Haptic interaction
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Contents
- Haptic definition
- Haptic model
- Haptic devices
- Measuring forces

Haptic Technologies
- Haptics refers to manual interactions with environments, such as sensorial exploration of information about the environment—Srinivasan, M., Basdogan, M.
- Haptic: adjective technical; of or relating to the sense of touch, in particular relating to the perception and manipulation of objects using the senses of touch and proprioception—ORIGIN late 19th cent.: from Greek haptikos ‘able to touch or grasp’, from haptai ‘fasten’.

Machine Haptics:

Types of Haptic Devices
- Force feedback Displays (Kinesthetic: position)
- Tactile Displays (skin)
Haptic interaction

- Making use of force and movement
- To convey force
- To convey movement of objects
- To convey realism of objects:
  - Give them physical rigidity
  - To give them surface properties
  - Give them resistance
  - Give them weight

Humans and machines

Integration of Vision and Touch

Haptic Rendering with a Force Display
```c
void calculate_force(Vector &force)
{
    float X, Y, Z, distance;
    float R = 20.0;
    X = HIP[0] - Hand[0];
    Y = HIP[1] - Hand[1];

    distance = sqrt(X*X + Y*Y + Z*Z);

    force[0] = stiffness * (R-distance);
    force[1] = stiffness * (R-distance);
    force[2] = stiffness * (R-distance);

    if (distance < R) /
    {
        force[0] = X/distance * (R-distance);
        force[1] = Y/distance * (R-distance);
        force[2] = Z/distance * (R-distance);
    }
}
```

Haptic Rendering of 3D Objects via Proxy (point-object interaction)

**HIP** = Haptic Interface Point: True (real world) position of stylus tip

**Hand** = always drawn outside the sphere

Haptic Rendering of Polygonal Surfaces

**HIP** = actual tip position

**HIP** = Proxy point

Haptic Display of Surface Details

- Haptic smoothing of object surfaces (similar to Phong shading)
- Rendering of haptic textures
- Haptic rendering of surfaces with friction

Haptic Rendering of 3D Objects via Proxy (point-object interaction)

- **d** = Proxy to Tip distance
- **F** = Hooke’s Law
- **F** = k * d

Assumption:

- Stiffness = 1.0

If in doubt: the visual sense will override the sense of touch …

Haptic Rendering of Polygonal Surfaces

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Haptic Texturing

- image-based
- procedural

Haptic Interface

- Haptic Interface Characteristics
  - Tracking the user
    - position
    - velocity
  - Display haptic feedback
    - force
    - roughness
    - temperature

Haptic Components

- Human and haptic system components
  - Mechanical
  - Sensory
  - Motor
  - Cognitive
- Haptic interfaces
- Computer haptics

Haptics Classification

- By location:
  - Ground based
  - Body based
  - Hybrid systems
- By output technology:
  - Force feedback devices
  - Tactile feedback devices
  - Shape forming devices
Force Feedback Requirements

- Low back-drive inertia and friction
- No constraints in motion imposed by drive kinematics (free motion)
  - should not be able to push through solid objects
  - avoid unintended vibrations through low servo rates
  - fast, high resolution responses are required
- Range, resolution, bandwidth
- Ergonomics and comfort
  - Must be safe
  - Discomfort or pain are wreckers

Technologies

- Motor driven
- Electromagnetic
- Hydraulic
  - Enormously powerful
- Gyroscopic
  - Good for impacts

Motor characteristics

- Stepper motors
  - Less powerful
  - Digital device:
    - Easy to control
- Moving Coil Motors
  - Much more powerful
  - Analogue device
  - Much harder to control
  - Needs precise feedback from sensors

Force Feedback

- Essentially robot arm technology
  - Where joint motors used to give force feedback
  - Derived from telerobotics
  - Compliant effectors
- Issues:
  - Working volume
  - Just how much force can be fed back
  - Haptic resolution
**Force Feedback Devices**

