Haptic Rendering of Interaction between Textured Models

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1 Introduction

Haptic rendering of forces and torques between interacting objects, also known as 6 degree-of-freedom (DoF) haptics, has been demonstrated to improve task performance in applications such as molecular docking, nanomanipulation, medical training, and mechanical assembly in virtual prototyping. Moreover, surface texture can provide a compelling cue to object identity and strongly influences the forces that must be applied in manipulation [Klatzky and Lederman 2002]. However, up to date haptic rendering of texture effects has been limited to the case of point-object interaction. Previous techniques for 6-DoF haptic rendering, such as [McNeely et al. 1999], could not capture high-frequency geometric detail, due to voxelization and point sampling limitations. Otaduy and Lin [2003] proposed a technique that selected object resolution adaptively at each contact. This approach also filtered high resolution geometric detail, thus texture effects were completely ignored.

We have developed a novel haptic rendering algorithm that, similar to graphic texture mapping, represents objects as low resolution polygonal models along with texture images storing fine geometric detail. We are able to haptically display intricate interaction between highly complex models using *haptic textures* instead of actual surface geometry (See Fig. 1).

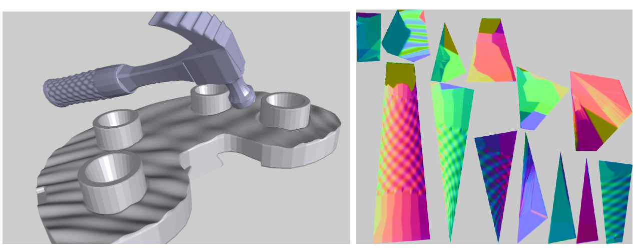

Figure 1: **Haptic Texture Rendering.** *Left: high resolution textured hammer (433K polygons) and CAD part (658K polygons). Right: hammer texture of fine geometric detail.*

2 Haptic Texture Rendering Algorithm

Our haptic texture rendering algorithm works as follows:

1. Each frame starts by performing object-space collision detection between low-resolution polygonal meshes. We identify intersecting surface patches as contacts and characterize them by a pair of contact points and a penetration direction.
2. At each contact, we approximate the directional penetration depth and its gradient using fine geometric detail from haptic textures. We have designed an image-space algorithm and developed a GPU-based implementation that enables fast computation at haptic rates.
3. We compute per-contact force and torque using a novel force model for texture rendering, inspired by perceptual studies [Klatzky and Lederman 2002]. The vibratory motion that conveys haptic texture information is induced by forces and torques proportional to the gradient of penetration depth.
4. Finally, net force and torque are computed, and rendered to the user using a virtual coupling method to improve stability.

*http://gamma.cs.unc.edu/HTextures

3 Results

We have tested our new haptic rendering algorithm on polygonal models of high complexity (several hundred thousand triangles) with rich surface texture, as shown in Fig. 1. The models are simplified down to a few hundred triangles, which is the average size that can be handled by prior haptic rendering techniques [Otaduy and Lin 2003]. Such a drastic simplification eliminates all texture information from the actual surface geometry. With our approach, high resolution geometric detail is recaptured in haptic textures. At runtime we use haptic textures to refine object penetration depth, so we can compute force and torque that render the resulting texture effects.

We have created benchmarks to test how well our algorithm conveys texture effects. In Fig. 2 we show test scenarios for translational and rotational motion. The graph reflects force and motion profiles for the translation case. The low resolution models do not present any bumps, so the high frequency components in both force and motion are generated solely by our new haptic texture rendering algorithm.

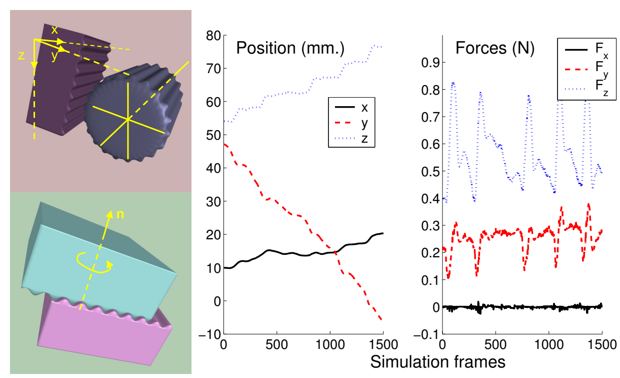

Figure 2: **Force and Motion Profiles.** *Left: test scenarios for translational (top) and rotational (bottom) motion. Right: position and force profiles for the translational case.*

The GPU-based implementation of penetration depth computation enables rendering rates of 500Hz for the benchmarks shown in Fig. 2, and worst-case update rates between 100 and 400Hz for highly challenging contact scenarios as shown in Fig. 1. With the performance growth curve of GPUs exceeding Moore's Law, we expect to achieve rendering rates of 1kHz in a year or two without further optimizations.

References

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