개발이 되었다. 본 논문에서는 해틱 피드백이 의료 분야에 적용된 사례들에 집중하였다. 즉, 햅틱 피드백과 이들이 의료 분야에 응용된 사례들을 정리하여 발표하였다.

Abstract Medicine is one of great application fields where Virtual Reality (VR) technologies have been successfully utilized. The VR technologies in medicine bring together an interdisciplinary community of computer scientists and engineers, physicians and surgeon, medical educator and students, military medical specialists, and biomedical futurists. The primary feedback of a VR system has been visual feedback. The complex geometry for graphic objects and utilizing hardware acceleration can be incorporated with in order to produce realistic virtual environments. To enhance human-computer interaction (HCI), in term of immersive experiences perceived by users, haptic, speech, olfactory and other non-traditional interfaces should also be exploited. Among those, hapic feedback has been tightly coupled with visual feedback. The combination of the two sensory feedbacks can give users more immersive, realistic and perceptive VR environments. Haptic feedback has been studied over decades and many haptic based VR systems have been developed. This paper focuses on haptic feedback in term of its medical usages. It presents a survey of haptic feedback techniques with their applications in medicine.

핵심어:* *VR, Haptic feedback, Haptic Rendering, Medical Imaging, Medical Training

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1. Introduction

Believable experiences of users are one of the most important goals of Virtual Reality (VR) system. Among most VR systems, visual feedback has been sufficient to provide users with immersive and believable experiences. It has been reported that non-visual feedbacks such as auditory and haptic feedbacks could also provide believable experiences. So the quality of interactions could be enhanced. In medical applications, haptic feedback particularly plays an important role. Haptic feedback, the sense of touch, is natural for human beings. The sense gives us the right dimensions of the physical world around us [1]. Palpation, surgical interventions, phlebotomy and other interventional procedures are examples where the sense of touch is of importance. The recent achievement of haptics feedback enables the user to see and touch virtual object.

P-J Fager provided a survey of the use of haptic in medicine with many examples [1]. In his discussion, broad areas of applications of VR/haptic in medicine are two-fold: *medical training* and *clinical practice*. The training area can be subdivided into *procedure training* and *anatomy learning*, and clinical practice can be subdivided into three main areas: *surgery/treatment planning, robotic surgery*, and *diagnostics*. To apply haptic feedback, it is needed to consider types of feedback, device interface, rendering algorithm and so on.

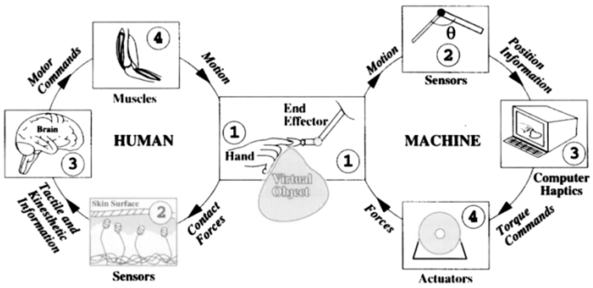
In general, the sense of touch, however, can be classified into two categories: tactile and kinesthetic. Today, most of haptic products available in market is based on these types of haptic feedbacks. More recent account of haptic devices has been produced by Laycock and Day [9]. This paper only focuses on kinesthetic haptic, the tactile haptic will not be discussed here.

The research in haptic can be categorized into three main areas: Human Haptics, Machine Haptic that in its turn including Haptic Interface and Computer Haptics [10]. Haptic interface covers the design of haptic devices or physical interfaces. Computer haptics can be considered as the techniques of generating and rendering of feedback forces. An early survey of haptic rendering techniques was presented in [2].

In this paper, we present a survey of recent applications of haptic feedback in term of its usages in medicine. The next section discusses human haptic and machine haptic. The correspondence of each human kinesthetic haptic in medical operation and machine haptic will be shown. In Section 3, an up-to-date survey of haptic rendering techniques used in medicine is presented. Section 4 will present some typical medical applications of haptic feedbacks.

2. Haptic feedbacks

The main purpose of haptic feedback in VR is to give to user a new way to interact with virtual environment or a new information channel, enabling an easy way, immersive metaphor to manipulate virtual object. There are two techniques including human haptic and machine haptic. Both are important and necessary to understanding a VR/Haptic system. The subsystem and information flow underlying interaction between human users and haptic interface are shown in Figure 1. More detailed explanation can be found in [10, 19].



