A VR Environment for Assessing Dental Surgical Expertise

Phattanapon RHIENMORA[a,1], Peter HADDAWY[a],
Siriwan SUEBNUKARN[b] and Matthew N. DAILEY[a]
[a] *School of Engineering and Technology, Asian Institute of Technology*
[b] *Faculty of Dentistry, Thammasat University*

Abstract. Traditional methods of dental surgical skills training and assessment are being challenged by complications such as unavailability of expert supervision and the subjective manner of surgical skills assessment. This paper presents a dental surgical skills training system that provides a virtual reality environment with a haptic device for dental students to practice tooth preparation procedures. The system monitors important features of the procedures, objectively assesses the quality of the performed procedure and provides objective feedback on the user's performance for each stage in the procedure. We evaluated the accuracy of the skill assessment with data collected from novice dental students as well as experienced dentists. The experimental results show high accuracy in classifying users into novice and expert. The evaluation of the system's generated feedback also indicated a high acceptance rate.

Keywords. Surgical skills training and assessment, intelligent tutoring system

Introduction

Dental surgical skill assessment is usually conducted by having an experienced dentist observes the procedure. However, the level of detail of human expert assessment is limited. With virtual reality (VR) surgical simulators, it is possible to collect every aspect of the operator's work. This valuable data can be analyzed further to provide a fine-grained objective assessment. To add more educational value, simulators should also be able to provide tutoring feedback in order to reduce the time required for instructors to supervise trainees. Unfortunately, current VR dental simulators [1, 2] do not offer these important functionalities.

In this paper, we describe the first VR dental training system to combine realistic haptic feedback with an objective dental performance assessment and feedback generation mechanism.

1. Objective Assessment of Dental Surgical Skills

Based on interviews with experienced dentists, we hypothesized that important features for distinguishing experts from novices in dental surgery are tool movement (position

[1] Phattanapon Rhienmora, CSIM, School of Engineering and Technology,
Asian Institute of Technology, Pathumthani, Thailand, 12120; E-mail: phattanapon@gmail.com.

and orientation of the tool) and applied force during a procedure. An example of the difference between tool movements of an expert and a novice is shown in Figure 1. We recruited five novices and five experts to perform a tooth preparation using our simulator [3] which requires that 13 stages be performed on the incisal and labial surfaces. All of the important features mentioned previously are monitored and recorded. After that, we developed discrete hidden Markov models (HMMs) to classify procedure sequences as novice or expert. HMMs were successfully applied in objective evaluation of laparoscopic surgical skills [4, 5]. In our model, the hidden states are the thirteen stages of tooth preparation. The observed feature vector includes force calculated during the simulation as well as positions and orientations of the dental tool. Stage labels were not used in training HMMs. We first converted the feature vectors into symbols using the k-means clustering algorithm with k = 13. We performed five-fold cross validation with 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 and four expert sequences. To determine the accuracy of the method, after training the two HMMs in each fold, we fed the test novice and expert data to each model. If the log likelihood of the test sequence under the novice HMM is greater than that under the expert HMM, the system classifies the test sequence as a novice sequence; otherwise, the system classifies it as an expert sequence. The experimental result indicated that, for every cross validation fold, the log likelihood of a test sequence for its corresponding HMM was higher than that for another HMM. This demonstrated the ability of HMM to distinguish between novice and expert performance with high accuracy (a hundred percent). However we note that the number of participants (10) was relatively small.

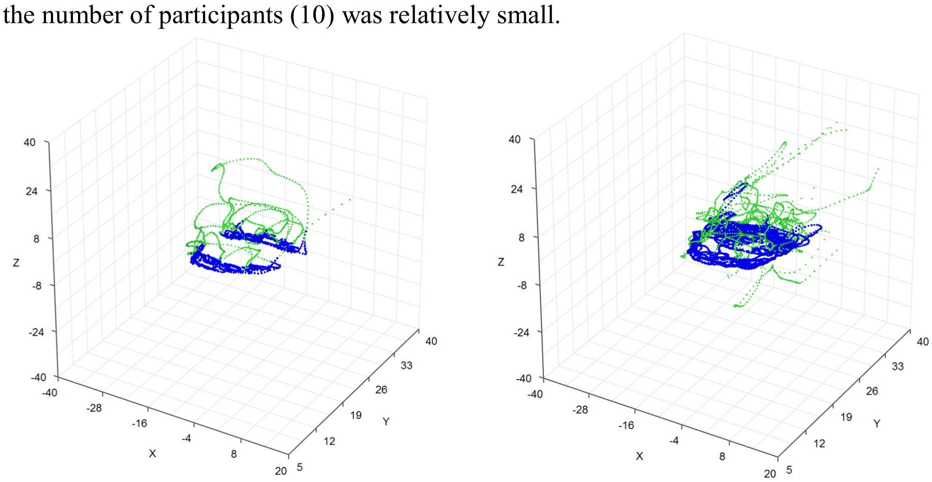

Figure 1. An example of the tool movements of an expert (left) and a novice (right).

2. Tutoring Feedback Generation

The average position, orientation, force, and main axis for force direction differ between procedure stages. These characteristics can be observed by the simulator and compared to a gold standard in order to generate useful feedback. A total of 65 tutoring feedback messages for every stage of all five novices were generated. An experienced dentist was asked to rate the acceptability of each feedback message on a scale of 1-5, where 1 implied unacceptable and 5 implied acceptable. Examples of generated feedbacks and their scores are as follows. For a mid-upper-labial depth cut, where the main force should be applied in the minus Z direction, the average force applied by a novice in this direction was not within one standard deviation from the expert mean. Since the novice's average force was around half that of the expert, the system generated *"Force in minus Z direction should be 2 times higher"* as a tutoring feedback. This feedback was rated as *acceptable* (score 5). However, during one of a mid-incisal depth cut, the generated feedback, *"Force in minus Y direction should be 3 times higher"*, was *close to acceptable* (score 4). The experienced dentist commented that a novice could accidentally damage a tooth in this stage if he/she tried to applied force too much, therefore, suggested feedback could possibly be only *"2 times higher"* (instead of 3). Feedback for position and orientation is generated and scored using the same strategy. The average score for all 65 feedback messages was 4.154 with the standard deviation of 0.795.

3. Conclusions

We describe our VR dental surgical simulator which is able to classify the performance of a particular operator as novice-level or expert-level based on the force applied, tool position, and tool orientation using hidden Markov models. The simulator can later generate tutoring feedback with quality comparable to the feedback provided by human tutors. Additional tutoring strategies will be explored in the future work. The evaluation results are promising and prove the applicability of the simulator as a supplemental training and performance assessment tool for dental surgical skills.

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