Haptic and Tactile Feedback

M. Cenk Cavusoglu, PhD
cavusoglu@case.edu

Case Western Reserve University
Dept. of Electrical Eng. and Computer Sci.

http://vorlon.cwru.edu/~mcc14/
http://simcen.usuhs.mil/miccai2003

Haptics

- Haptic :

  Relating to or based on the sense of touch.

  Force feedback
  Tactile feedback
  } Haptic feedback

- Surgical simulation as haptic interaction with virtual surgical environments

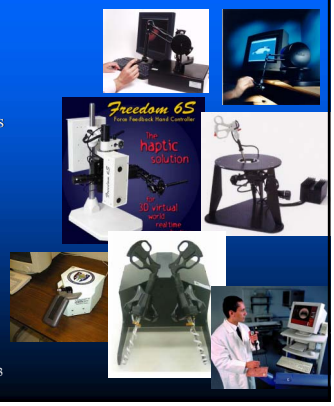
Research Issues in Haptic Interfacing to Virtual Environments

- 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

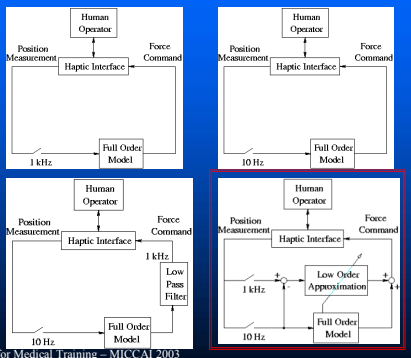


Generation of Force Feedback

Haptic Interaction with Deformable Bodies in VE's

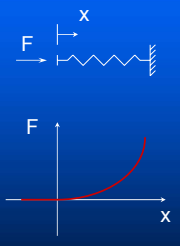
- Deformable bodies are simulated with very high order dynamical models
- Haptic interaction require bandwidth of ~1kHz, but these high order models can only be simulated at ~10Hz
- This affects the stability and fidelity of interaction

Simulation Schemes

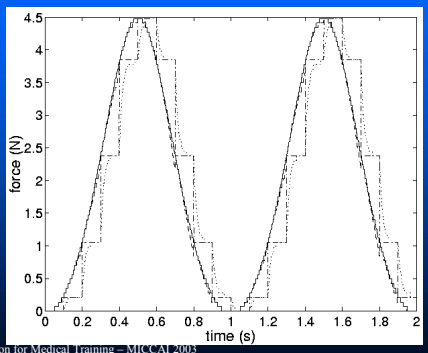


Demonstration of the Problem

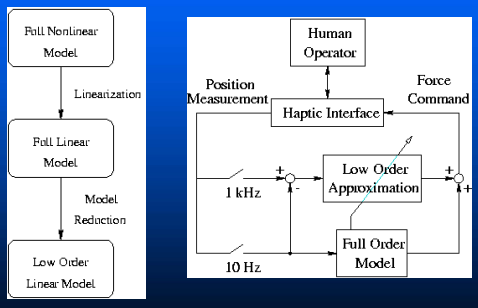
- Interaction with a nonlinear spring in one dimension
  - 10 Hz model update
  - 1 kHz haptic update



Demonstration of the Problem

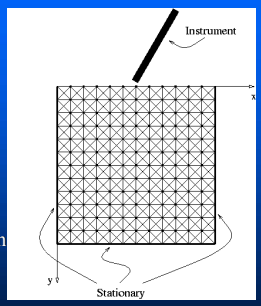


Low Order Linear Approximation to Model Intersample Behavior

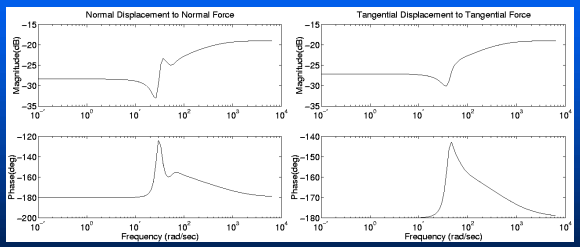


Model Reduction

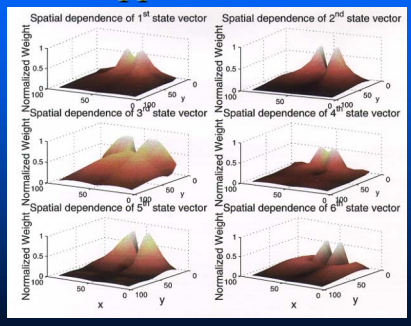
- 12x12 2-D lumped element model
  - 2 input 2 output dynamical system
  - 524th order dynamics
- Balanced model reduction
  - 10th order approximation with less than 1% error



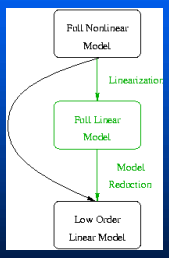
Model Reduction

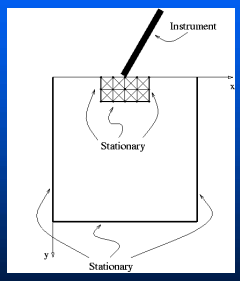


Reduced Order Model Is a Local Approximation

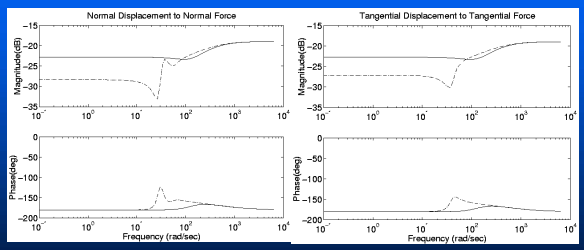


Constructing a Local Model in Real Time



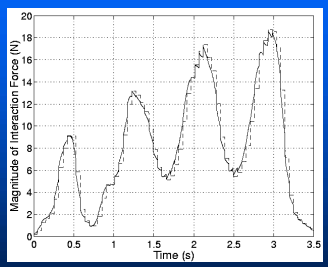


Constructing a Local Model in Real Time



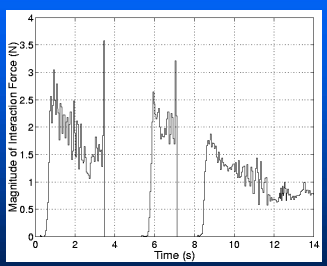
Implementation

- 6x6x6 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

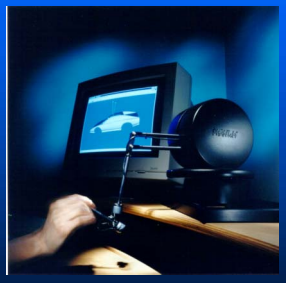
Coming up in the Tissue Modeling section of the tutorial !

Human Factors for Enhanced Force Feedback in MIS

Simulated Surface Compliance Discrimination

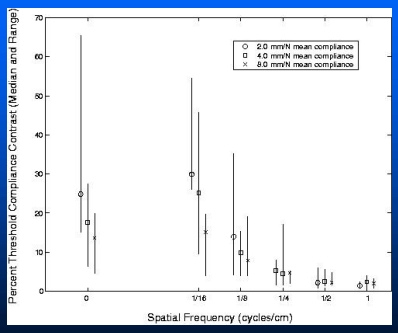
- Psychophysics literature on compliance has measured difference thresholds
- Surgeons often need to detect spatial variation in surface compliance, e.g. to detect embedded lesion
- Two tasks:
  - spatial variation in compliance
  - temporal oscillation in force

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

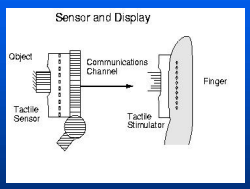
Compliance Discrimination and Contrast Sensitivity



Experimental Results from Dhruv and Tendick (2000)

Tactile Sensing and Display

Tactile Sensing and Display



8x8 1mm² Tactile Sensor Array

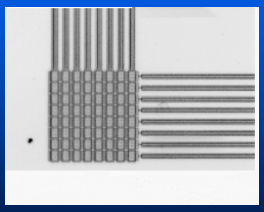
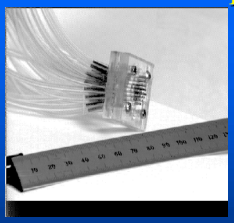
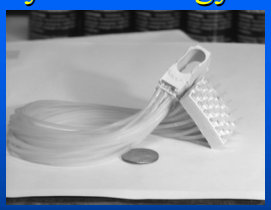
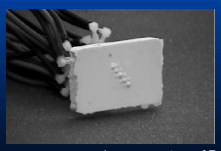


Image courtesy of Gray and Fearing

Tactile Display Technology



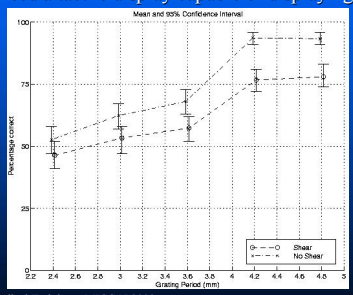




Images courtesy of Fearing et al.

Human Factors in Tactile Sensing and Display

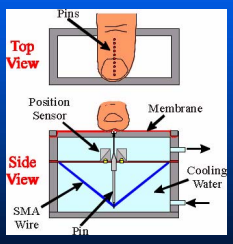
- Do we need a tactile display capable of displaying shear stress ?



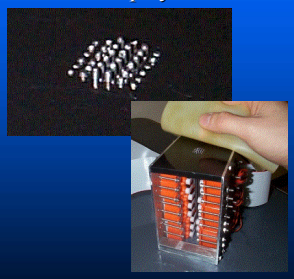
Experimental results from Moy and Fearing (1998)

Tactile Feedback

- SMA based tactile display



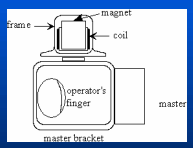
- DC servomotor based tactile display

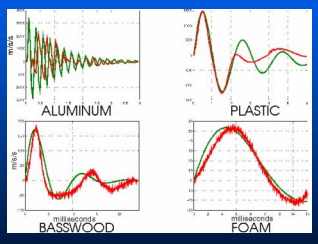


Images courtesy of Howe et al.