(a) (b)

Figure 1: Haptic interaction between human and device (adopted from [10]): (a) human sensorimotor loop, (b) machine sensorimotor loop.

2.1 Human haptics

Human haptic is the study of how people sense and manipulate the world through touch. There are many studies of human haptic published. Considering haptic study as a study of how to couple the human sense of touch with a computer-generated world or how to presence the sense of touch in a long distance, haptic research can be subdivide into two subfields: force (kinesthetic) feedback and tactile feedback [10]. Kinesthetic feedback is the area of haptic that deals with devices interacting with the muscle and tendons. They give human the sense of a force and torque being applied and usually stimulated by bodily movements. Tactile feedback deals with the devices that interact with the nerve ending in the skin which indicate heat, pressure, and texture.

Before clinical staffs can practice medicine safely, a lot of training sessions has to be done. In early days, the training was done on animal, cadavers or living patients. In more recent days, mannequins or artificial body part models were used. However, in practice, the way of learning medicine does change. These practicing modalities all aim to give the trainee the experience of touch. In palpating diagnosis, a feel of touching soft tissue need feedback to trainee, for instant stiffness, friction, roughness, and so on. Additionally, the trainee also can feel temperature of patient's skin. In surgery, the sense of touch plays an essential role. It even requires more dexterous skills of operators than in palpation. In addition, awkward students always make mistake during training, therefore the guidance of an expert is necessary. The expert can guide the trainee by hand-holding, give the trainee the feel of guiding forces. In virtual worlds, to simulate expert guidance, the very fine forces need to be rendered and placed to trainee's hand. Hence, research of human haptic is essential to understand what kind of sense of touch the user undergo during operation, and how they react.

In training applications, understanding human haptic of each specific application is important. In procedure training, where the trainee needs to take training procedure like in the real operation. For instance, in [14, 15], a simulation of minimally invasive surgery also called laparoscopic surgery was presented. In this sort of minimal surgery, the view of surgeon is narrow. In addition, the operation of grasping, clipping, etc. require dexterous movements and manipulations that only achieve by coupling feel of touch which operator can feel via the trocars, and image from the camera. This is the same in other training procedure such as colonoscopy [16, 17].

In clinical practices, the most popular application of haptic feedback is in diagnostic, surgery and treatment planning or robotic surgery. In this field of application, it is not necessary to simulate the realistic force placing to user. The force feedback in this kind of application play the role as guiding force, in purpose to guide the operator manipulate efficiently and accuracy. Hence, the importance of an implement is how to make haptic forces be more in line with the user expectation and roles, and reduce the conflict between haptic implementation and user's own [18].

In fact, the type of human haptic is different depending on specific application such as individual training procedure (laparascopic, colonoscopy, etc.) or medical image analysis, surgical planning, etc. Therefore, the first requirement of each medical application of haptic feedback will be the knowledge about human haptic taking place in the applications.

2.2 Machine haptics

Most traditional input devices such as mouse, keyboard, digital pen, etc. and output devices such as monitor are unidirectional I/O devices providing visual and auditory information. Those devices do not exploit advances of capabilities of human kinesthetic and touch channels. Haptic interface may be viewed as an approach to address this limitation. It can be classified in area of human-computer interfaces [19]. Machine haptics covers the design of haptic devices or physical interfaces. Machine haptics associates human gestures to touch and kinesthetic to provide for communication between the humans and machines.

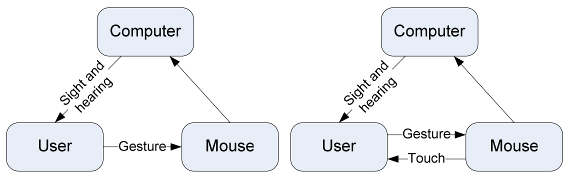


Figure 2: Conventional mouse and haptically-enabled mouse.

A good discussion of haptic interface and devices is given in [19]. One of important features of haptic interface is bidirectional information channel and demonstrating by considering an example of a "haptically enabled" mouse and a conventional mouse (Figure 2). The explanation shows that typical mouse does not receive any information from it movements, although its friction and inertial properties may assist user in performing skillful movements. The haptic mouse, on other hand, can provide user with programmable feedback based on the sense of touch, allowing a faster and more intuitive interaction with the machine.

