Simulator for Operative Extraction of Wisdom Teeth

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Figure 1: *Oral surgeon in cooperative evaluation*

Abstract

Hands-on practical experience in oral surgery is highly requested by dental students and faculty. For the purpose of training, a haptic enabled simulator for surgical extraction of wisdom teeth was designed. A prototype was implemented and evaluated with surgeons from Karolinska Institute as part of a user centered design approach.

Keywords: haptics, medical simulation, user centered design

1 Background

Dental education in Sweden covers the theoretical aspects of oral surgery, but students unfortunately receive no or negligible practical practice due to limited resources. However, hands-on practical experience in surgical procedures is highly requested by students. The purpose of the research is to develop, through an applied user-centered design approach, a simulator that allows students to practice and perfect surgical procedures for wisdom tooth extraction before operating on live patients.

2 Surgery simulators

Some of the difficulties associated to the creation of a haptic enabled surgery simulator are the real-time constraints. A successful simulator requires real-time interaction with virtual organs via a force feedback interface in combination with real time visualization of the applied deformations. Simulators work best with multimodal displays, especially audio combined with haptics [Roberts and Panels 2007].

Commercially successful medical simulators exists in the field of endoscopy training. It has been proven that simulator based training of the required visual-spatial and psycho-motor skills required for such procedures significantly improves the performance of students [Fellnder-Tsai and Wredmark 2004]. The improvement of students performance can be measured in time and in some procedures as level of patient discomfort. It has been shown that students perform faster and with less patient discomfort in the first live patient examinations after undergoing simulator based training [Ahlberg et al. 2005].

Bone and dental surgery simulators have not yet been as extensively evaluated, but there are numerous research projects related to applications in bone surgery simulation technology. The main tool of use with these kind of simulators is the rotating drill and the object of deformation is hard tissue. For example research at Stanford focuses on both mandibular surgery and temporal bone surgery [Morris et al. 2006].

3 User centered design

In this project, a user centered method based on the ISO 13407 was used. The ISO standard model comprises of four design activities that form one iteration, which is by definition [ISO 1999]:

1. Understand and specify the context of use
2. Specify the user and organisational requirements
3. Produce design solutions
4. Evaluate design against requirements

The method was applied by conducting a Contextual Inquiry comprising of interviews, surgery observations and hands-on drilling experiments, followed by implementation of a prototype simulator that was evaluated with surgeons. The process should be considered the first development iteration, where results from the evaluation is input to the following design iteration.

4 Simulator implementation

An immersive setup was used, see figure 1, where the user control the handle of a Sensable Phantom haptic device while looking at a monitor through a mirror, positioned so that the handle is co-located with the image of the virtual drill. Stereo shutter glasses provides the user with depth vision and the simulation ran on a Pentium 4, 3.4 GHz computer equipped with a Nvidia Quadro FX1400 (128mb) graphics card. The software was implemented in C++ based on SenseGraphics open source API's.

The contextual inquiry suggested that it was of great importance to visually constrain the work space since the mimicked environment context was a patient's mouth. The context of choice was a polygon mesh of a standard head, modified to suit the particular surgical task. In the model's mouth, a carvable jaw part was placed that contain a partially impacted wisdom tooth and proximity bone and teeth, as seen in Figure 2.

4.1 Haptic rendering

The three degree of freedom haptic device simulates a one-point interaction and therefore needs active hand movement to provide

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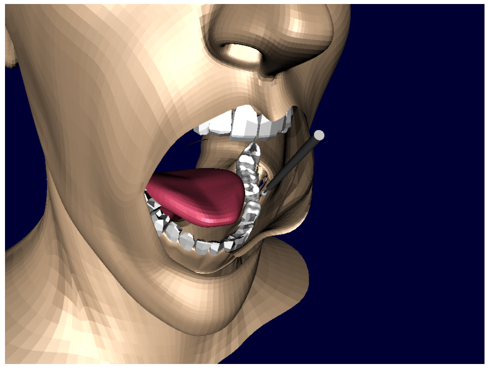

Figure 2: *Screenshot of the volume rendered jaw part placed in a polygon mesh model.*

exploration of a virtual surface. In our case the virtual surface is the human jaw, and the tool of exploration is the drill.

Virtual shapes are simulated by rendering forces to the haptic device in an update rate of normally 1000 hz. The basis for the haptic algorithm implemented in this project is a volume intersection model developed by Marco Agus, where the force magnitude and direction are calculated from the sampled volume intersection of the spherical drill and the volume model [Agus 2004].

The carvable jaw part was cropped from a 512x512x277 scalar field volume obtained from a Computed Tomography scan of a live patient's head. An attenuation threshold classification method was used to binary classify voxels as part of material or not. Material was considered as attenuation values above soft bone, lower values was considered air (although most was flesh etc). Since the classification was the basis for the force calculation, having only one threshold value creates artifacts perceived as an undulated rough surface. Given the stochastic nature of the x-ray attenuation, a one-sided Gauss filtering was applied which reduced the roughness [Forsslund 2008].

4.2 Graphical rendering

The same jaw part volume used for haptic rendering was rendered visually by a ray cast based volume rendering method provided by API. An opacity transfer function was used, but with no explicit segmentation. The model was updated in almost real time without further optimization. The base for the contextual polygon mesh model was obtained from a modeling tool called MakeHuman and modified in standard 3D modeling software, Blender.

5 Evaluation

The goal of the 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 has been given a task to perform but relative freedom of operation. It is important to get the user to provide constant feedback in order to capture the user's goal and if the system's response is as expected [Monk et al. 1993].

A first Cooperative Evaluation of the prototype with four surgeons from Karolinska Institute was conducted in late 2007. The task was, after a preliminary free exploration of the simulator's capabilities, to perform the first mandibular bone carving procedure of the wisdom tooth extraction surgery. The study was performed on a protocol based on Appendix 1 of Monk et al's work [Monk et al. 1993].

6 Results

The Contextual Inquiry revealed that tacit knowledge that surgeons rely on, using vision, hearing and touch was essential in surgery. For vision, the very constrained environment of the mouth implied the design of the context mesh has to be taken into account to accurately reflect the actual surgical environment. The interviews suggested that simulated audio was not important, but later proved to have greater importance in the evaluation. Overall, the results of the Cooperative Evaluation showed that training by virtual jaw bone drilling was possible.

The source code for this simulator has been rewritten and released as free and open source software under the name "forssim".

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