Haptic and Tactile Feedback

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Haptics

- Haptic:
  Relating to or based on the sense of touch:
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  \begin{align*}
  \text{Force feedback} \\
  \text{Tactile feedback}
  \end{align*}
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  \[
  \text{Haptic feedback}
  \]

- Surgical simulation as haptic interaction with virtual surgical environments

Research Issues in Haptic Interfacing to Virtual Environments

- Haptic interface devices
- Stability of haptic interaction with virtual environments
- Simulation of stiff walls
- Haptic rendering of surface texture
- Haptic interaction with deformable bodies
- Realistic modeling of tool-tissue interaction
  - Cutting, suturing, needle insertion
- Tactile sensing and display

Force Feedback Haptic Devices

Commercial Systems:
- Phantom
  - 3 DOF and 6 DOF versions
- Immersion
  - Impulse Engine
  - CathSim AccuTouch
    - Endovascular
    - Bronchoscopy
  - Laparoscopic Interface
- Freedom 6S
  - 6 DOF force feedback

Generation of Force Feedback

Haptic Interaction with Deformable Bodies in VE’s

- Deformable bodies are simulated with very high order dynamical models
- Haptic interaction require bandwidth of ~1kHz, but these high order models can only be simulated at ~10Hz
- This affects the stability and fidelity of interaction
Simulation Schemes

Demonstration of the Problem
- Interaction with a nonlinear spring in one dimension
  - 10 Hz model update
  - 1 kHz haptic update

Low Order Linear Approximation to Model Intersample Behavior

Model Reduction
- 12x12 2-D lumped element model
  - 2 input 2 output dynamical system
  - 524th order dynamics
- Balanced model reduction
  - 10th order approximation with less than 1% error
Reduced Order Model Is a Local Approximation

Constructing a Local Model in Real Time

Implementation
- 6×6×6 3-D model
- Simulation run on a dual processor SGI octane
- C++, OpenGL
- Phantom™ v1.5 as the haptic interface
- 20 Hz model update
- 1 kHz haptic update

Stability Implications
- Update rate of simulation is a critical factor for stability of interaction.
- 1 kHz haptic simulation instead of 10 Hz improves stability.
- Oscillatory behavior present in low frequency simulation is not observed.

Discussion
- This method is applicable only if the local modes are dominant.
- Interaction stability is improved significantly.
- It is informative to study other local models.
Other Methods for Generation of Haptic Feedback

- Constraint-Based Methods (Zilles and Salisbury 1995)
- Planar and Spherical Local Approximations (d’Aulignac et al. 2000)
- Norton Equivalent Models (Astley and Hayward 1998)
- Force Fields (Montgomery et al. 2002)

Modeling of Needle Insertion

Coming up in the Tissue Modeling section of the tutorial!

Human Factors for Enhanced Force Feedback in MIS

Psychophysics literature on compliance has measured difference thresholds. Surgeons often need to detect spatial variation in surface compliance, e.g., to detect embedded lesion.

Two tasks:
- spatial variation in compliance
- temporal oscillation in force

Methods

- Phantom 1.5 haptic interface
- Adaptive 2-down 1-up procedure (corresponds to 71% accuracy)
- 8 subjects
- 3 mean compliance levels: 2, 4, and 8 mm/N
- 3 mean force levels: 0.5, 1, and 2 N

Simulated Surface Compliance Discrimination

Psychophysics literature on compliance has measured difference thresholds. Surgeons often need to detect spatial variation in surface compliance, e.g., to detect embedded lesion.

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Human Factors for Enhanced Force Feedback in MIS

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Compliance Discrimination and Contrast Sensitivity

Psychophysics literature on compliance has measured difference thresholds. Surgeons often need to detect spatial variation in surface compliance, e.g., to detect embedded lesion.

Two tasks:
- spatial variation in compliance
- temporal oscillation in force

Compliance Discrimination and Contrast Sensitivity
Tactile Sensing and Display

8x8 1mm² Tactile Sensor Array

Image courtesy of Gray and Fearing

Tactile Display Technology

Images courtesy of Fearing et al.

Human Factors in Tactile Sensing and Display

Do we need a tactile display capable of displaying shear stress?

Experimental results from Moy and Fearing (1998)

Tactile Feedback

- SMA based tactile display
- DC servomotor based tactile display

Images courtesy of Howe et al.

Vibrotactile Feedback

Images courtesy of Howe et al.
References

Simulation of Stiff Walls


Stability of Haptic Interaction with VEs


References

Commercial Force Feedback Haptic Devices

- Sensable Technologies, Inc. (http://www.sensible.com)
- Immersion Medical, Inc. (http://www.immersion.com)
- MPB Technologies, Inc. (http://www.mpbtechnologies.ca)

Haptic Interaction with Deformable Bodies


References

Human Factors for Enhanced Force Feedback


References

Modeling of Needle Insertion


Tactile Sensors and Display Technologies