Bidirectional devices of haptic feedbacks provide the users with the feelings of more really involving in operating process compared to conventional devices. This distinction is clearer if we consider that visual, auditory, olfactory and vestibular signals can be recorded and played without human involution. On the other side, there must be human involution in recording and replaying kinesthetic or tactile sensations except for vibro-tactile sensations [19]. Bidirectionality is the single most distinguishing feature of haptic interfaces compared with others. Haptic devices must be possible to "read and write" from human hand [19] (or foot, or other part of human body). While "read" exist in many types of devices, the "write" is comparatively more difficult to achieve, especially to recreate relationships between variables of flow and effort. In this case, haptic devices need to make use of the extensive and exquisite capabilities of human touch. To achieve this, they must be programmable, having capability of recreating mechanical phenomena of perceptual relevance and functional importance. In medicine application, this property of a haptic device is apparently significant. Each decision of operator of doctor made based on his experience is achieved via touching interaction.

A comparison of haptic interfaces with tele-operation gives a plain image of position of haptic device in the whole picture. Instead of interacting with a remote real environment, the remote slave in haptic application system is purely computational, i.e. "virtual. This gives some advances, for example, the virtual world is not restricted by normal physical constraints. That can be seen in application of haptic in clinical practice such as medical image diagnosis, surgery or treatment planning, where such that physical constraints do not always have to be followed.

Haptic devices can be classified into two classes, conventionally termed passive or active but they both share the property of programmable. Passive devices are often designed to have programmable dissipation, as a function of position and time such as controllable brakes. For active devices, energy exchange between a user and the machine is entirely a function of the feedback control applied. Usually, active devices are used to reproduce virtual environment such that these environments are passive, for example, to simulate a surgical action. These kinds of simulations require the interaction to be active. Passive devices cannot create active simulations.

3. Haptic rendering technique

Computer haptic is defined as the discipline concerned with generating and rendering haptic stimuli to the human user, just as computer graphic that deals with generating and rendering visual image to user. A haptic interface and computer haptic together are included in machine haptic. While a haptic interface concerned as a physical interface to user, computer haptic usually is considered as computer algorithms to compute force based on information from interface and generate feedback information and command to its interface. Generating and rendering force feedback is usually accompanied with matter of representation of haptic probe in virtual world, interaction techniques between haptic and surface, haptic display of shape, optimal balance between the complexity of models and the realism of the visual and haptic displays in real-time and hatic display of surface detail such as haptic texture, haptic smoothing and friction of surface etc. Based on these addressed problems, a good survey of haptic rendering techniques is given in [2].

In this paper, in consideration of haptics in medicine, we will present a survey according to usage of haptic feedback in its applications: haptic feedback in simulation, haptic feedback as guidance force, haptic as information channel.

3.1 Haptic in Medical Simulation

Most of medical simulations represent specific medical procedure such as: needle procedure, virtual colonoscopy, minimally invasive surgery, bone drilling, virtual dental, etc. Procedures feedback different types of force and require different skills from operators. Hence, the simulation system should have specific haptic interface and rendering algorithm to provide operator with the feeling of real procedure. The specificity of medical simulation usually includes: physical properties of organs, equipment of procedure, virtual tools, and procedure interaction. While equipments of the procedure are usually simulated by haptic interfaces [14, 15, 16, 17, 21, 22, 23], the interface is designed as same as the real equipment. The haptic rendering depends on virtual organs, virtual tools and interactions. Different human organs of interest can have different shapes and materials. For instance, human colon has tubular shape and soft material. Human bone has hard material and convex shape. In needle insertion simulation, intersection of a needle and virtual organ is only a point. The shape of organ does not play important role but the physically properties of elements inside organ is more important. Haptic rendering algorithm is tightly coupled with organ modelling. Here, we classified virtual organs into two classes in interm of its physical metarials: rigid organs (bone, tooth, etc.) [11, 24-27], soft organs (muscle, colon, lung, etc.) which are deformable [15, 17, 21, 22, 23].

Procedures applied to rigid parts of human body usually are: drilling, burring, sawing, milling or cutting such as in virtual dental simulation [24], bone cutting simulation for virtual petrous bone surgery [11, 27]. In general, the simulation of force feedback needs to render in such of applications including the force caused by the collision of virtual tool with virtual model, friction caused simulate movement of tool over the surface of model and effect of carving or adding. The haptic rendering algorithms of these force feedback are generally classified into two categories: surface haptic and volume haptic [25]. This classification of haptic rendering techniques according to representation of virtual of object is surface representation or volumetric representation. However, using surface based representation to create a model for medical applications, the knowledge about the interior structures of the organs is lost. This knowledge is very important when simulating interactive cutting bone operations required for surgery simulation. In addition, input data of most of medical applications are volumetric dataset such as CT scan dataset, or MRI dataset. Hence, most of haptic rendering algorithm applied to this category of application use volume haptic.

Generally to achieve the realistic haptic force feedback rendering, collisions between the tool and the static scene must be computed and a collision-free position must be determined. Figure 3 shows a situation where user moves the tools from position 1 to position 2. Since the tools cannot penetrate the object in reality, the rendering algorithm must calculate position 3 which should have been reached in reality. The force which pushes the haptic device to position 3 must be applied.

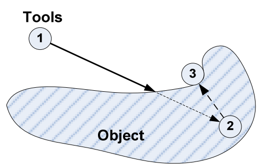


Figure 3: Situation of virtual tool movement

In order to develop a simulator for bone surgery which allows realistic drilling into the mastoid bone, the following points concerning haptics have to be considered: First, since the drilling tool is a single point representation, haptic rendering should be based on multi-point collision detection to allow realistic tool-object interactions for passive interaction. Second, for material removal, an algorithm is needed to work with sub-voxel resolution so that users can simulate the effect of small tools as in petrous bone surgery. Third, for realistic haptic interaction while modifying the models, the force rendering algorithm must calculate realistic drilling forces based on parameters such as amount of removed material, distribution of material around the drill which provides the information of local effected voxel region around drill, etc.

An early haptic rendering implementation of this simulation was shown in [29]. In this work, the virtual tool was a sphere with multi-active points on the surface which are involved in collision detection Figure 4.

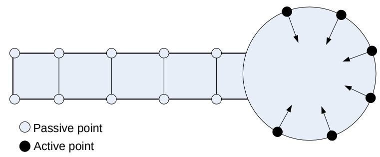


Figure 4 Tool represented by surface points and inward pointing normal vectors

To calculate force direction, collision of virtual tool with object is calculated using the active points as illustrated in Figure 5. All surface points P_i of virtual tool are checked, whether they are inside or outside the object. Corresponding forces f_i can be computed based on how much P_i penetrates the object. The equation of force computation for each individual force can be a simple spring equation (Hooke's law): $f_i = k.x_i$, where k is the spring constant and x represents the penetration of P_i into object. The sum vector f_D is direction of the force vector which is applied to the haptic device. The problem of instability comes up [28, 29] when the tool-object penetration exceeds a threshold (a certain number of surface points inside object). In order to overcome this problem, a proxy object algorithm such as god-object method is applied [30].

In order to generate realistic force feedback during drilling process, the movement of tools and the material distribution of object around the tools must be involved in force calculation. This method of bone surgery simulation was inherited and improved [27] in response of overcoming several artifacts by applying volume sampling (Figure 6). For simulating a drill rotation, tangential force is defined in response to simulate the drill bit rotation instead of using surface point [29].

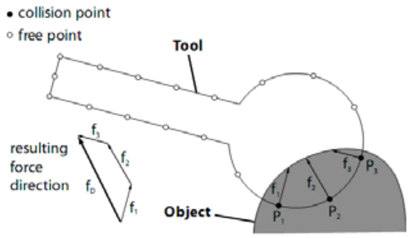


Figure 5: Calculation of force during passive interactions: f_D is calculated based on components: f_1, f_2, f_3

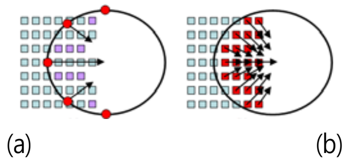


Figure 6: (adopted from [27]) Improvement of tool voxel sampling. (a) The ray-tracing approach. (b) The volume-sampling approach.

A more analytical approach of bone simulation is present in [31, 32]. To circumvent complication of simulation, the cutting process is divided into two successive steps. The first step estimates the bone material deformation and the resulting elastic forces, given the relative position of the burr with respect to the bone. The second step estimates the local rate of cutting of bone by using a-postulated-energy balance between the mechanical work performed by the burr motor and the energy needed to cut the bone, that it is assumed to be proportional to the removed bone mass [31]. Another dental training in [24] has a different approach of force rendering based on different collision detection techniques. Instead of a multi-point collision like in [28, 29] they use a single point of the virtual tool but collision detection and force computation are performed on an offset surface rather than the implicit surface. The offset value from the implicit surface is determined by the radius of bounding sphere of the tool. The center point of the bounding sphere becomes a single point (Figure 7-a) of points which collide with the offset surface. The system computes the force vector based on the offset surface (Figure 7-b). This approach can match both visual and haptic sensation and provides stable force feedback rendering.

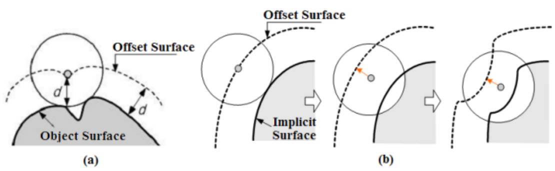


Figure 7: (a) Collision detection (b) Force computation

The challenge of surgical simulation of medical procedure that works with soft human body part is "soft tissue" modeling. Most of existing medical simulators use only the anatomy geometry and ignore usage of linear viscous elastic properties of tissues. The main challenge to achieve realism in medical simulator is to obtain deformable tissue models that are interactive, i.e. efficient to be simulated in real-time, visually and haptically realistic under some operations, for instance, manipulating, cutting and suturing. Modeling and simulation of deformable objects for real-time is not-trivial task and not in scope of this paper. In [34], a survey done by Gibson and Mirtich, they described much of work done until 1997. In brief, they divided deformable models into two parts: non-physically based models and physically-based models. Further, physically based models can be divided into discrete object models and others that based on continuum mechanic. The later review publication [33] determines some new models: Finite Element Methods (FEM) and Long Element Methods.

When haptic feedback is applied to applications interacting with deformable objects, multiple problems arise, for example, time-consuming computation, numerical instability in the integration of the body dynamics, time delays, etc. Complex and lengthy computations are forbidden in haptic systems in response to obtain realistic force feedback that require high update rate (about 1 KHz). The update rate of the simulated physical object is normally of the order of 20 to 150 Hz. The gap of simulation rates can cause an oscillatory behavior in the haptic device that can become highly unstable and inflict harm on the operator.

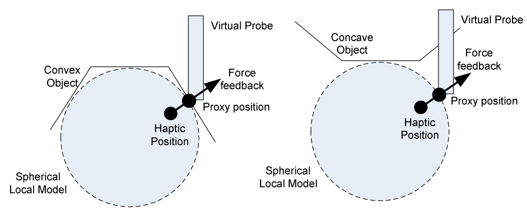


Figure 8: Intermediate representation: (a) Convex object, without graphics artifact (b) Concave object, graphic artifact occurred

Critical problems causing time consumption for computations is collision detection of objects and updating of deformable objects. To overcome this problem, the first solution was introduced in [35]. Adachi was the first researcher to apply the technique to virtual environment force-feedback system. Rather than simply supplying a single force vector to the force-feedback controller, they supplied an *intermediate representation*. This presentation is updated infrequently by the application code, but evaluated at a high update rate by force-feedback controller. This technique is adopted to use in deformable-haptic model [36, 37]. To bridge the disparity between the physical model update frequency, and the haptic rendering frequency, an intermediate representation of physical model is proposed to make haptic interaction. Instead of the complete model, the haptic loop will evaluate a simpler model. This intermediate representation will be updated at the same rate as the physical model. The early implementations of this method [37] using spheres can be regarded as intermediate models for the haptic interaction. The method can only work with convex objects. If the interaction happens to occur on a concave section, several problems can come up: graphical rendering will show the virtual probe in the object, and bad force feedback is obtained. (Figure 8).

An overcoming solution was introduced in [36]. A new local model based on topology of the virtual object is used. Instead of making the haptic interaction of all facets, a set of the facets is used. A long bar is attached to the virtual probe (Figure 9). The collisions of the long bar with objects are detected and the facet touched by the bar is determined. Only the neighboring facets to the touched-facet will compose the local topological model.

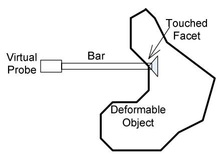


Figure 9: a long bar is added to overcome the problem caused by concave shape

Based on the intermediate representation of physical model of deformable object, the displacement of the collision can be calculated. This displacement will be used in equation for force computation. One of the most used to evaluate force is Hooke's law:

$$F_{Haptic} = \begin{cases} k \cdot d \cdot f_{model} & if\ d < 0 \\ 0 & otherwise \end{cases}$$

where *k* represents the stiffness, the physical model force f_{model} gives a more realistic feedback, and *d* is minimal distance between the local model and the haptic tool. To avoid the vibration due to sudden change in the values of f_{model}, the haptic update procedure is gradually exercised in haptic iteration until the new value is reached. The computation of the minimal distance, *d*, depends on the intermediate representation. Two main approaches were shown in [36]: *analytic based* and *local topology based*. Analytic based approach is oriented to non-highly deformable objects (for example, echographic simulation of human thigh) where *d* is computed by obtaining the distance to a sphere or to a single plane. Local topology based approach is aimed for highly deformable objects. The computation of *d* is more complicated, however updating the intermediate representation is easier since it is constructed by using the colliding facets and its neighboring facets as a set of planes.

3.2 Haptic information channel as guidance

Rather than giving realistic force in medical simulation where the force feedback should provide users with real sense of touch, haptic can be used as extra information channel to guide user to do some tasks that are usually not easy to do, for example, when a user is overwhelmed with 3D environment, or when the vision of users is limited. The goal of guiding force is to give not realistic feedback but feasibility to do the task. Hence, the force in such application is not needed to follow physical law as in simulation applications. This type of haptic usually applied in pre-procedures of medical treatment such as surgery planning and medical image diagnostics.

There are several motivations to use haptic feedbacks as guiding forces. This is often justified by the problems that come up with adding another dimension to the user interactions: Editing, controlling and interacting in three dimensions often overwhelms the perceptual powers of operator; Desktop metaphors are based on two dimensional interaction and cannot easily be extended to three dimensions; The visual channel of the human sensory system is not suitable for the perception of volumetric data. For instance, in semi-auto segmentation task of medical image, instead of do tedious seeding task again and again for each 2D image, the 3D direct seeding task is introduced. However, several issues come along with increase of dimension. With only graphic cues, the user needs skilled eyes and to be trained to do place the seeding point inside the 3D object that have volumetric representation.

In contrast to complexity of force rendering in simulation, haptic rendering algorithm is quite simpler in this case. To guide user doing tasks, some forces should be place to the haptic interface in response to force user hand to the right place during the tasks. The guide force is rendered based on the object being examined. There are two approaches for this: an intermediate representation is extracted (for example, center line of colon model [38]) and then the force constraint is established between the intermediate representation and haptic probe; the force is rendered directly based on volumetric intensity of input dataset [39]. Matthias Harders and Gábor Székely [38] proposed a haptic interaction to improve medical image segmentation. The intermediate representation is center line of intestine. First, the input dataset is binarized by thresholding, and then an Euclidean distance map is calculated (based on this distance map. The center line and force constraint are computed in order to force user hand follow the center line during placing seeding-points process.

Ida Olofsson et al [41] investigated the use of interactive 3D visualization and haptics to perform the dose planning in stereo-static radio-surgery. Intermediate iso-dose surfaces are extracted. The force is interactively rendered with the help from the user who feels the current dose distribution. The user can make a good dose-distribution for the radio-surgery.

Without any intermediate representation, Erik Vidholm et al used the direct volume haptic approach that was proposed in [8, 40]. The force computation is based on the distance between the physical position of the probe, and its virtual position and the proxy position. By using tri-linear interpolation, an intensity value and a gradient vector can be defined at arbitrary points within the volume image. The gradient is used as a surface normal that defines a virtual surface to which the proxy is constrained and the intensity value determines properties like stiffness, viscosity, and friction.

4. Applications in medicine

Applications of haptic feedback in medicine are two-folds including medical training applications and clinical practice applications. The training applications can be further classified into procedure training and anatomy learning. The clinical application can be divided into three main areas: surgery, treatment planning robotic surgery and diagnostics.

4.1 Medical training

Medical procedure training with haptic feedback can be various. According to specific procedure and the organ of interest, the configurations of the training systems are different. There are very few commercial medical simulators for procedure training available on the market. The main reason for this was cost and lack of fidelity. The first commercial product was first introduced in 1998 by Reachin company. These were the anastomosis (suturing of blood vessels) simulator from Boston Dynamics and a simulator for training in arthrosopy. It was not a commercial success and only 4-5 of them were ever manufactured. No further development and they eventually were removed from the market. Since then, there had been several initiatives to produce surgical simulators. In 2004, six to seven companies were marketing simulators for different types of procedures [1].

The most common training procedures are minimally invasive surgical (MIS) procedures, endoscopy, vascular access etc. The motivation for developing VR training system is that the working conditions in MIS are very different from open surgery such as the limit of view, indirect access to organ through thin and long instruments. The procedure is mimicked by inserting the endoscope or other instruments into a type of mannequin and followed on the screen. Haptic feedback is provided depending on how the instrument is moved in the body. This is relatively easy to do. There are several products on the market for practicing MIS, endoscopy or vascular access [26, 32, 42]. Figure 10 shows an arthroscopic training of shoulder surgery system.

Another common procedure is laparoscopic cholecystectomy (removal of the gall bladder) [14, 15, 26, 32, 42]. The system allows training of various dissection techniques used for liberating the gall bladder from the liver and for removing fat around the cystic-duct or insert clips around tubular structures and cut them.

Figure 10: For arthroscopic training surgery system.

One remarkable point of all available applications is whether the organ model is non-deformable such as bone or deformable with low level of deformable such as MIS or cataract surgery. It is because of the modality of procedure the instrument is restricted by limited movements. The major challenge in developing surgical simulators with haptics lies in soft tissue modeling. The model must look, feel and behave like real tissues. They must be deformable, cut, electro-coagulate, bleed etc. Meanwhile, it must maintain the realistic haptic sensation and in most medical procedure the sensation is required for both hands. It means there must be two haptic devices in the simulation system.

Another problem must be faced with is validation. Validation of simulator and identification of its precise role in the medical training curriculum is also an important issue. Particularly in medicine, the validation of training must be performed to ensure its benefits and its importance. Although in most case, the validation shows the benefits and advantages of the system, there still are studies with less positive outcomes [18, 43].

The other challenge in applying haptic in open surgery is "coupling haptic and graphics". An open surgery simulator should give user the 3D graphics feedback in order to provide them the feeling of presence in real-surgery. There are a number of commercial VR products on the market which can solve this problem, for instance, Reachin Display [44] or SenseGraphics [45].

Teaching anatomy is also a medical training application. Mannequins, plastic models, and 3D pictures are widely used at present. They provide the good insight view, tactile sensation. 3D images give the right shape but lack of feelings of touch, and mannequins give right shapes, but lack fidelity to touch and palpation. A simulated medical learning environment was introduced in [46]. In general the haptically-enabled anatomy learning applications also have to face with problems that procedure training applications have such as: deformable organ, collision detection, etc.

4.2 Clinical practice

Compared to procedure training applications, clinical practice is still in early phases of development. Many research works are in proceeding. Clinical practices can be exercised depending on their types whether patient directly involved, or surgical planning and diagnostic. The first type is especially related to robotic surgery such as remote surgery which is out of scope of this paper. The other two areas, surgical planning and diagnostics, might grow faster because of their fewer regulatory constraints.

Diagnostic applications are usually related to medical image analysis and detecting diseases. For instance, interpretation of 3D visualization of body is a skill requiring training, time and skilled eye, automatic segmentation of images do not satisfy requirements of accuracy. Semi-automatic segmentation is most prominent at this time, and haptic assistance is proved that it can improve segmentation process [38, 39, 47-49]. Virtual endoscopy is continuously researched. That means invasive diagnostic procedures like gastroscopy and colonoscopy may be rendered non-invasive. With haptic feedback, the borders between organs can be felt and traveling inside structures of organs becomes possible. This can significantly help in interpreting data from virtual endoscopies.

The results from diagnostic can be very useful for planning phases. It is really helpful to know how the target of operations looks like. Based on the facts, the best target approach strategy can be achieved. In radio-surgery, dose-distribution planning before operation time is important. In [41], a haptic interface for dose planning in stereo-tactic radio-surgery was proposed.

5. Conclusions

Haptic feedback and its applications are still under development today. The review of the prominent applications of haptic feedback in medicine shows us that a lot of potential applications of haptic feedback are needed to work on.

Products for medical training in surgery and other procedure simulators are already on the market, but in areas such as medical image interpretation for diagnostics and surgery and treatment planning are still in early stage. But they will greatly benefit from technologies in the future. Challenges of open surgery due to soft tissue modeling are also great areas to work on in order to have realistic and more free-form surgery simulations.

Collaboration between users in medical training system is one of great potential study. This enables users to share their knowledge which is one of the most important goals of the training systems.

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