Augmented Reality Haptics System for Dental Surgical Skills Training

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Abstract

We have developed a virtual reality (VR) and an augmented reality (AR) dental training simulator utilizing a haptic device. The simulators utilize volumetric force feedback computation and real time modification of the volumetric data. They include a virtual mirror to facilitate indirect vision during a simulated operation. The AR environment allows students to practice surgery in correct postures by combining the 3D tooth and tool models with the real-world view and displaying the result through a video see-through head-mounted display (HMD). Preliminary results from an initial evaluation show that the system is a promising tool to supplement dental training and that there are advantages of the AR over the VR approach.

CR Categories: H.5.1 [Information Interfaces And Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces And Presentation]: User Interfaces—Haptic I/O

Keywords: Dental training simulator, augmented reality, haptics

1 Introduction

Traditional methods for dental surgical training rely on practicing procedural skills on plastic teeth or live patients under the supervision of dental experts. The limitations of this approach include a lack of real-world cases and concerns for patient safety. Recently, integration of virtual reality (VR) technology and haptic technology has resulted in a number of dental simulators for clinical and surgical training [Yau et al. 2006; Kim and Park 2009]. The advantages of these simulators are that the students are allowed to make errors and are able to practice procedures as many times as they want at no incremental cost.

A realistic dental simulator for surgical training would allow a student to drill into a virtual tooth and feel the different stiffness of different anatomical structures. To achieve this, volumetric representations of tooth models can be applied as they provide information about the internal structure of a tooth crucial for realistic graphical display and haptic force feedback.

Many VR simulators do not implement a virtual dental mirror, despite the fact that dental mirror is a vital instrument for many operations, especially those requiring indirect vision. Another issue with many VR simulators is that they are not co-located; users have to look at the monitor instead of their hands during an operation. This makes hand-eye coordination difficult and results in unrealistic simulation. Thus, skills acquired from these simulator might not transfer well to the operating room.

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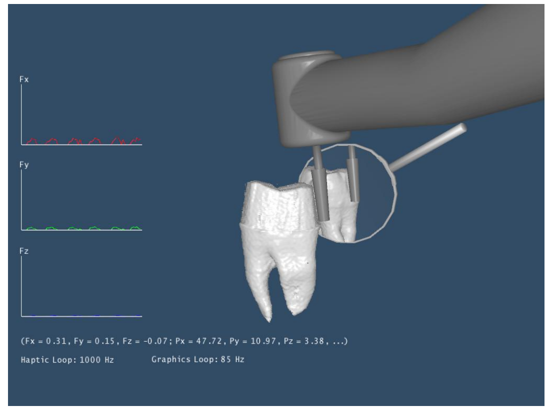

Figure 1: *Screenshot of the VR dental simulator.*

2 Dental Simulator with Volumetric Haptics

Our VR dental simulator (Figure 1) consists of a graphical display and a haptic device for simulation of virtual dental tools. The system allows dentists to practice using a probe to examine the surface of a tooth, to feel its hardness, and to drill or cut it. We provide an optional second haptic device to control the virtual dental mirror. We use OpenGL's stencil buffer to realize real-time reflection. For a system with only one haptic device, we allow users to switch between the dental handpiece and mirror.

The tooth model used in our simulator is acquired from a micro-CT scanner at a voxel resolution of $128 \times 128 \times 256$ [Menz 2006]. The tooth is stored in the form of a three dimensional grid of voxels representing the density of the structure at each point with a value between 0 and 255.

Our system performs visualization, haptic rendering, and real-time modification of the volumetric data with the help of the the PolyVox library [Williams 2010]. PolyVox provides a hybrid data structure consisting of a 3D volumetric grid, used for haptic rendering and real time modification, and a triangular surface mesh, used for graphic rendering. PolyVox extracts the surface mesh from the 3D grid and updates it whenever a change to the 3D grid occurs. We perform uniform volumetric sampling of a set of points from the bur region of the handpiece; these sample points are used for collision detection and haptic rendering.

