Tangible Images

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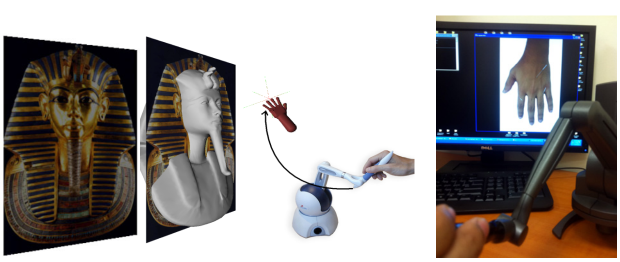
Figure 1: *Haptic interaction with a video captured by a depth sensing camera.*

1 Introduction

Visual and haptic rendering pipelines exist concurrently and compete for computing resources while the refresh rate of haptic rendering is two orders of magnitude higher than that of visual rendering (1000 Hz vs. 30-50Hz). However, in certain cases, 3D visual rendering can be replaced by merely displaying 2D images, thus releasing the resources to image-driven haptic rendering algorithms. A number of approaches have been proposed to provide haptic interaction with 2D images but they suffer from various problems and do not provide a fully believable impression of haptic sensation of the 3D scene displayed in the image. Based on the method of haptic effect generation, the existing approaches can be classified into techniques that use information derived from the image, and techniques that use additional information along with the image to enable haptic interaction. Previously, we proposed our own method of augmenting images with haptic data for using them in shared virtual environments [Rasool and Sourin 2010]. The images were augmented with invisible haptic objects defined by implicit, explicit and parametric mathematical functions using the function-based extension of the Virtual Reality Modeling Language [Wei and Sourin, 2011].



(a) (b)

Figure 2: (a) *Augmenting images with invisible 3D haptic objects,* *(b) Augmented image-based acupuncture simulation.*

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Haptic interaction then is performed with these invisible objects so that there is an illusion that the objects displayed in the image are actually being touched by the haptic device (Figure 2).

2 Haptic images captured with depth sensors

Continuing our research, we propose new algorithms to perform image-driven haptic interaction using depth information provided both by depth sensing cameras and/or obtained from the image itself. Specifically, we first devised and implemented a new haptic rendering algorithm that uses depth information captured by a low cost depth sensor Microsoft Kinect™, then expanded this algorithm to the case where depth information can be obtained directly from the image, and finally combined these two methods with the algorithm calculating fine haptic textures.

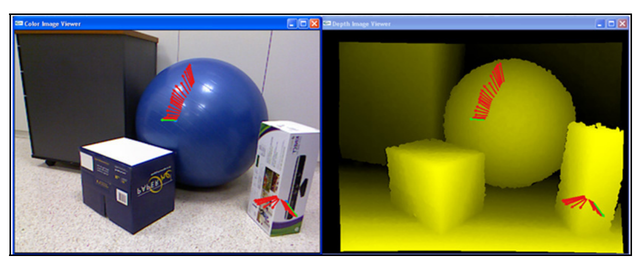

Figure 3: *Screenshots showing haptic force directions at various points in the scene, overlaid on color image and depth map.*

Use of low cost depth sensors to provide haptic feedback from captured point clouds has previously been reported for automatic generation of virtual fixtures in real time, e.g. [Ryden et al, 2011]. We propose a very different approach. Our algorithm does not generate a point cloud but rather uses the depth map of the scene directly to generate haptic feedback forces at each point of interaction. Hence, neither 3D reconstruction nor polygonal models are involved in the haptic force calculation. The pixel-wise depth captured is estimated based on the distance from the camera. In our method, depth image is used as a height profile of

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the scene in a 3D space. Haptic feedback forces are calculated based on these depth values. As the haptic interface point (HIP) moves in the virtual space, it is tested for collisions with the height profile of the scene at every frame. Collision detection then is merely a test to check if the HIP lies above or below the height profile. This will require, however, additional measures to smooth the force feedback vector calculation to avoid kicking and buzzing. This is done by super-sampling the force vector calculation and averaging it at a few previous calculations and neighboring locations. In Figures 1 and 3, we illustrate how such haptic interaction can be performed. Red arrows show the direction and magnitude of the 3D haptic force calculated when interacting with the image.

When depth sensing cameras are used, fine geometric details of the object surfaces cannot be normally felt with haptic devices due to the precision of the depth camera. Therefore, we propose to combine the depth-based method with shading-based haptic texture rendering techniques, such as [Vasudevan and Manivannan 2008], to provide haptic sensation of both geometry of the objects displayed in the image and fine haptic textures on their surfaces. This is illustrated in Figure 4 where combination of methods permits to feel both the overall visible geometry of the captured objects as well as fine surface details.

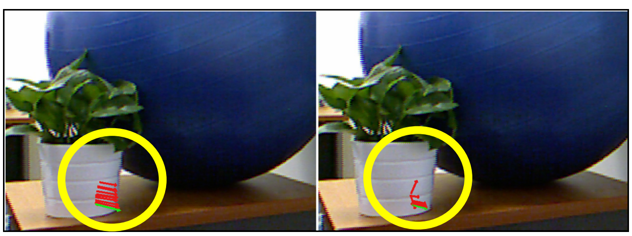

Figure 4: *Combining geometry and texture rendering algorithm. Smooth surface is felt using depth information alone (left). The combined force direction due to addition of shading-based haptic texture forces is being calculated (right).*

When the depth information cannot be obtained from the depth sensing cameras, we propose how to derive it from the image itself. This approach although is limited to mostly natural images (e.g. photos of human body parts, images from guidance devices in minimal invasion surgery). These images are normally obtained with frontal illumination and the captured objects do not have fine color patterns that can be confused for surface variations. We smooth the images based on the color statistic information, perform their segmentation to assign different haptic properties to different parts of the image (e.g., in medical images: solid bone surface or soft and viscous tissues and fat), convert them to gray-scaled maps and calculate depth values proportional to the pixel values of this processed image. The original image is still used as a guide for haptic interaction. In Figure 5 (a-b) we show how the proposed algorith can be applied to surgical training system that uses actual views obtained through the guidance system when a minimally invasive knee surgery is performed. In Figure 5 (c), the respective segmented image is shown, and, in Figure 5 (d), smoothing of the depth data obtained from the image is illustrated.

Video demos illustrating the results achieved can be seen at http://www.ntu.edu.sg/home/assourin/Tanimage/Video.htm.

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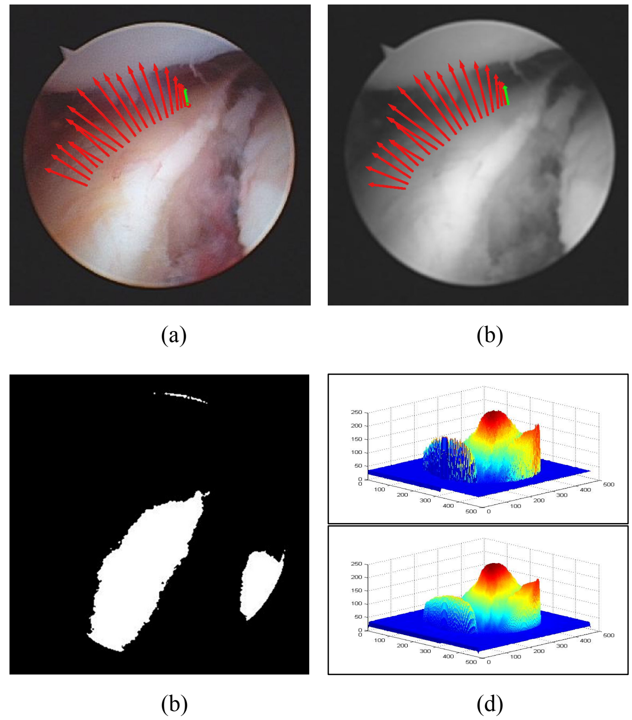

Figure 5: *Shading-based haptic texture rendering algorithm applied to 2D minimal surgery images. (a) Actual image as seen in the viewer of the minimal invasion surgery guidance system, (b) Smoothed depth map obtained from the image, (c) Segmented image, and (d) Smoothing of the respective depth data derived from the image.*

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