

A Virtual Reality Simulator for Teaching and Evaluating Dental Procedures

P. Rhienmora¹; P. Haddawy¹; P. Khanal²; S. Suebnukarn²; M. N. Dailey¹

¹School of Engineering and Technology, Asian Institute of Technology, Klongluang, Pathumthani, Thailand;

²Faculty of Dentistry, Thammasat University, Pathumthani, Thailand

Keywords

Virtual reality, haptic interface, dental skills training, dental performance assessment, hidden Markov model, intelligent training system

Summary

Objectives: We present a dental training system with a haptic interface that allows dental students or experts to practice dental procedures in a virtual environment. The simulator is able to monitor and classify the performance of an operator into *novice* or *expert* categories. The intelligent training module allows a student to simultaneously and proactively follow the correct dental procedures demonstrated by an intelligent tutor.

Methods: The virtual reality (VR) simulator simulates the *tooth preparation* procedure both graphically and haptically, using a video display and haptic device. We evaluated the performance of users using hidden Markov models (HMMs) incorporating various data

collected by the simulator. We implemented an intelligent training module which is able to record and replay the procedure that was performed by an expert and allows students to follow the correct steps and apply force proactively by themselves while reproducing the procedure.

Results: We find that the level of graphics and haptics fidelity is acceptable as evaluated by dentists. The accuracy of the objective performance assessment using HMMs is encouraging with 100 percent accuracy.

Conclusions: The simulator can simulate realistic tooth surface exploration and cutting. The accuracy of automatic performance assessment system using HMMs is also acceptable on relatively small data sets. The intelligent training allows skill transfer in a proactive manner which is an advantage over the passive method in a traditional training. We will soon conduct experiments with more participants and implement a variety of training strategies.

lators are that surgeons are able to practice the procedures as many times as they want at no incremental cost and that the training can take place anywhere. The realism of these simulators has increased with the introduction of *haptic devices* that provide tactile sensations to the users. Haptic devices allow surgeons to touch and feel objects such as surgical tools and human organs in a virtual environment, and to perform operations like pushing, pulling, and cutting of soft or hard tissue with realistic force feedback.

Dental skill training with a VR simulator provides a new opportunity that is difficult to realize otherwise: *objective assessment of surgical competency* [3]. Skill assessment is usually conducted by having an expert surgeon observe the procedure or only the final outcome. However, the level of detail of human expert assessment is limited. With VR simulators, every aspect of the operator's work can be collected during the simulation and analyzed further to provide a fine-grained objective assessment.

A few research groups have developed haptic-enabled virtual reality dental simulators. Luciano [4] developed PerioSim, which allows a trainee to practice diagnosing periodontal diseases. This procedure does not require deformation of tooth surface. Wang et al. [5] worked on a simulator that allows probing and cutting of a tooth model, but the virtual tool implementation is limited to a spherical shape. Kim et al. [6] developed a dental training system with a multi-modal workbench providing visual, audio, and haptic feedback. This system uses volume-based haptic modeling which represents a tooth as a volumetric implicit surface. It allows burring and drilling on the tooth but like Wang et al.'s system, it is limited to a spherical tool. Yau et al. [7] proposed a dental training system utilizing

Correspondence to:

Phattanon Rhienmora
Computer Science and Information Management
School of Engineering and Technology
Asian Institute of Technology
Klongluang
Pathumthani 12120
Thailand
E-mail: phattanon@gmail.com

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1. Introduction

Dental students obtain their surgical skills training from various sources. Traditional methods rely on practicing procedural skills on plastic teeth or live patients under the supervision of dental experts. This master-apprentice type of training has been carried out for decades [1]. However,

it is being challenged by the complications such as the increasing cost of training materials, ethical concerns for the safety of patients, and the unavailability of many real-world challenging cases.

With recent advances in virtual reality (VR) technology, VR simulators for medical and dental surgery have been introduced [2]. The advantages of these simu-

material stiffness and a spring force function. This simulation uses an adaptive octree data structure for the tooth model and an oriented bounding box (OBB) for the boundary of the cutting tool. Yau et al. introduce different cutting tool shapes but do not provide details on how forces are rendered for irregular-shaped cutting tools, and they also do not explain how to handle the torque that might occur in the case of non-spherical tool.

Most of these dental simulators are in the early or experimental stage. Many of them are limited to the use of spherical tools, which are simple to implement but greatly limit the realism of the simulation of dental surgery, in which many kinds of tools in various shapes and sizes are required. There are few systems that overcome this limitation but they do not provide sufficient technical detail to reproduce the results. Moreover, none of these simulators have been evaluated for realism by dental experts.

Other important functionality missing in current VR dental simulators are automatic performance assessment and appropriate training methods to allow transfer of procedural skills from experts to novices. There has been some related works in other fields, however. Rosen et al. [8] present a technique for objective evaluation of laparoscopic surgical skills using hidden Markov models (HMMs). The models are based on force/torque (F/T) information obtained from a surgical robot. Lin et al. [9] collected various measurements from the da Vinci surgical robot while an operator performed a suturing task. The aim of their study was to automatically detect and segment surgical gestures, which is a part of their ongoing research on automatic skills evaluation. As the da Vinci surgical robot does not provide haptic feedback, their research did not consider force applied during the operation.

2. Objectives

In this paper, we describe the first virtual reality dental training system to combine realistic haptic feedback with an objective dental performance assessment and an intelligent training module. We address the

limitations of previous systems and introduce new techniques as follows:

- We represent tooth data as a 3D multi-resolution surface model reconstructed from a patient's volumetric tooth data to improve real-time rendering performance when compared to a direct volume rendering technique.
- We apply collision detection and a collision response algorithm that can handle a cylindrical tool by extending the algorithm presented in [5].
- We simulate tooth surface exploration and cutting with a cylindrical burr by utilizing a surface displacement technique.
- We learn HMMs of novices and experts based on data collected while they perform the procedure using our simulator.