- **The Phantom**
  - Six degrees of freedom
  - Precision positioning input
  - High fidelity force feedback

**Phantom characteristics**

- Provides a tool to touch objects
- 'pen-like' tool
- Tip 'shape' definable
- Very precise control
  - Resolution at the tip ~0.02mm (in 3DOF)
  - Resolution permits detection of surface qualities in the scene (roughness)
  - Requires very high update rate (~1KHz)

**What it’s good for...**

- Suitable for simulating:
  - Pen/Paintbrush
  - Probe
  - Medical instruments
- Not suitable for:
  - Heavy objects
  - Can’t deliver enough force
  - Can’t press in the correct way
  • Could remove ‘pen’ and use dummy object

**Force Feedback Devices**

- **The Phantom FreeForm Modelling System**
  - Reduces the learning curve
  - Offers unlimited expression
  - May speed up development
  - Still looking at a projected 2D image
Force Feedback Devices

- Surgical Simulation and Training Carnegie-Mellon University, MIT
  - Use of force-feedback to interact with volumetric object models
  - Modeling interactive deformation and cutting of soft tissues using Volume Graphics
  - Real-time volume rendering techniques

Virtual surgery

- Drilling in human bone
  - Application developed by Melerit AB
  - Must work quickly
  - Doctor (and patient) gets X-ray dose while they work
  - Must work accurately
  - Mistakes can make the situation worse
- Off-line training very beneficial

Bone-drilling

- Use the actual bone drill
  - Weight is right
  - Behaviour is correct
- Replace the ‘pen’ grip on the Phantom
  - Attach by the drill ‘bit’
- Simulate bone and drilling with haptics
  - Rigidity
  - Surface qualities
  - Locking effect of the bone on drill

Force Feedback Devices

- Haptic Master: Nissho Electronics
  - Desktop device
  - Six degrees of freedom
  - Displays hardness, elasticity and flow
  - Small working volume
  - 2.5 Kg maximum load
  - Lack of back drivability (reduction of friction)
Force Feedback Devices

- **Haptic Master Interface for Fingertips**

Force Feedback Devices

- **MagLev Wrist: Carnegie Mellon University**
  - Uses magnetic levitation technology
  - Lorentz forces used to levitate & control the body

Force Feedback Devices

- **Rutgers Master II: Rutgers University**
  - Used in VR & telerobotics
  - Reads hand gestures
  - Displays forces to four figures in real time

Force Feedback Devices

- **Master Arm**
  - Four revolute joints
  - Tracks shoulder elbow motions
  - Pneumatic system
  - Attached to the operator’s chair
Force Feedback Devices

- **CyberImpact**
  - The DDOF, a three degree of freedom force feedback device
  - The 6DOF, which was developed for NASA for use in the space station
  - It is a six degree of freedom force feedback input/output device.
  - The SPACEPEN that was created for use in conceptual design and design evaluation

Exoskeletons

- **Put robot components around human ones**
  - Obvious safety issues
- **Cybergrasp**
  - Force-reflecting exoskeleton: fits over CyberGlove, adding resistive force feedback to each finger.
  - Network of tendons routed to the fingertips via the exoskeleton
  - Five actuators, individually programmed
  - Grasp forces are roughly perpendicular to the fingertips

Tactile Feedback Devices

- **Cybergrasp**
  - Impulse Engine 2000
  - 5 DOF Haptic Interface
  - University of Colorado

- **Laparoscopic Impulse Engine**

- **Eye Surgery Simulator: Medical College, Georgia**
  - Real-time "feel" of tool-tissue interaction
  - Tactile recording facility
Tactile Feedback Devices

- Utah-MIT Dextrus Arm
- Master Sensuit
- Teleoperation: Sarcos

Stimulation Delivery Methods
- Pneumatic
- Vibro-tactile
- Electro-tactile
- Functional neuro-muscular

Actuator Pin Display:
- Forschungszentrum Karlsruhe
- Spring force $F_{max} > 2.5$ N
- Maximum pin travel 3.5 mm
- Pins can stop at any position

