A User-Centered Designed FOSS Implementation of Bone Surgery Simulations

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Abstract

Different aspects of bone surgery simulation has been a popular topic in haptics research field. This demonstration paper has two major results: a Free and Open Source Software (FOSS) implementation of a well known algorithm for tool-bone interaction force estimation, and an evaluation conducted as part of a suggested User-centered design approach for creation of a surgery simulator targeting Oral Surgery in particular.

Index Terms: H.1.2 [MODELS AND PRINCIPLES]: User/Machine Systems—Human factors I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O; I.3.8 [Computer Graphics]: Applications—Simulation

1 Introduction

Bone drilling is an important topic in haptics research, with applications in both dental industry and other surgery simulations. In the search for effective haptic rendering of collision between a spherical burr and volumetric representations of bone tissues, two pricipal methods have been presented by Petersik et al. (e.g. in [5]) and Agus et al. (e.g. in [1]), respectively. Petersik et al. choose to model their burr by a shell of discrete points and calculate their individual interaction with the tissue data. The algorithm by Agus et al. on the other hand, keeps the continuous representation of the burr and calculate the intersection of this sphere and the voxels classified as bone tissue. By keeping the continuous representation of the burr, this method is void of feedback discontinuities.

Creation of a surgery simulator involves many aspects, where haptic feedback is a major part among others. There are still unanswered questions to what is the learning objective and what is the most important part of a particular procedure to simulate, and to what extent it can be simulated successfully. An approach to these questions while designing a new surgery simulator is by utilizing a User-centered design process, where the users, the surgeon teachers and their students, are closely involved in the process.

Foundation principles of User-centered design is to early focus on users and tasks, perform empirical measurements by getting user feedback and reactions on design and prototypes, and apply iterative design [6].

2 The Demonstration

The hands-on demonstration at World Haptics 2009 is based on the two results: the software package and the Oral Surgery application. The functionality and available parameters of the software package is demonstrated as small examples of XML code and executed on a computer with attached haptic device. The demonstration include how the examples can be used by non-programmers for psychophysical experiments, and real-time parameter adjustments. In the Oral Surgery simulator case, an immersive setup (figure 2b) is displayed which provides a multimodal experience for the audience, who is given a guided instruction of where to drill in a standard operation procedure.

3 The Software

The philosophy behind the implementation presented here is to provide a complete Free and Open Source Software stack that can be used as the basis for surgery simulators, psychophysical experiments and evaluations. The aim is to have the reference implementation built using industry best practices as we know it.

3.1 Force Estimation Algorithm

The basis for the haptic algorithm is the direct volume sampling algorithm developed by Agus et al [1]. In short, it calculates the force magnitude as the height of the sphere segment that has the same volume as the intersection of tool and bone classified material, and the force direction as a weighted sum of the intersected voxels vectors. The calculations are helped by treating the voxels as spheres with same volume as the cubed sample distance (figure 1). In the current

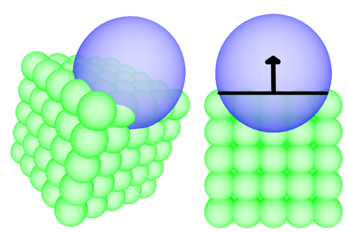

Figure 1: Illustration of Agus algorithm. The sample data is treated as spherical voxels and the force magnitude is related to the intersection of drill and volume.

implementation, we have however estimated the force magnitude to the total intersected volume instead of the sphere segment height, and also normalized it according to the chosen radius of the sphere drill tool.

The algorithm is packaged as a node to be used in a scene graph, where the basic parameters: radius, force constant (to be multiplied by estimated force), optional damping constant and iso value for bone classification. These can be set by editing an X3D (XML) file without re-compiling any code.

In addition to the parameters mentioned above, one can specify a standard variance to the iso value, which given the stochastic nature of the underlaying Computed Tomography data, can classify material as part of bone by a factor.

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3.2 Material Eroding

Material erosion has been implemented separately from force estimation and feedback node to enable exchange and evaluation of different algorithms. The standard algorithm is holding a separate lookup table of equal size of the volume, which keeps track of intersection time and erodes material accordingly to a per-voxel specified factor.

3.3 Package

Source code, scripts and examples are released in a package called "forssim" which is written in C++ and based on an free and open source scene graph implementation, H3D.

Additional graphical rendering is provided by API for real-time ray cast based volume rendering and parallelized marching cubes.

4 Application: Oral Surgery

The objective of development for the forssim package was to create a viable Oral Surgery simulator. Surgical extraction of wisdom teeth is an important procedure of which theoretical aspects are taught in dental education in Sweden. Unfortunately the students get no or negligible practical training due to limited resources, although it is highly requested by graduated dentists and current students [2].

