The Visible Ear Surgery Simulator

Peter Trier[1], Karsten Østergaard Noe[2], Mads Sølvsten Sørensen[3], and Jesper Mosegaard[4] (mail@JesperMosegaard.dk)
[1] Alexandra Institute, [2] Department of Computer Science, [4] Institute of Information and Media Studies, University of Aarhus, Denmark [3] Department of Otolaryngology Head and Neck Surgery, Rigshospitalet, University of Copenhagen, Denmark.

BACKGROUND

We present the initial development of a computer simulation of surgical procedures in the inner and middle ear based on volume rendering and haptic interaction. We utilize a unique voxel based true-coloured data set called "The Visible Ear" [1].

We are concerned with a number of surgical procedures which all have in common that the surgeon must drill into the temporal bone to achieve access to the middle or inner ear. The anatomy of the temporal bone is very complex and contains delicate structures. In order to navigate safely during ear surgery one of the primary difficulties for the surgeon is recognizing the spatial arrangement of the neural and vascular structures in the middle and inner ear through landmarks and features seen through slight transparent material. An accurate and "true-coloured" visualization including transparency is hence a crucial element. Existing simulators (e.g. [2,3]) are based on MR and CT images and consequently cannot deliver a true-coloured visualization.

METHOD

The simulator supports the basic use cases of positioning the patient, adjusting lighting, and drilling into the bone structures near the ear of the patient. The user interacts with the simulator using a haptic feedback device (Phantom Omni). Shadowing and surface shading in the tissue and bone, aids the surgeon in recognizing anatomical landmarks. Each segmented part of the volume data-set can be turned on or off in the visualization.

We use ray casting implemented as a fragment program executed on the Graphics Processing Unit. Dispatching of rays is optimized through the use of a Cube-Texture [4]. We divide the rendering into an "active camera" and a "passive camera" mode. In the case of an active camera the primary role of the visualization is to guide the surgeon in the overall rotation and position of the patient. Hence, an accurate visualization is not necessary, but should have a fast frame rate. In this mode we do not include transparency in our visualization model, and simply display the colour of the front most surface in our volume data This surface is found through hit point refinement [5]. In the case of a passive camera we can assume that the viewing direction does not change since the surgeon is operating on the patient. If we where to ray march through the entire volume we would potentially spend a lot of time stepping through "empty" voxels. We have consequently implemented a *depth peel* pre-processing step, inspired by [6] for polygon based transparency. In the depth peel process we detect front facing iso-surfaces for each ray, and save that information into a number of 2D textures (see figure 2). In subsequent rendering steps we look into those textures and use the information to skip regions of empty space. The self shadowing for a surface voxel is determined by tracing a secondary ray towards the light source. Shadowing from instrument to volume is realized by constructing a cube map around the light source. Into this cube map we render the polygon based drilling instrument and store the depth from light to instrument in each pixel. This method is inspired by the shadow maps method [7].

We use the technique of [8] to implement a multi point collision detection scheme in combination with proxy-objects [9]. Consequently, the total force is the sum of the two kinds of forces; multi point contact based and proxy object based. Contact forces are sampled at point positions evenly distributed on a sphere surrounding the drill head. Colliding points contribute to the total force with a force directed towards the center of the sphere.

RESULTS

The simulation has been executed on a 3.2 ghz pentium 4 / Nvidia 8800GTX resulting in 78 fps including phong lighting term, self shadowing, and tool shadows enabled (screen resolution 800x800 and data resolution 256x256x512). See figure 1.

DISCUSSION / CONCLUSION

We have developed a simulator for surgical procedures in the middle and inner ear. In terms of performance the simulator has shown to easily fulfil real time requirements. In addition the system has been classified by an expert to fulfil the initial requirements in terms of visual and interaction realism.

REFERENCES

[1] M. S. Sørensen et al. The Visible Ear: A Digital Inage Library of the Temporal Bone. In 'ORL Journal for Oto-Rhino-Laryngology and Its Related Specialties. Vol. 64, No. 6, 2002
[2] M. A. Hutchins et al. A networked haptic virtual environment for teaching temporal bone surgery. Stud Health Technol Inform. 2005;111. Pages 204-7.
[3] J. Bryan et al. Virtual temporal bone dissection: a case study. In Proceedings of the Conference on Visualization '01. Pages 497-500, 2001.
[4] S. Roettger et al. Smart hardware-accelerated volume rendering. Proc. Symposium on Data Visualisation 2003. 231-238, 2003.
[5] M. Hadwiger et al. Real-Time Ray-Casting and Advanced Shading of Discrete Isosurfaces Computer Graphics Forum Volume 24 Issue 3. September 2005. 303.

[6] C. Everitt. Interactive order-independent transparency. White paper, Nvidia 1999.
[7] M. J. Kilgard. Shadow Mapping with Today's OpenGL Hardware. White paper, Nvidia 2001
[8] A. Petersik et al. Realistic Haptic Interaction in Volume Sculpting for Surgery Simulation. Surgery Simulation and Soft Tissue Modeling, International Symposium, IS4TM 2003. 192-202
[9] C.B Zilles et al. A constraint-based god-object method for haptics display. Proc. International Conference on Intelligent Robots and Systems. Volume 3. 3146, 1995.

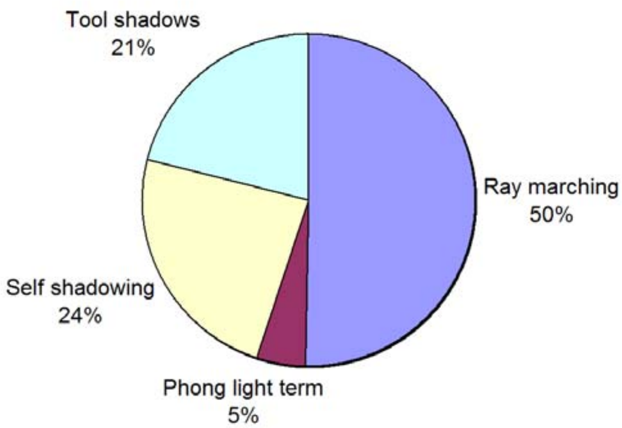

Figure 1. Pie chart depicting distribution of rendering time spent on the different parts of calculations in active camera mode. The values are average measurements.

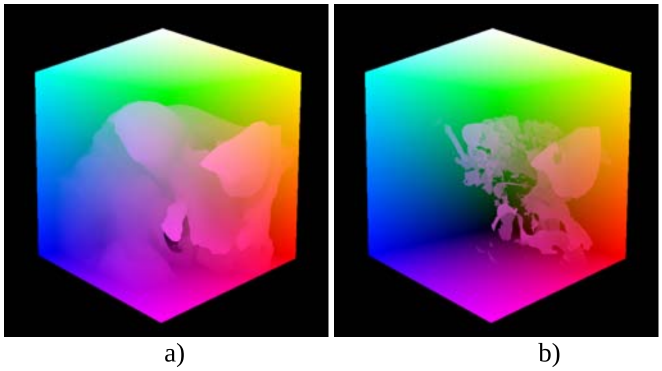

Figure 2. Depth peel textures showing the first two front facing layers a) and b).

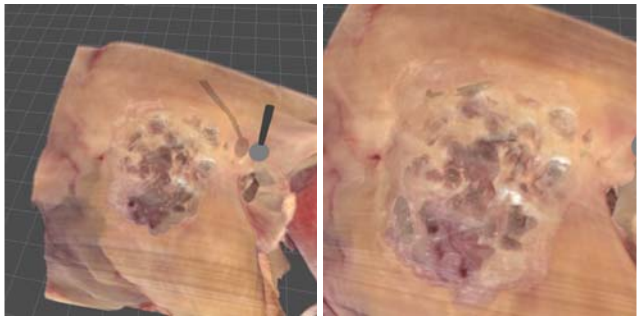

Figure 3. Drilling into the ear, removing bone fragments.

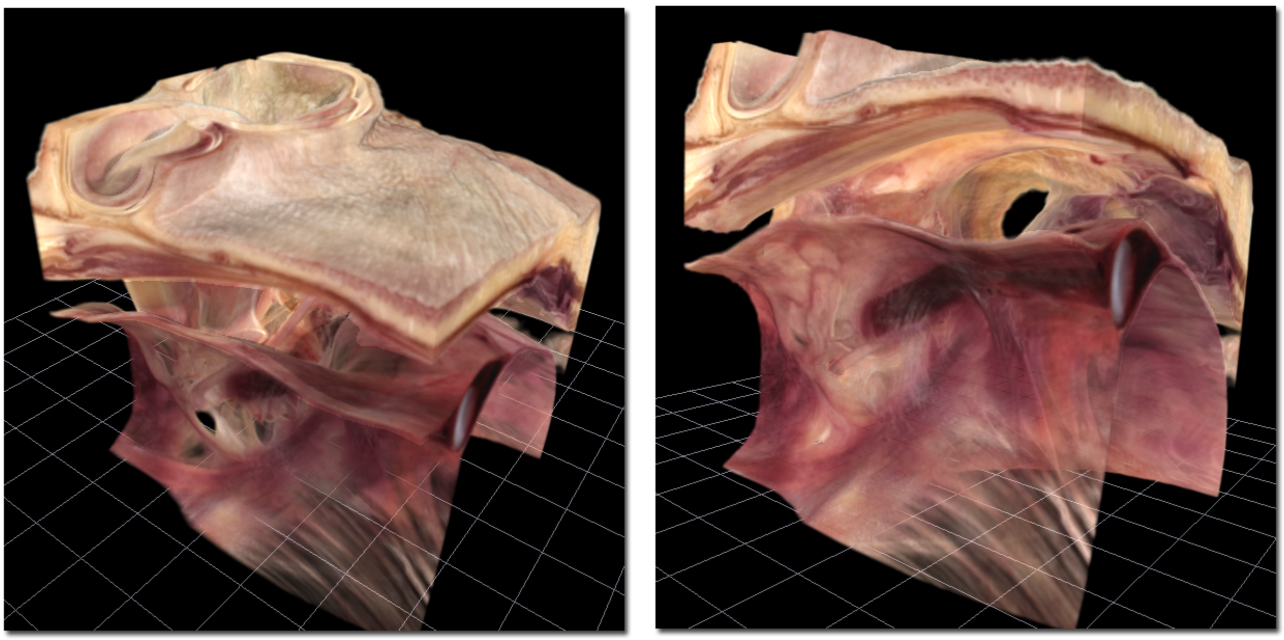

Figure 4. Screenshots from the Visual Ear Simulator.