A collision occurs when a volume sample point in the bur intersects with the tooth volume. Once a collision is detected, we compute force feedback based on the number of immersed sample points and the tooth density in the colliding region. The direction of the

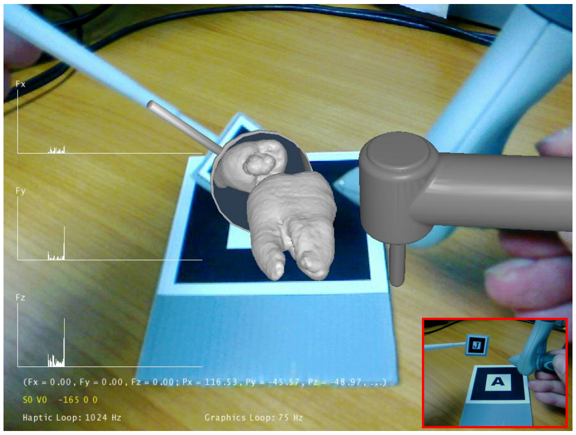

Figure 2: *An AR scene displayed in the HMD screen*

output force vector is based on a summation of force vectors corresponding to individual sample points. We also smooth the computed force vectors using a weighted moving average technique to reduce vibration effects due to abrupt changes in the direction of the rendered force.

When the user activates cutting, on each iteration of the haptic loop, every 3D model voxel in collision with a tool sample point is set to a density of 0.

3 Augmented Reality Environment

We transformed our VR dental simulator into an AR environment using a video see-through head-mounted display (HMD) with an attached monocular camera. Figure 2 shows an example of an image displayed on the HMD screen. The registration of the 3D tooth in the actual environment is realized by ARToolKit [Kato and Billinghurst 2010], an open source AR library.

Within this AR environment, the haptic device is co-located with the 3D graphics, giving users a more natural way to practice dental surgery, in which hand-eye coordination is crucial. Real-time head tracking is made possible by continuously grabbing camera images, detecting AR markers, and registering the 3D tooth accordingly. By attaching another AR marker to a real dental mirror, as shown in Figure 2 (inset), we can register the virtual mirror and render reflections onto it. This technique allows a dentist to use a familiar tool and also eliminates the need for a second haptic device.

4 Preliminary Evaluation and Discussion

In previous work, we asked dental students and a dental instructor to evaluate the VR system in the context of a tooth preparation procedure. The users found the realism of the VR system's graphical and haptic rendering to be acceptable, but some evaluators found it difficult to navigate and control the dental tool in the simulator. We attribute this problem to the difficulty of hand-eye coordination in non-co-located VR systems.

On completion of the AR prototype, we asked a dental instructor from a the Faculty of Dentistry at Thammasat University, Thailand, to give a preliminary evaluation of the new approach in the context of crown preparation and a pulp access opening operations. The expert agreed that the new environment is much closer to a real clinical setting. She also suggested an ideal setting in which the virtual tooth is overlaid on a traditional mannequin along with other tangible real teeth.

There are few concerns regarding the use of a video see-trough HMD. First, the HMD is relatively heavy for long-lasting simulation sessions. However, all of the procedures we currently simulate can be completed in approximately two to five minutes, so the weight is acceptable for this short period. Another issue is that users' depth perception is limited by the use of a monocular camera. Accurate depth perception is important in dental surgery, and stereo cameras would improve users' sense of depth dramatically. Unfortunately, for the time being, HMDs with stereo cameras are prohibitively expensive. Finally, the display resolution is limited by the camera's specifications. However, compared to other solutions for co-located visuo-haptic system such as a half-mirror, HMDs are still our preferred technique, due to their mobility and performance.

5 Conclusion And Future Work

In this paper, we have given an overview of our VR and AR dental training simulators. The simulators use volumetric force feedback and allow real time modification of the volumetric data. To represent tools, we use a volumetric sampling approach that is computationally efficient yet provides for realistic, stable cutting simulations. The virtual mirror implemented using basic computer graphics techniques is quite valuable for dental simulations.

As expected by us and confirmed by an experienced dentist, there are many advantages of the AR approach over the VR approach to dental surgical simulation. The co-located visuo-haptic display in the AR environment is closer to the actual clinical setting. As a result, skills acquired using the simulator should transfer well to the operating room.

We plan to combine the current setup with a mannequin with real teeth as suggested by the expert for better realism. We will also look for alternatives to ARToolKit's fiducial markers, such as retroreflective markers or natural features. Finally, we are collecting logged data from students and experts who perform operations with the simulator towards constructing automatic performance assessment tools and an intelligent tutor that can provide feedback during an operation.

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