Virtual Reality Technology and Programming

TNM053:
Lecture 8: Haptic Devices

Haptic

- 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 haptein 'fasten'.

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

Delivering haptic sensation

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

Toys

Vibration can be employed

- FakeSpace Cybertouch
- Employs vibration to tell the user
  - That their finger has reached a surface
  - Information about the surface
- Quite limited but usable
Home cinema experience!

- D-Box Odyssee
- Hydraulic
- Central unit signals drivers
  - Shake, vibrate and jolt sofa
  - Actual movement is ~1.3cm
- Synchronized with DVD

Mechanical - Motors

- 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.

SensAble Phantom devices

- Designed to deliver force feedback
  - Also a mechanical tracking device
  - May deliver less FF DOF than tracking
- Models in the NVIS VR lab:
  - SensAble Phantom Desktop
  - 6DOF tracking
  - 3DOF force-feedback.

Phantom Desktop

- Motors with Position sensors
- Pivot with position sensors

Phantom Desktop DOFs
Phantom Desktop

- 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 surface qualities in the scene (roughness)
  - Requires very high update rate (>1kHz)

Phantom Desktop

- Suitable to simulate:
  - 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

Phantom Desktop: Common use

- Often built into 3D display
  - Augmented Reality
  - Based on half-silvered mirror
- Hand moves probe in reflected 3D scene
  - Can interact with the scene
- Very effective interface

Phantom 1.5/6DOF

- Similar but…
  - Bigger
  - Wider range of motion
  - More powerful
- Provides 3 more DOF at the tip
  - Full FF in 6DOF of the ‘handle’

Phantom 1.5/6DOF

- 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

Example application
**Melerit AB - 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

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**Drilling in human bone**

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**Bone drilling**

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**Pinning joint fractures**

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**Working applications**

- Rapid design and testing of "gearshift feel" in trucks.
- Replaces expensive physical models.

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**StoraEnso**

- Virtually test the "grip stiffness" of cardboard boxes
- Adjust type of board
- Create cost efficient way to design
Force Feedback Gloves.

- Immersion 'CyberGrasp'
- Full hand force feedback
  - Feel objects in the scene
  - Objects are weightless

Glove plus armature

- Immersion 'CyberForce'
- Adds weight to objects
- User can rest hand on an object
- Resolution
  - ±0.06mm, ±0.09°
- Delivers Force of 8.8N
  - Less than 1Kg equivalent

Delta Haptic Device

- Armature-based haptic devices have a problem with force.
  - Nothing like enough of it.
  - Even less torque
- New device is considerably better
**Delta Haptic Device**

- Strange armature gives sizeable coverage
  - 36cm diameter x 30cm
- Much more force and torque
  - 25N (~3Kg)
  - 0.2Nm
- Less good resolution than phantom
  - 0.1mm x 0.04 degrees

**Magnetic Levitation Haptic Device**

- Torque delivered through ‘wrist’
- Motion range:
  - 15-20 degrees rotation
  - 25 mm translation
- Position sensitivity: 5-10 µm
- Maximum stiffness of 25 N/mm
- Maximum force/torque: 55 N / 6 Nm

**Sensor Arm - U. Tokyo**

- 6 DOF
  - Shoulder (3)
  - Elbow
  - Wrist (2)
- All measured
- All force-enabled

**Sensor Glove - U. Tokyo**

- 20DOF
- Every finger joint
- +1 for each digit
- All force-enabled
Virtual Chanbara - U. Tokyo

Summary:
Haptic equipment

- Mechanical devices are a way forward
  - Need range of movement
  - Need high resolution
  - Need levels of force that are hard to find
    - Still not giving enough
- Current devices limited in range
  - Largest devices give ~1m movement
  - No (general) portable devices available

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Lecture 8.5: Haptics force modelling

Forces and physical models

- (3DOF) 6DOF hand set
- How are the forces derived?

Mathematical models

- 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
- Complex set of forces derived

#### 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: \( \alpha = \frac{(\text{force} \times \text{distance})}{\text{moment of inertia}} \)

### