Volume Haptics Technologies and Applications

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1 Introduction

The human vision is often considered to be our most important channel of information. It is fast, intuitive and provides a high information bandwidth. Visualization technology and computer graphics, however, pushes the boundaries towards information overload. In these cases the introduction of haptics can be of great assistance, providing realistic interaction, natural constraints and improved control. It can also be used in a range of applications to intuitively reinforce visual information and provide guidance for increased speed and precision.

Applications and technologies for haptic interaction and feedback in the litterature typically based on the interaction with surfaces, such that we encounter in reality. These aim at providing a realistic copy of real stimuli. The power of computer generated haptic feedback, however, is not limited to mere surfaces. This presentation reviews applications and implementations that are empowered by the use of non-surface data or feedback metaphors.

2 Virtual Prototyping

Volumetric data can be used to describe real object for surface simulation. Since a volume is structured, algorithms applied on such data can be made much faster than on unstructured data, such as polygonal meshes. This effect has been applied in algorithms for virtual prototyping, for example in the *Voxmap Point-shell* method by McNeely in [McNeely 1993], where the static world is converted into a volumetric mesh and the haptic probe is converted into a point cloud. For each single point in the cloud the proximity and interaction with the imlicit surfaces in the volume can be effectively calculated and the combined effects can be used to simulated both translational and rotational feedback. This approach can also be made stable for most situations [Wan and McNeely 2003].

3 Scientific Visualization

The immense amount of information in scientific, volumetric data, such as the medical Computer Tomography (CT) and the simulated Computational Fluid Dynamics (CFD), can be overwhelming and overly complex in a purly visual interface. The addition of haptic cues and guidance has great potential to increase the capabilities of such interfaces. A formative study presented in [Lundin et al. 2006] identifies two primary uses of haptic feedback in volume visualization: information, both reinforcing visual impressions and providing complementary cues, and guidance, for finding and following features as well as mental guidance. To achieve this goal there exists a range of haptic representations of data.

A straightforward approach to provide *guidance* in volumetric data is to render a pushing or pulling force towards an area of interest or in the direction of the gradient vector, e.g. as presented in [Wall et al. 2002; Olofsson et al. 2004; Bartz and Gürvit 2000; Lawrence et al. 2004]. Several researchers have also described the use of the force metaphor to convey *information* about scalar data to a user. This approach was first introduced by Iwata et al. in [Iwata and Noma 1993] where a force in the direction of the gradient vector is used to represent the orientation of scalar data in combination with viscosity to represent the magnitude of the local scalars. A similar technique has been presented also by other research groups, e.g. in [Avila and Sobierajski 1996; Mor et al. 1996; Hashimoto and Iwata 1997]. From vector data a method to convey information is to use the vector as force feedback[Iwata and Noma 1993], although more advanced approaches have been proposed[Pao and Lawrence 1998; Donald and Henle 2000; Lawrence et al. 2004].

Another common way to provide feedback from scalar volume data is to extract an explicit local or global surface (e.g. [Körner et al. 1999]) from which classical surface haptics can be calculated, or to render the haptic feedback directly from the implicit representation of surfaces, e.g. as presented in [Salisbury and Tarr 1997; Thompson II et al. 1997]. A similar approach can be used to generate a shape representation from vector data[Lawrence et al. 2004]. It should be noted that by defining distinct shapes, every piece of data not part of that subset is unrepresented in the haptic rendering. Furthermore, haptic occlusion of potentially important areas is introduced by impenetrable shapes in the volume.

The yielding shapes as a representation of volumetric data was first introduced in [Lundin et al. 2002]. To avoid occlusion by impenetrable shapes these shapes are configured to yield if subjected to a force exceeding their appointed strengths. Thus, the strength is a property that can also be used to represent information in the data, for example how distinct a feature in the data is or how certain a shape estimation is. This approach has been used in volume visualization both to provide guidance (e.g. [Vidholm et al. 2004]) and information (e.g. [Lundin et al. 2005b]). A powerful implementation based on haptic primitives was presented in [Lundin et al. 2005a].

4 Tissue Simulation

While large body of research on surgery simulation concentrates on surface simulation for realistic deformations and speed, tissues are really much more than just surfaces. Volumetric representations of tissue data and accompanying algorithms are necessary to get realistic feedback in cases where the sense of touch is of importance. Examples can be found in simulation of both soft tissues and hard tissues, such as bone.

There exists two main approaches for bone drilling, the first one being similar to the Voxmap Point-shell method described above. This method was presented by Petersik et al. in [Petersik et al. 2002]. The volume mesh is here used to describe bone density instead of proximity to static surfaces. The other approach was introduced by Agus et al. and is described e.g. in [Agus et al. 2003]. Here the intersection between a spherical drill and the voxels in the volume describing the tissues is calculated. The sum of the values in the intersection is a measure of the drill's penetration of tissues and is used to estimate the feedback.

A typical example of soft tissue interaction where touch is of utmost importance is needle insertion and punctuation. In [Zhang et al. 2008], Zhang et al. use the haptic primitives described above to simulate the haptic feedback in a spinal anaesthesia needle insertion simulator. The haptics cues that indicate tissue penetration can be felt and the correct procedure trained.

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