- We perform a formal evaluation of a prototype simulator's realism and accuracy in a tooth preparation procedure with a group of dental students and experienced dentists.
- We present a new training strategy with the potential to allow transfer of dental skills from experts to novices.

3. Methods

3.1 Prototype of a VR Dental Simulator

The prototype system operates on a HP Pavilion dv5000 laptop with a 1.6 GHz Intel processor and 2 GB of main memory. The system's graphics card is nVIDIA GeForce



Fig. 1 PHANTOM Omni Haptic Device (SensAble Technologies Inc.)

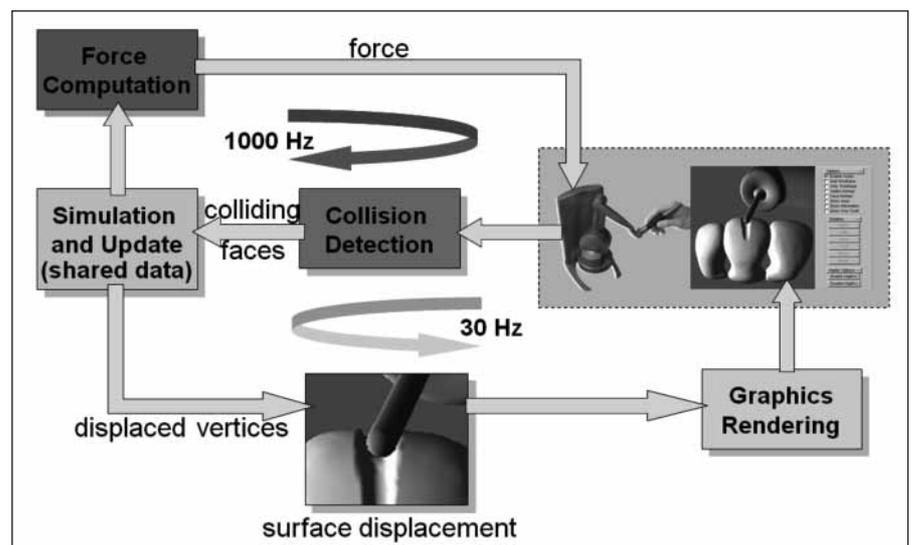


Fig. 2 System architecture

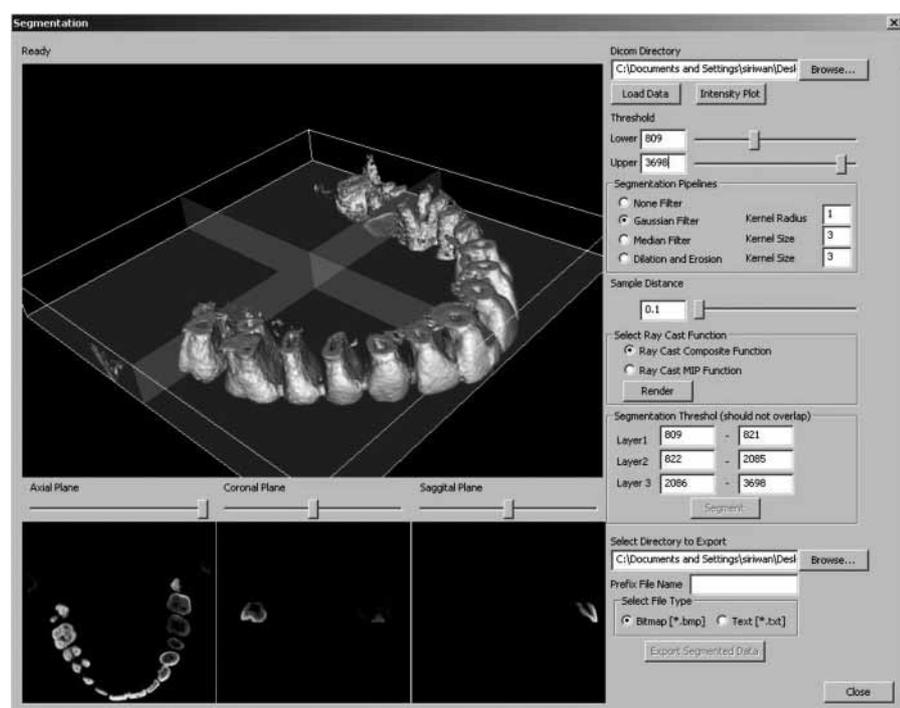


Fig. 3 Our segmentation tool showing a three-dimensional volume of teeth with a Gaussian smoothing filter applied [12]

Go 7400 with 256 MB of video memory. We use a PHANToM Omni haptic device (► Fig. 1) which allows six degrees of freedom for positional sensing and generates three degrees of freedom for force feedback. We developed the simulator software using C++, OpenGL, Optimized Collision Detection (OPCODE) [10], and the OpenHaptics SDK (HDAPI) [11].

The simulation system is composed of several components as illustrated in ► Figure 2. The simulator contains two separate loops (threads), namely the haptic loop and the graphics loop, running at different frequencies. We use a surface model to represent teeth and the tool for high-quality rendering. The graphics loop runs at a minimum frequency of 30 Hz.

Our virtual dental handpiece has six degrees of freedom and is locked to the position and orientation of a haptic stylus. The collision detection and tooth cutting simulation run within the haptic loop at 1 KHz thus results in a force feedback latency of only 1 millisecond. This means that the system computes realistic force feedback and simulates tooth cutting within 1 millisecond. This is possible due to the OPCODE fast collision detection library [10] and the

computational efficiency of the surface displacement algorithm that we implemented.

Some data must be shared by the graphics and haptic threads. In order to access and manipulate this data, the threads need to be synchronized with each other to prevent an inconsistent state. However, the haptic thread running at a higher frequency should not wait too long for the much slower graphics thread to finish its rendering task. This problem is solved by making fast synchronous calls from the graphics thread that block the haptic thread temporarily and create a snapshot copy of shared data for graphics rendering.

