FORCE FEEDBACK

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Outline

- Force feedback interfaces
- Force feedback devices
- Haptic rendering
Force feedback interface

- Force feedback interfaces can be viewed as having two basic functions (Tan et al., 1994)
  - to measure the positions and contact forces of the user’s hand (and/or other body parts), and
  - to display contact forces and positions to the user.
Force feedback for display of texture and shape

- In figure A, the sensation of a textured surface can be produced via a stylus that moves according to the virtual surface texture.
- In figure B, a stylus can be used to probe the surface characteristics of a virtual object.
Haptic interaction
Physical modeling for virtual objects

Haptic interface control

Surface deformation

Compliance & texture

Grasping

Hard contact

Collision detection

Physical constraints

HAPTIC INTERFACE

(Adopted from Burdea, 1996)
Haptic system architecture

- User
- Distributed computing platform
- Haptic interface
- Interface controller

Haptic feedback

Visual, audio feedback

High-level control

Low-level control

Bi-directional energy flow

One-way information flow

(Adopted from Burdea, 1996)
Stiffness

- Mechanical behavior of most solid objects in a virtual world is modeled with **elastic stiffness**.
  - Many virtual objects are supposed to appear rigid.
  - In the virtual environments stiffness and rigidity are perceptual notions that need to be decided case-specifically.

- What is the stiffness required to convince a user that an object is rigid?
  - Perceived rigidity depends on both the stiffness of the interface hardware and whether the comparison is done among a set of virtual object simulations or between a simulation and a real object.
  - For example, users can consistently judge the relative stiffness of different virtual walls even though they are never as rigid as the real walls due to hardware limitations.
Force Feedback Devices
Force feedback devices

- **1 Degree of freedom**
  - Steering Wheels
  - Hard Driving (Atari)
  - Ultimate Per4mer (SC&T2)
- **2 Degrees of freedom**
  - Pens and Mice
  - Pen-Based Force Display (Hannaford, U. Wash)
  - MouseCAT/PenCAT (Hayward, Haptic Tech., Canada)
  - Feel-It Mouse (Immersion)
  - Joysticks
  - Force FX (CH Products)
  - Sidewinder Force Feedback Pro (Microsoft)
Force feedback devices

- 3 Degrees of freedom
  - PHANToM (SensAble Technologies)
  - ForceDimension Delta and Omega
  - Novint Falcon
  - Impulse engine (Immersion)

- 6+ Degrees of freedom
  - PHANTOM Premium 6 DOF, ForceDimension Delta 6 DOF, ...
  - Teleoperator masters (MA-23, Argonne, CRL)
  - Freedom 6/7 (Hayward, MPB Technologies)
Sensible Technologies: PHANTOM

http://www.sensible.com/
ForceDimension Omega and Delta

http://www.forcedimension.com/
Novint Technologies: Falcon

http://www.novint.com/
FCS Systems: HapticMASTER

http://www.fcs-robotics.com
Medical Force Feedback Systems

http://www.immersion.com
Immersion CyberGrasp

http://www.immersion.com
MPB Technologies: 3-7 DOF devices

http://www.mpb-technologies.ca/
Haption: 3-6 DOF Virtuose devices

http://www.mpb-technologies.ca/
Butterfly Haptics: Maglev 200

http://butterflyhaptics.com/
What makes a good haptic interface?

- The interface must operate within human abilities and limitations
- Approximations of real-world haptic interactions are determined by limits of human performance
What makes a good haptic interface?

- Free motion must feel free
  - Low back-drive inertia and friction
  - No motion constraints
- Ergonomics and comfort
  - Sizing and fatigue are also important issues, especially for exoskeletal devices
  - Pain, discomfort and fatigue will detract from the experience
  - Bad ergonomics can easily ruin otherwise excellent haptic display.
What makes a good haptic interface?