Tactile Feedback

- Vibrotactile Feedback





Images courtesy of Howe et al.

References

References

Commercial Force Feedback Haptic Devices

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

Haptic Interaction with Deformable Bodies

- C. B. Zilles and J. K. Salisbury. A constraint-based god-object method for haptic display. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS'95)*, pages 146-151, 1995.
- O. Astley and V. Hayward. Multirate haptic simulation achieved by coupling finite element meshes through norton equivalents. In *Proc. of the IEEE Int. T Conf. on Robotics and Automation*, pp. 989-994, 1998
- M. C. Cavusoglu and F. Tendick. Multirate Simulation for High Fidelity Haptic Interaction with Deformable Objects in Virtual Environments. In *Proc. of the IEEE Int. Conf. on Robotics and Automation*, volume 3, pages 2458-2465, 2000.
- D. d'Aulinac, R. Balaniuk, and C. Laugier. A Haptic Interface for a Virtual Exam of the Human Thigh. In *Proc. of the IEEE Int. Conf. on Robotics and Automation*, volume 3, pages 2452--2457, 2000.

References

Simulation of Stiff Walls

- S. E. Salcudean and T. D. Vlaar. On the emulation of stiff walls and static friction with a magnetically levitated input/output device. *Journal of Dynamical Systems*, 119:127-132, March 1997.
- J. E. Colgate, P. E. Grafing, M. C. Stanley, and G. Schenkel. Implementation of stiff virtual walls in force reflecting interfaces. In *Proceedings of the IEEE Virtual Reality Annual Symposium*, pages 202-208, 1993.

Stability of Haptic Interaction with VEs

- M. Minsky, M. Ouh-young, O. Steele, Jr. F. P. Brooks, and M. Behensky. Feeling and seeing: Issues in force display. In Computer Graphics, volume 24, pages 235-243, March 1990. ACM Symposium on Interactive 3D Graphics.
- J. E. Colgate, M. C. Stanley, and J. M. Brown. Issues in the haptic display of tool use. In Proceedings of the IEEE/RSJ International Conference on Intelligent Robotics and Systems (IROS'95), pages 140-145, 1995.
- R. J. Adams and B. Hannaford. Stable haptic interaction with virtual environments. IEEE Transactions on Robotics and Automation, 15(3):465-474, June 1999.

References

Human Factors for Enhanced Force Feedback

- L.A. Jones, and I.W. Hunter, A Perceptual Analysis of Stiffness, *Experimental Brain Research*, vol. 79, pp. 150–156, 1990.
- X.D. Pang, H.Z. Tan, and N.I. Durlach, Manual Discrimination of Force Using Active Finger Motion, *Perception and Psychophysics*, vol. 49, pp. 531–540, 1991.
- M.A. Srinivasan, and R. LaMotte, Tactual Discrimination of Softness, *J. Neurophys.*, vol. 73, pp. 88–101 , 1995.
- F. Tendick, M. C. Cavusoglu, N. Dhruv, and A. Sherman. Maximizing the Sensation of Compliance in Teleoperative Surgery. In *Proceedings of the Eighth International Symposium on Robotics with Applications, part of the World Automation Congress (WAC 2000)*, Maui, HI, June 11-16, 2000.
- N. Dhruv and F. Tendick, Frequency Dependence of Compliance Contrast Detection, in S.S. Nair, ed., *Proc. ASME Dynamic Systems and Control Division, vol. DSC 69-2*, Nov. 2000, pp. 1087-93.

References

Modeling of Needle Insertion

- S.P. DiMaio, and S.E. Salcudean, Needle insertion modeling and simulation, *IEEE Transactions on Robotics and Automation*, vol.19, no.5, Oct. 2003, pp. 864- 875.
- C. Simone and A. M. Okamura, Haptic Modeling of Needle Insertion for Robot-Assisted Percutaneous Therapy. *In,Proceedings of the IEEE International Conference on Robotics and Automation*, 2002, pp. 2085-2091.

Tactile Sensor and Display Technologies

- G. Moy, C. Wagner, and R.S. Fearing, A Compliant Tactile Display for Teletaction, *IEEE Int. Conf. on Robotics and Automation*, April 2000.
- G. Moy, U. Singh, E. Tan, and R.S. Fearing, Human Psychophysics for Teletaction System Design, *Haptics-e The Electronics Journal of Haptics Research,* Vol. 1, No. 3, February, 18, 2000.
- B.L. Gray and R.S. Fearing, A Surface Micromachined Microtactile Sensor Array, *IEEE Int. Conf. Robotics and Automation*, April 1996.
- D. A. Kontarinis and R. D. Howe, Tactile display of vibratory information in teleoperation and virtual environments, *Presence*, 4(4):387-402, 1995.