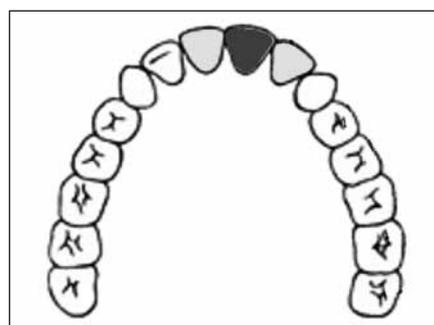


Fig. 4 Three teeth (filled) used in the simulator

3.1.1 Data Acquisition

Volumetric teeth data were acquired from a volunteer (a 23-year-old male) who underwent orthodontic treatment and gave written consent in accordance with the Thammasat University institutional review board prior to the study. The data were obtained from an i-CAT Cone Beam Computed Tomography machine (Imaging Sciences International, PA, USA) covering the whole maxilla and mandible.

We first processed the volumetric data using three-dimensional volume visualization and segmentation software developed by our group [12] (shown in ► Fig. 3). The software allows interactive filtering and segmentation.

3.1.2 Data Representation

Volumetric data can be visualized by extracting isosurfaces (surfaces of equal density value) from the volumetric density data and rendering those surfaces as polygonal meshes, or by rendering the volume directly as a block of data (direct volume rendering). The advantage of the surface extraction method over the direct volume rendering method is that it is computationally inexpensive and appropriate for real-time rendering and editing, though it is slightly less realistic than the volumetric method. The *marching cubes* algorithm [13] is a common technique for extracting an isosurface from volumetric data.

We construct a surface mesh from the segmented volumetric output of the segmentation tool using the marching cubes algorithm. We currently choose three maxillaries (upper teeth, shown as opaque in ► Fig. 4) as the model for a tooth preparation procedure.

The left maxillary central incisor (tooth No. 21, according to FDI World Dental Federation Two-Digit Notation, eighth from the right in ► Fig. 4) is the main tooth used in the tooth preparation simulation. The surface mesh of this particular tooth is further subdivided using a loop subdivision algorithm [14]. The final number of triangles for this mesh is 38,270.

Much of the previous work on VR dental simulation [5, 6, 15] uses overly simplistic virtual dental tools. To increase realism in our virtual environment, we gener-

ated a three-dimensional surface model of a dental handpiece with three different burrs (see ► Fig. 6 for one example). However, the only burr that is evaluated in this paper is a cylindrical shape.

3.1.3 Force Calculation

When there is a collision between the tool and the tooth, the tool penetrates into the tooth at the area of collision and the depth of penetration determines the force feedback. When we detect this penetration, we must compute the forces to be rendered by the haptic device in the direction opposite to the movement of the tool, in order to avoid further penetration. The reaction force is directly linearly proportional to the depth of penetration as shown in Equation 1:

$$\vec{F} = k\vec{x} \tag{1}$$

where \vec{F} is the 3D force vector calculated at the contact surface; k is the stiffness constant, which determines the perceived hardness of the tooth surface; and \vec{x} is the maximum depth of penetration from the surface of the tooth to the immersed position of the tool inside the tooth surface.

To calculate \vec{x} , we adapt Wang et al.'s [5] method for spherical tools to the case of a cylindrical tool. We first find contact points at the surface of the tooth, as mentioned in [5]. When the tool is in contact with the tooth surface for the first time, the initial virtual proxy position (the position of the tool at first contact) (\vec{X}_0) is stored. On the subsequent iterations, when the tool penetrates the surface of the tooth, the new actual position of the tool is recorded as \vec{X}_v . The immersion depth is the distance from \vec{X}_0 to \vec{X}_v . So long as the tool in actual position causes it to penetrate the surface of the tooth, we push it back to the surface of the tooth along the direction of surface normal at the contact point (\vec{X}_c). The displaced position of the virtual tool is \vec{X}_s . Finally the displacement vector is calculated as:

$$\vec{x} = \vec{X}_c - \vec{X}_s \tag{2}$$

3.1.4 Force Filtering

Due to the effect of averaging the normals for each vertices as well as calculating the

center point of the contact surface, the force \vec{F} will not vary smoothly over time. This is undesirable because, in reality, force is smooth and continuous. To reduce the problem, following [5], we limit the change in force between two consecutive intervals.

$$\vec{F}'_k = \begin{cases} \vec{F}'_{k-1} + \frac{\delta \Delta \vec{F}}{\|\Delta \vec{F}\|}, & \|\Delta \vec{F}\| > \delta \\ \vec{F}_k, & \|\Delta \vec{F}\| \leq \delta \end{cases} \tag{3}$$

where

\vec{F}'_k : filtered force,
 \vec{F}_k and \vec{F}_{k-1} : forces calculated in two consecutive instances,
 $\Delta \vec{F} = \vec{F}_k - \vec{F}_{k-1}$, and
 δ : threshold value for force change.

After filtering the force, as described, there is still the possibility of obtaining an overly large magnitude of \vec{F}'_k , which might exceed the maximum force that the haptic device can render. To avoid that from happening, we clamp the force magnitude at the maxi-

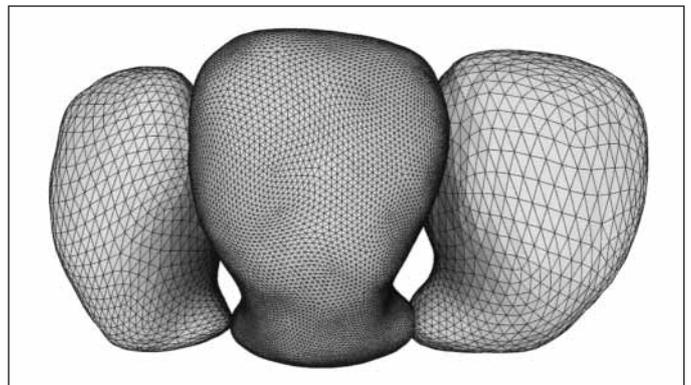


Fig. 5 Three teeth visualized in wireframe. (Note a finer resolution of the middle one.)

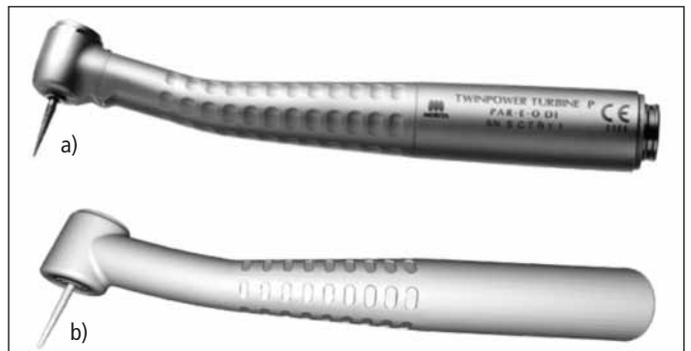


Fig. 6 a) Photo of a real dental handpiece used in tooth preparation (TWIN POWER TURBINE P, J. MORITA CORP.). b) Our virtual handpiece

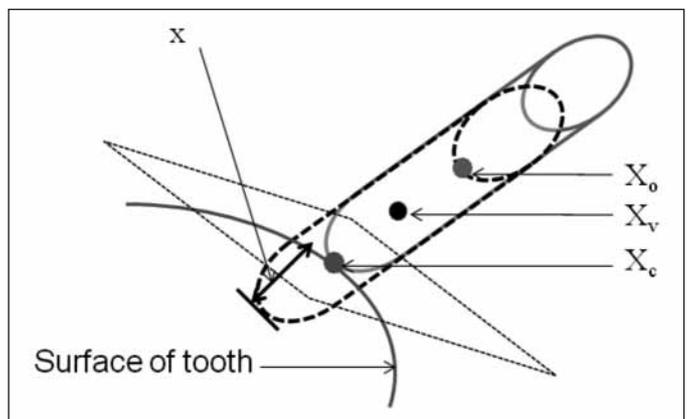


Fig. 7 Depth of penetration (\vec{x}) of virtual tool inside the tooth surface

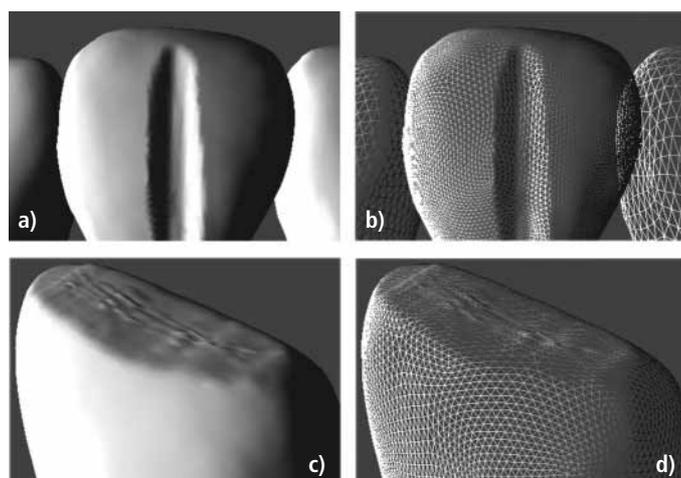


Fig. 8

a) Tooth cutting at the labial surface. b) Wireframe representation of the cut tooth of (a). c) Tooth cutting at the incisal part. d) Wireframe representation of the cut tooth from (c)

for a simple approach to cutting simulation that yields acceptable results as shown in ▶Figure 8.

The graphical user interface (GUI) of our simulator is illustrated in ▶Figure 9. It consists of a workspace for the dental operation and a control panel that can be activated by mouse or keyboard shortcuts. The current position and force feedback of the virtual tool are displayed near the bottom of the interface along with the current percentage of the teeth volume that has been removed.

3.2 Performance Assessment Using HMMs

During an operation we can store the forces, times, positions and orientations of the virtual tool, button press events, and surface geometry of the tooth model. Pressing the haptic device's button enables drilling. ▶Figures 10a and 10b show the movement of the tool by an expert and by a novice. The lighter dots represent the position of the tool when the button was not pressed whereas the darker dots represent the position of the tool keeping the button pressed. From the two graphs, we can see that the expert path has fewer dots compared to the novice path. In the expert plot, we can clearly see proper separation of labial reduction (gingival) and labial reduction (incisal) (stages k and l in ▶Fig. 13) but we cannot see proper separation of the two reductions in the novice plot.

We also plotted the magnitude of the force applied by the novice and the expert over time (▶Fig. 11) and the time they took to perform the preparation (▶Fig. 12).

In ▶Figure 11, we can see that the force applied by the expert varies at each stage of tooth preparation and is greater than the force applied by the novice. The force applied by the novice in each stage is more uniform. This information suggests that force feedback from a haptic device is valuable in distinguishing expert and novice performance. The chart in ▶Figure 12 shows that the expert performs the procedure substantially faster than the novice does.

After collecting data from novices and experts we developed discrete HMMs to classify sequences as novice or expert tooth preparation performances. In our system,

imum nominal continuous force for the haptic device.

3.1.5 Tooth Cutting Simulation

To simulate tooth cutting during the tooth preparation process, we use a surface displacement technique. This technique is utilized in many digital sculpting software packages. SharpConstruct [16] is one example. Wang et al. [5] use a similar technique for their tooth cutting simulation.

The cutting simulation starts when a collision between the tooth and the tool is detected while a button on the haptic stylus is pressed. Only tooth mesh vertices within the collision area are displaced. For each colliding vertex, we compute the distance from the vertex to the tool in the direction of the local surface normal and then we displace the vertex by the computed distance. Note that this need not be the shortest distance between the vertex and the tool.

With this technique, neither the number of triangle faces and vertices nor the structure of the mesh can change. This is there-

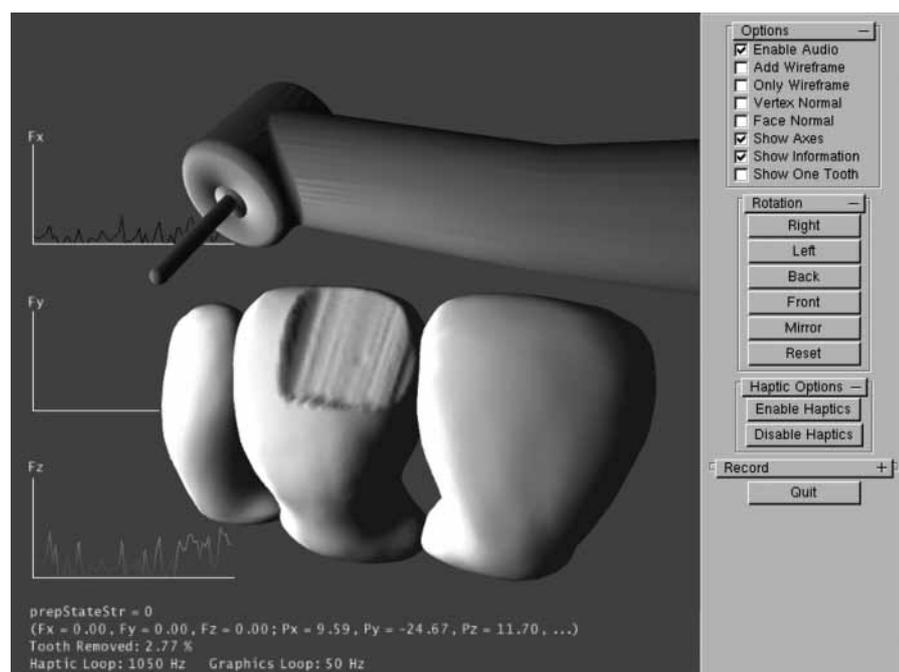


Fig. 9 Graphical user interface of the prototype

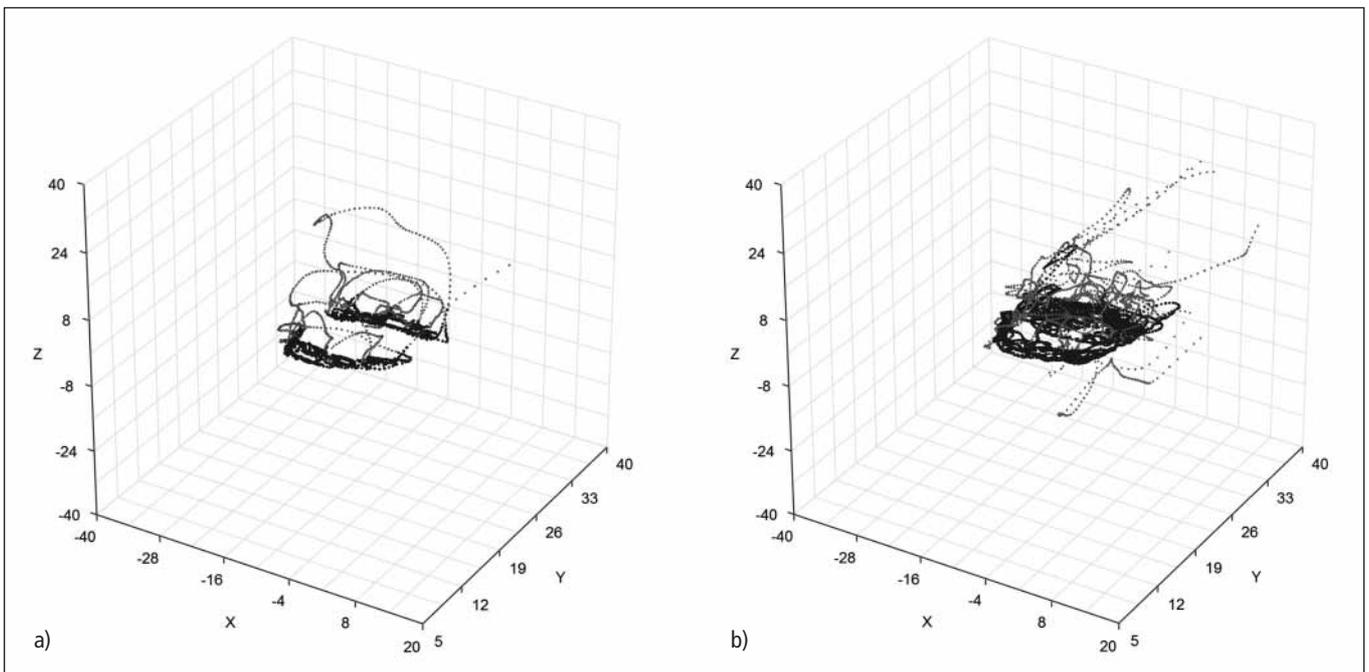


Fig. 10 a) Expert tooth preparation sequence. b) Novice tooth preparation sequence