- Suitable range, resolution and bandwidth
  - User should not be able to go through rigid objects by exceeding force range (include mechanical stopping)
  - No unintended vibrations
  - Solid objects must feel stiff
Haptic rendering
Haptic rendering

- *Haptic rendering* is the process of computing and generating forces in response to use interactions with virtual objects, based on the position of the device.
- Haptic rendering of an object can be seen as pushing the device out of the object whenever it moves inside it.
- The human sense of touch is sensitive enough to require a processing speed of at least 1000 Hz in terms of haptic rendering.
Haptic rendering

- The haptic rendering needs to provide forces that push the user out of the object.
- The further inside the object you move, the greater the force pushing you out.
- This makes the surface feel solid.
1000 Hz Performance Requirement

- The user becomes a part of the simulation loop.
- 1000 Hz is necessary so that the whole system doesn’t suffer from disturbing oscillations.
- The PHANTOM haptic devices run their control loop at 1000 Hz.
- The consequence: we are limited on the amount of computation that we can do.
1 kHz haptics rendering: update speeds

Haptic real-time loop (~1000 Hz)
- Necessary due to the high sensitivity of human touch.
- Not necessary to look at every object in the scene 1000 times per second.

Visual scene-graph loop (~60 Hz)
- Looks at every object in the scene and generates surface instances that are rendered at 1000 Hz.
1 kHz haptics rendering

- The real-time “surface” is a parametric surface.
- This means that it can be curved to closely match the real surface curvature locally.
- The finger is the actual position of the haptic device.
The real-time “surface” has a 2D coordinate space to allow programmers to define haptic surface effects as a function of position and penetration depth.
1 kHz haptics rendering

- 3-DOF haptic devices are rendered in the API using a spherical “proxy”.
- The proxy stays on the surface of objects, and it is maintained in such a way that it is at the closest point on the surface of an object to the haptic device.
3DOF Haptics: Introduction

- Output: 3D force $\rightarrow$ 3DOF haptics
- Limited to applications where point-object interaction is enough.
  - Haptic visualization of data
  - Painting and sculpting
  - Some medical applications
6DOF Haptics: Introduction

- Output: 3D force + 3D torque
- For applications related to manipulation.
  - Assembly and maintenance oriented design.
  - Removal of parts from complex structures.
Haptic rendering

- Two parts: collision detection, response
Two types of interactions

• Point-based haptic interactions
  - Only end point of device, or haptic interface point (HIP), interacts with virtual object
  - When moved, collision detection algorithm checks to see if the end point is inside the virtual object
  - Depth calculated as distance between HIP and closest surface point
Two types of interactions (2)

- Ray-based haptic interactions
  - Probe of haptic device modeled as a line-segment the orientation of which matters
  - Can touch multiple objects simultaneously when the line touches them
F_{\text{user}} is a force vector calculated based on position of the proxy, direction of movement and properties of the surface.
History of force feedback systems

- Argonne 1954, first master-slave systems.
- Minsky 1990, the Sandpaper.
- Massie & Salisbury 1994, the PHANTOM device.
- Early 1990’s to 1997, 3DOF haptics.
- Late 1990’s to today, 6DOF haptics.
This presentation is partly based on presentations by the following people:

- Pierre Boulanger, Department of Computing Science, University of Alberta
- Max Smolens, University of North Carolina at Chapel Hill
- Ming C. Lin, University of North Carolina at Chapel Hill
- Ida Olofsson, Reachin Technologies AB
FORCE FEEDBACK APPLICATIONS

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Some applications for haptics

Games, simulations

- The simulated world feels more real when the user can explore it via touch and other senses.

bowling

driving

learning to play drums
Some applications for haptics

Three-dimensional modeling

- The user does not just see the object but can also feel it: helps to better understand the shape of an object.
- Virtual prototyping of new products.
Some applications for haptics

- Training of medical operations
  - Related to haptic modeling and visualization; no need to use paid volunteers or dead bodies when training the doctors.
Some applications for haptics

- Applications for visually impaired people
  - For example, presenting virtual models or information with a haptic display.
Some applications for haptics

- Applications for people with motor impairment
  - For example, supporting weak muscles or removing tremble in the movement.
Enabling the user

New multimodal technologies enable the user
• to be better engaged in the interaction
• to receive more information through several modalities

Multimodal interaction makes using of information technology possible for people with special needs, e.g., for blind and visually impaired people.
History (1/2)

• Ivan Sutherland's vision of "The Ultimate Display" (1965)
  - The vision has provided a research program for interactive computer graphics ever since, included seeing, hearing, and feeling in the virtual world.