A User-centered design method based on the ISO 13407 was applied in this project. The standard comprises of four design activities that form one iteration, which is by definition to [3]:

1. understand and specify the context of use
2. specify the user and organizational requirements
3. produce design solutions
4. evaluate design against requirements

A first iteration of the design process was conducted in second half of 2007, by performing field studies, contextual inquiry, prototype design and implementation and a cooperative evaluation. The field work included study visits both to hospitals and odontology class rooms. The contextual inquiry compromised mainly by three surgery observations which was then followed up by semi-structured interviews and drilling experiments.

The results from the studies were the foundation for the prototype design. In interviews surgeons emphasized that a big factor for the difficulties of third molar procedures was the restricting context – the mouth, and that it was impossible to drill from all angles. This lead to the design decision to include a polygon mesh face model as a non-interactive context surrounding the area of surgery, which was obtained from CT scan of a live patients head (figure 2a). The area of surgery was visually rendered by a ray cast based direct volume rendering method provided by underlying API.

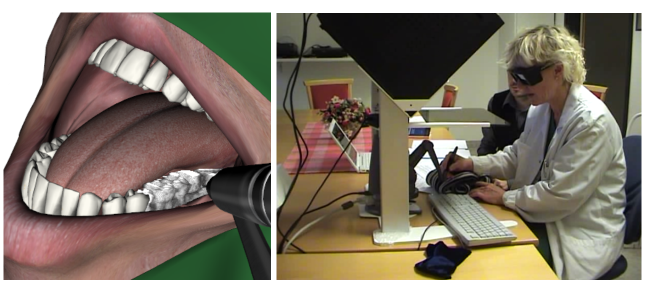

Figure 2: a) Screenshot from Oral Surgery project. Note the volume rendered molar teeth and bone inserted in the polygon mesh face. b) Immersive setup used in Oral Surgery project during Cooperative Evalution. Note the hand supportin scarf.

The first iteration's prototype simulator was constructed along with the developed software, using an immersive setup, comprising of a co-located Sensable Phantom haptic device, seen by the user through a mirrored image with stereo shutter glasses, (figure 2b).

5 Evaluation

The goal of the first evaluation was to verify design decisions and get input for modifications in future iterations. Cooperative Evaluation is a method where the evaluator sits next to the user, who is requested to "think aloud" while performing a given task with relative freedom of operation. In this method both the evaluator and the user are cooperating and the evaluator is allowed to and expected to have a continuous dialog with the user [4].

Together with four surgeons from Karolinska Institutet, the first Cooperative Evaluation of the prototype was performed in late 2007. The task comprised of a preliminary free exploration of the simulator's capabilities, followed by the surgeons performing the mandibular bone carving part of the extraction procedure.

The protocol for this study was based on Appendix 1 of Monk et al's work[4]. The Cooperative Evaluation session was followed immediately by a short interview to summarize the user's experience and evaluate the prototype design.

5.1 Evaluation results

The results from the first Cooperative Evaluation captured several aspects not revealed in previous studies in the project. For example the position and angle of the patients head should be laying down and accessed from the side. One surgeon expressed the need of having a hand support since they support their hand to patients head. In the evaluation one surgeon tried with positive outcome to support the hand with a scarf (figure 2b). One important result related to haptic feedback was the "painting movement" surgeons requested. The surgeons carve by a sweeping motion that differs from the engineer's own trials. What the exact meaning of "painting movement" is subject to further research. This requirement was not revealed until the Cooperative Evaluation.

In the post-Cooperative Evalution interviews, the importance of having a contextual (polygon mesh) head was confirmed. There were also requests to interactively control the surgical tissue flap with a wound hook. Overall feedback was positive in the sense that the surgeons clearly saw the potential and that simulator based surgical training in this field was within reach.

6 Conclusion

We have in this demonstration paper presented a Free and Open Source Software stack providing a volume based haptic algorithm that has been demonstrated to be applicable in the construction of an Oral Surgery simulator prototype. Additionally the applied User-centered design approach has in the Oral Surgery project been a very useful tool that is recommended for adoption.

References

[1] M. Agus. *Haptic and Visual Simulation of Bone Dissection*. PhD thesis, Dept. of Mechanical Engineering, University of Cagliari, Italy, 2004.

[2] J. Forsslund. Simulator för operativ extraktion av visdomständer. Master's thesis, Kungliga Tekniska Hgskolan, 2008.

[3] ISO. *Human-centred design processes for interactive systems (ISO 13407:1999)*. International Organization for Standardization, 1999.

[4] A. Monk, P. Wright, J. Haber, and L. Davenport. *Improving you human-computer interface: a practical technique*. A volume in the BCS Practitioner Series, Prenice-Hall, ISBN 0-13-010034-X, 1993.

[5] A. Petersik, B. Pflesser, U. Tiede, K. H. Hhne, and R. Leuwer. Realistic haptic volume interaction for petrous bone surgery simulation. *CARS*, 2002.

[6] J. Preece, H. Sharp, and Y. Rogers. *Interaction Design*. Wiley, 2002.