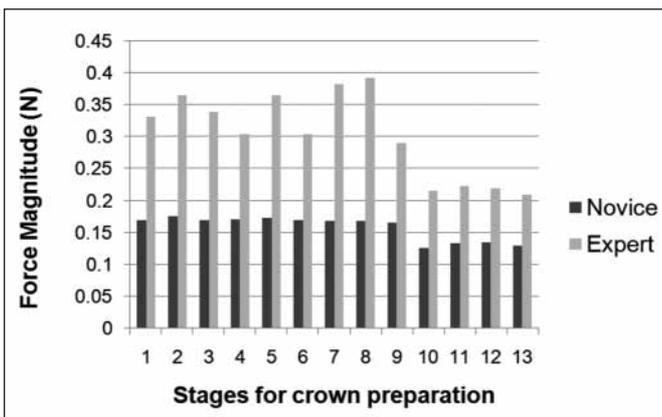


Fig. 11 Force applied at each stage of tooth preparation by expert and novice

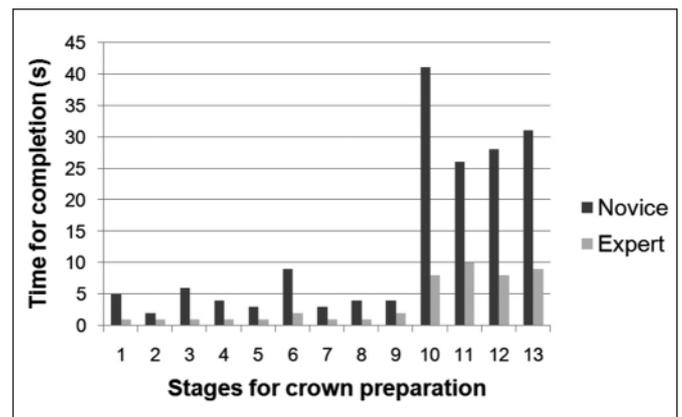


Fig. 12 Time taken at each stage of tooth preparation by expert and novice

the hidden states are the thirteen stages of tooth preparation shown in Figure 13. The observations are the force calculated during the simulation and the positions and orientations of the tool through time. Since we use discrete HMMs we convert these feature vectors into symbols using the k-means clustering algorithm with $k = 13$.

According to Rabiner [17], four elements should be defined in order to specify HMM λ : 1) the number of states N in the model; 2) the state transition probability distribution matrix A ; 3) the observation symbol probability distribution matrix B ; and 4) the in-

itial state distribution vector π . The HMM can thus be defined by:

$$\lambda = (A, B, \pi)$$

In our system, the number of states is 13. We train the novice and expert HMMs by adjusting the model parameters (A, B, π) to maximize the probability (P) of the training sequence as follows:

Given: $\lambda = (A, B, \pi)$
 Adjust: A, B, π
 Maximize: $P(O|\lambda)$

After training the models, we compute the probability of the observation sequence, given the model and the observation sequence as follows:

Given: $\lambda = (A, B, \pi), O = o_1, o_2, o_3, \dots, o_t$
 Compute: $P(O|\lambda)$

We calculate the probability and log likelihood of the test sequence under the novice and expert HMMs. If the log likelihood of the test sequence under novice HMM is greater than that under the expert HMM, the system classifies the test sequence as a

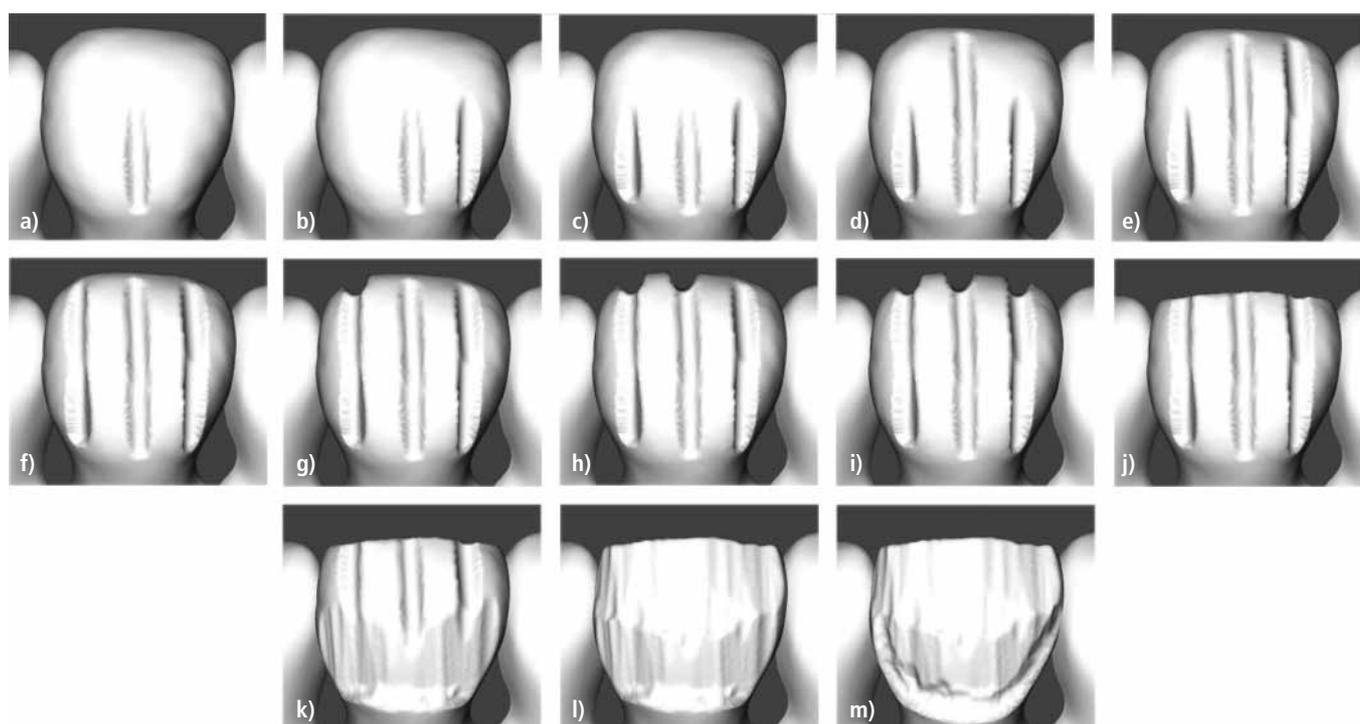


Fig. 13 Thirteen stages of tooth preparation on the labial and incisal surfaces: a) labial gingival guiding (central); b) labial gingival guiding (mesial); c) labial gingival guiding (distal); d) labial incisal guiding (central); e) labial incisal guiding (mesial); f) labial incisal guiding (distal); g) incisal guiding (distal); h) incisal guiding (central); i) incisal guiding (mesial); j) incisal reduction; k) Labial reduction (gingival); l) labial reduction (incisal); m) labial cervical margin

novice sequence; otherwise, we classify as an expert sequence.

