A Shared Haptic Virtual Environment for Dental Surgical Skill Training

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Introduction

- Dentistry is difficult to learn
  - Training costs $352,184 [Segal et al., 2017]
  - Training facilities are scarce
- Remote learning is more relevant than ever
  - Currently limited to knowledge & cognitive skills
- Dentistry requires fine motor skills
- VR can help motor skill transfer
  - High immersion, natural interaction
  - Low operating cost
- Our Contribution: Shared VR environment with haptic feedback
Related Work

- Several VR dental simulators exist

- Commercial products
  - Simodont: +haptic feedback, +3D, -no head tracking, -no collaboration
  - VirTeaSy: +haptic feedback, stationary AR, -no 3D, -no collaboration

- Research projects
  - DenTeach: physical teeth, -only video
  - Morris et al.: same force, -no evaluation
  - Rhienmora et al., Su Yin et al.: opposite force, force recording
  - Kuchenbeker et al.: vibrotactile recording
Design – Simulator

[Images of dental simulators and related equipment]
Design – Collaboration

Diagram showing the flow of forces and simulations between master and slave systems in a teleteaching strategy.
Teleteaching Strategies

1. “Same Force” \( F_s = F_m \)
   - User forces handle near center
   - Defines a force

2. “Opposite Force” \( F_s = -F_m \)
   - Same user behaviour

3. “Delta Force” \( F_s = (p_m - p_s)k \)
   - User gives in to force
   - Defines a position
Methods – Simulation

- Sphere packing volumetric representation [Weller et al.]
  - Constraint-based haptic feedback @ 1 kHz
  - Drilling simulation @ 1 kHz

Original mesh  Sphere packing  Runtime generated mesh
Methods – Visualization

- Dynamic material visualization
  - At interactive rates
  - Vertex colors to visualize cariousity
- CPU+GPU algorithm with 3 stages:
  1. Distance- & Normal Field Generation (CPU)
  2. Bilateral Smoothing Kernel (GPU)
  3. Marching Cubes (GPU)
- runs @ 10 Hz (resolution $200^3$)
Methods – Scoring

- Metric to compare drilling results
- Ideal result as reference for comparison
  - Easy to determine: remove caries
  - Root canal treatment reference done by expert
- Set comparison metric: DICE coefficient

\[ s = \frac{2 \times TP}{2 \times TP + FP + FN} \]

- True Positive \( TP \): unremoved non-carious tissue
- False Negative \( FN \): unremoved carious tissue
- False Positive \( FP \): removed non-carious tissue
Evaluation

Assessed for eligibility

Exclude
- experience with the haptic VR simulations
- unwilling to give written informed consent

Stratified randomization
- Familiarization

Group I
Caries removal with *same* teleteaching

Group II
Caries removal with *opposite* teleteaching

Group III
Caries removal with *delta* teleteaching

Group IV
Caries removal without force

Training
- Instructor – Demonstrate
- Student – Follow [with different force training strategies]
- Student – Practice

x3 sessions

Questionaire
Conclusion

- Novel collaborative system for motor skill training
- 3 strategies for teleteaching of drill force & trajectory
- Simulation design tailored for application domain
  - General enough for multiple use-cases
- Several optimizations
  - High fidelity haptic rendering @ 1000 Hz
  - Interactive drillable material @ 10 Hz
- Completely planned out evaluation
Future Work

- Complete the evaluation
- Replicate with 6DOF haptic devices
- Experiment with new teleteaching strategies
- Further optimization of visualization
  - Field generation on GPU (currently on CPU)
  - Data hazard needs to be resolved
Thank you for your attention!