Actuator Pin Display: VR Thermal Kit
- Hot or cold stimuli
- Temperature differential up to 600 K
- Constructed of Peltier cooling blocks
Shape Forming Devices

- Haptic Screen: Tsukuba University
  - Shape forming device
  - Variable surface hardness
  - Difficult to simulate virtual objects
  - Very application specific

Shape Forming Devices

- Elastic Force Sensor: Tsukuba University
  - Force reading device
  - Force magnitude dictates the level of deformation
  - Very application specific
  - Difficult to simulate virtual objects

Using vibration

- FakeSpace Cybertouch
  - Employs vibration to tell the user that their finger has reached a surface
    - Technology from mobile phones (‘silent’ mode)
- Information about the surface
- Quite limited but usable

CyberTouch

The CyberTouch Glove is both an Input Device and a Feedback Device

- 3D graphics show the virtual hand and the objects being manipulated
- 3D tactile feedback
- Sensors detect hand joint angles and finger locations
- Mechanical vibrators on the 5 fingers provide 3D tactile feedback
Virtual Chanbara

- SIGGRAPH 2002
  - Virtual samurai fighting
  - Gyroscope used to give sensation of impact

Used for haptic feedback

- Weight
- Motion (inertia)
  - Moments of inertia
- Impact
- Deformable objects
- Surface haptics – Surface properties
- Volume haptics – Volume Properties

Modelling weight

- Vertical force
  - Derived from mass of object
- Produces complex set of forces

Modelling weight - 2

- Simple force
  - Leads to complex derived forces
- Determined by the object
  - Mass: inertia
  - Mass distribution: moments of inertia
- Determined by nature of the ‘handle’
  - The way in which it is attached
- Getting it wrong affects realism
  - People know how it should feel!
**Linear motion**

- User applies a force to an object:
  - It accelerates away from point of contact
  - Determined by mass
  - User feels a force
- When the user stops pushing:
  - Object decelerates?
  - Due to friction?
  - Perhaps modelled with a ‘spring damper’
  - User feels a force

**Angular motion**

- Object has a moment of inertia about any axis
- Force produces rotation about an axis
- Angular acceleration:
  - \( \frac{\text{force} \times \text{distance}}{\text{moment of inertia}} \)

**Force measurement**

- Haptic devices often have no means to measure force!
  - Technology exists but is hard to use
  - Device measures distance moved
  - Force applied to user’s probe accordingly
- Proxy object:
  - Virtual object holding position on the surface of the object
  - The proxy is the rendered object

**‘Measuring’ force**

- Model with ‘spring’
  - Force proportional to movement
  - Typically very small movement
Impacts

- Moving object in collision:
  - Imparts momentum to other object
  - Begins to push user’s probe away
- Imparts an impulse to other object
  - Fast moving objects in particular
  - Elastic and inelastic collisions
- Hard to do with phantom equipment
  - Insufficient force, delivered too slowly
  - Specialist kit often used - as in virtual chanbara
    - Impact only, not FF

Surface properties

- Whole area of research:
  - Surface haptics
- Looking at ways to model...
  - Surface roughness
  - Surface friction
  - ...on general (not flat) surfaces

Rendering and surface haptics

- Surfaces of objects are sometimes flat
  - Easy to render these
- General surfaces are not flat
  - Well established models to render these
  - Gouraud and and Phong shading models
  - Make them look smooth
- Want same effect in surface haptics

‘Real’ surfaces

- Surfaces in scene are rarely simple:
  - Most are irregular
  - All are composed of polygons
  - None is smooth
- How do we model surface interaction?
  Use:
  - a proxy: a virtual object reporting real surface
  - and ‘force shading’ rules
Using the proxy

- Proxy moves on polygon surface
  - Computes surface properties
  - Adds fictional forces to physical tip
- Physical tip "feels" interpolated normal
- Interpolated like phong shading model