3.3 Intelligent Training

Data collected from expert operations are very useful as a training resource. Replaying the recorded data to students as a demonstration and letting them repeat the task is one of

the simplest training strategies. But with the help of the haptic device, the stylus in the student's hand can also be forced to move along the expert path allowing the student to learn the path precisely. However, this training method is still somewhat passive method because the student cannot experience the actual forces applied by the expert.

Saga et al. [18, 19] present a haptic teaching technique to teach hand skills tasks such

as calligraphy by rendering the force applied by the expert on the haptic device but rendering it in the *opposite direction*. A student holding the haptic device must then apply the same amount of force in the original direction to cancel out the rendered opposite force to proceed with the operation.

We implemented this technique in our skills training module. ▶Figure 14 illustrates the idea of our implementation. In the figure, the expert's tool (E) movement is played back and a student (N) tries to learn the path by following the movement of the expert's tool. Since the expert was pressing the tooth surface with force \vec{F} , the force \vec{F}' with the same magnitude but opposite direction is rendered to the novice's stylus, pushing it away from the correct path. In order to keep up with the expert's movement as well as to stay on track, the novice has to apply force \vec{F} to cancel out the force \vec{F}' . With this technique, both the visual and haptic information from the expert's session can be transferred to the novice in a proactive manner. A screenshot of this training mode in action is shown in ▶Figure 15; the expert's and

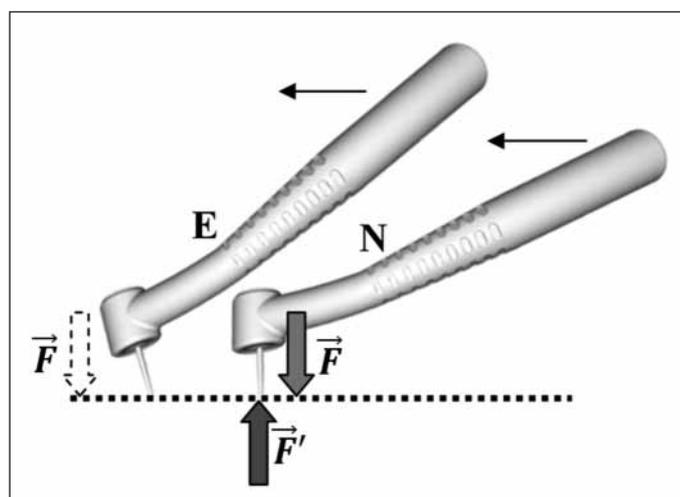


Fig. 14 Path and force learning in the intelligent skills training module

novice's tools are marked with 'E' and 'N', respectively.

4. Results

4.1 VR Dental Simulator

► Figure 16 illustrates a) the outcome of an expert performance and b) a novice performance. The realism of the simulator was evaluated by dental students from the School of Dentistry at Thammasat University. Five sixth-year dental students participated in the evaluation; three were female and two were male.

The survey was divided into three sub-sessions. There was a practice session to familiarize the participants with the haptic device and the simulator as a whole. In the second session, participants were given two minutes to perform an experiment in which they had to perform two operations: explore the tooth surface and partially execute the tooth preparation procedure. Finally, in the evaluation session they had to answer questions on an evaluation sheet. The questions were related to the operations they had performed during the experimental session. There were three sets of questions: general questions, questions related to exploring the tooth surface, and questions related to the tooth preparation operation. They were also given the opportunity to express their opinions regarding the simulator. Various conclusions can be made from the feedback about the realism of the system:

Tooth surface exploration: Three evaluators thought that the tooth surface felt almost real whereas two suggested that the surface hardness and roughness could be improved. For better perception of surface roughness, we might look into a technique which is able to haptically display fine surface textures [20]. Moreover, we could improve our force computation algorithm to handle friction on the tooth surface.

Tooth cutting for preparation: The force required while cutting the tooth was almost real, but the evaluators experienced inconsistent force responses while cutting. We found that each participant might be more or less sensitive to response force than others, especially when the amount of force is relatively small.

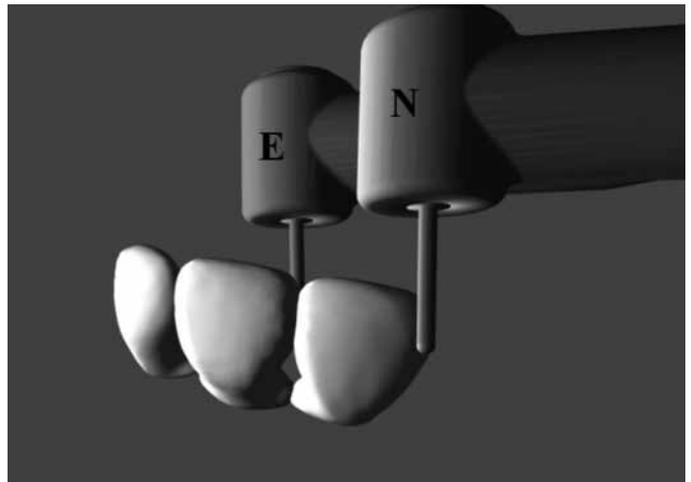


Fig. 15
Training mode

Graphical user interface (GUI) and ease of use: Some evaluators found it difficult to navigate and control the tool in the simulator. They added that the practice session should have been longer. Moreover, they found that pressing the device's button by hand is not a natural way to start cutting, as real dental chairs provide a foot switch for the task.

Feasibility of the simulator as a training system: Most of the evaluators were positive about the feasibility of using the simulator to teach the use of dental tools. They also added that the simulator could be useful to supplement the material provided in regular classes and that the simulator would be useful for practicing tooth preparation.