  "If the task of the display is to serve as a looking-glass into the mathematical wonderland constructed in computer memory, it should serve as many senses as possible."

  - Suggested a kinesthetic display (a small joystick)
  - The computer could easily sense the positions of almost any of our body muscles.
    - So far only the muscles of the hands and arms have been used for computer control
History (2/2)

- Project GROPE: systems for scientific visualization of interacting protein molecules
  - GROPE-I (1967): develop a 2 DoF haptic display for molecular forces (finger grip display)
  - GROPE-II (1976): 3-6 DoF (3 forces, 3 torques) in a remote manipulator (hand grip display)
  - GROPE-III (1990): full 6 DoF molecular docking system (hand grip display)
Haptics and music
HapticSound: video (0:41)

Haptics and Music: HapticSound™
Haptic instrument: video (0:33)

http://at.or.at/hans/stickmusic/
Haptic xylophile: video (0:34)

http://www.stanford.edu/class/cs277/projects.htm
Haptic dancing: video (1:34)

http://www.dcs.gla.ac.uk/~rod/Videos.html
vBow: haptic violin (1:31)

http://www.charlesnichols.com/
D’Groove: video (1:03)

Haptic sculpting and painting
Virtual clay modeling: video (0:29)
Haptic painting: dAb

• Baxter et al. (2001)
  - **dAb**: Interactive Haptic Painting with 3D Virtual Brushes
  - captures the sight, touch, action and feeling of painting
    • 3D deformable brush  [action]
    • haptic feedback  [touch]
    • paint model  [sight]
    • user interface  [action]
dAb: video (3:03)

http://gamma.cs.unc.edu/dab/
Medical applications
Haptics in medical applications

- Haptic interfaces for medical simulation have proved especially useful for training of minimally invasive procedures.
  - e.g. laparoscopic operations & needle insertion
  - provide realistic training

- Also applications for carrying out remote surgeries have been developed.
  - the best surgeons can perform many similar operations with less fatigue
  - a surgeon who performs more procedures will have statistically better outcomes for one’s patients
The FeTouch project

- Medical ultrasound imaging for the 3D reconstruction
  - visual-haptic model is calculated from the 3D graphic model of the fetus
  - forces applied by the operator are calculated through geometric considerations based on the 3D model of the organ
FeTouch: video (1:04)

http://sirslab.dii.unisi.it/fetouch/
HORUS (Haptic Operative Realistic Ultrasound Simulator)

- A medical simulator for the training of ultrasound guided needle insertion for biopsy and radiofrequency thermal ablation.

- Uses two PHANTOM Omni devices
  - one controls the position of the virtual ultrasonographic probe
  - the other controls the virtual needle

- HORUS renders the tactile sensations in real-time simulating those a practitioner feels during a real intervention
HORUS: video (1:26)

Virtual laparoscopic interface: video (0:34)

http://www.simcen.org/surgery/hardware/Laparoscopic_Simulator.htm
BoneSim: visuohaptic simulation of bone surgery (0:36)

http://jks-folks.stanford.edu/bonesim/
Teleoperation surgery: video (1:32)

http://vorlon.case.edu/~mcc14/research/research.html
Other applications
Telemanipulation: video (1:35)

http://www-cdr.stanford.edu/touch/tele_projects/
Touch TV: video (5:51)

http://www.sarc.qub.ac.uk/~somodhrain/palpable/projects.html
Misc examples