4.2 Performance Assessment Using HMMs

For the HMM performance assessment, we used five expert trials (by experienced dentists) and five novice trials (by sixth-year dental students) performing the partial tooth preparation task, consisting of the 13 stages shown in ► Figure 13. We performed a fivefold cross-validation on the expert as well as the novice data. We used a different k-means for every cross-validation fold and the same k-means for the novice and expert model in the same fold. For each fold, we trained the novice HMM with four novice data as well as the expert HMM with four expert data.

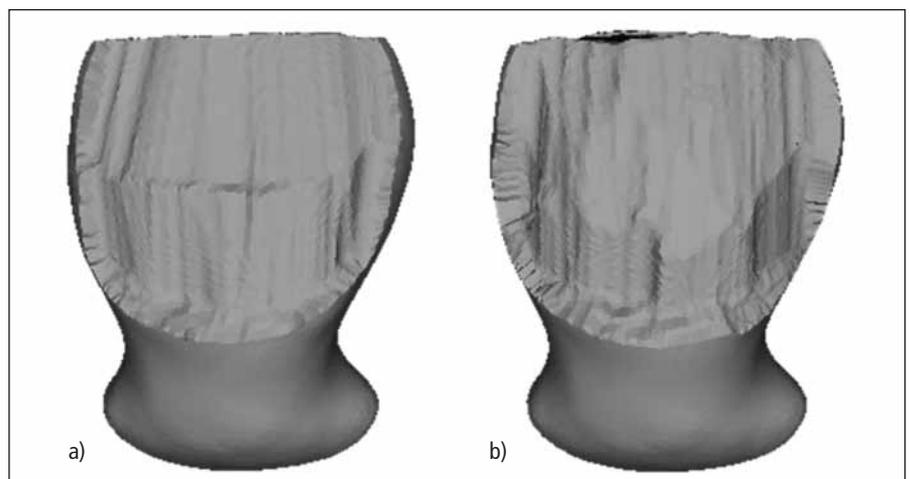


Fig. 16 The outcome of tooth preparation on the labial and incisal surfaces: a) an expert performance; b) a novice performance

Sequence	Log likelihood for Expert HMM	Log likelihood for Novice HMM
Expert performance	-3.574×10^3	-2.229×10^6
Novice performance	-6.272×10^5	-3.494×10^3

Table 1
Average log likelihood results for expert and novice performance sequences

an expert to finish the procedure; they can practice concurrently with the playback of the recorded expert's operation. Finally, students can learn how to apply force correctly during the operation in a proactive manner.

To determine the accuracy of the method, after training the two HMMs in each fold, we fed the test novice and expert data into each model. The average log likelihood of all sequences in five folds for the two HMMs is shown in ► Table 1.

For each cross-validation fold, the log likelihood of a test sequence for its corresponding HMM is always higher than that for another HMM. The result clearly demonstrates the ability of HMM to distinguish between novice and expert performance with 100 percent accuracy.

5. Discussion

Without force/torque measuring equipment, we could not collect force data from the actual tooth preparation procedure. Thus, realism of the feedback force generated by our force-rendering algorithm could only be evaluated by the sensations and judgments from dentists. However, the user feedback was invaluable for suggesting the highest priority improvement to our system.

According to some participants, the feeling of tooth surface was too rough in some situations. This problem occurred due to discontinuities in the magnitude of the depth of penetration. We subsequently addressed this problem by applying filtering methods to reduce the difference between the depths of penetrations at two different points on the surface. This improved the result to a great extent, but it still needs to be improved. The force shading algorithm [21] and its variants are interesting topics for future research.

A few participants had trouble navigating in the virtual environment. This might have resulted from the lack of depth perception on our two-dimensional display. We subsequently added a three-dimensional stereoscopic feature with shutter glasses to the simulator and let those participants try the new interface; the result

was positive. We also added a foot switch to replace the button on the haptic stylus for activating the dental drill; this allows operators to hold the haptic stylus in a more natural way. We again let dentists try this new user interface and the outcome was very positive.

Our dental training simulator currently simulates tooth preparation only. Other complex dental operations involve complicated factors such as cutting through different layers of a tooth, which have different tissue properties, and the need for other dental tools beside a dental drill. The current system would have some difficulty simulating operations that involve different tissue types with the surface displacement algorithm. We are currently looking into a volumetric approach to represent the tooth and a robust cutting simulation technique that works well with volumetric data. One of the most feasible solutions for cutting is re-executing the marching cube algorithm [13] locally to rebuild the local tooth surface where the cutting takes place as presented in [22]. The use of the octree data structure for spatial representation of three-dimensional tooth data is also attractive and will be further investigated [7, 22].

The accuracy of our automatic performance assessment system using HMMs is acceptable. The system can correctly classify the categories of all the test sequences. However, the number of participants in our study was relatively small and most had similar levels of expertise within their categories. Experiments with more participants and various skill levels will be conducted in future work.

In tutoring mode, dental students not only observe the recorded procedures carried out by an expert, but are also able to follow the operation alongside and feel the actual feedback force while moving the tool. This tutoring technique has many advantages over traditional training. For example, students do not need to wait for

6. Conclusion

In this paper, we describe the development of our dental skills training simulator. The prototype system can simulate tooth surface exploration and cutting for tooth preparation. Graphic and haptic computation and rendering are based on a triangle-mesh-based model. Collisions between the cylindrical tool and the tooth model are detected efficiently and appropriate magnitudes of forces are rendered through the haptic device. Surface cutting is simulated by displacing the surface mesh; this works quite well for tooth preparation. The haptic and graphic calculations are done in a computationally inexpensive way to maintain system stability while preserving realism.

The simulator is also able to classify the performance of a particular operator as novice-level or expert-level. The first prototype was evaluated by five dental students and five experienced dentists. The evaluation results are promising and prove the applicability of the simulator as a supplemental training and performance assessment tool for dental surgical skills.

Lastly, it is interesting to see that a variety of training strategies can be implemented with existing VR simulators to make most out of this new technology. Strong results may help improve the acceptance of VR training for skills and problem-solving in dentistry and medicine.

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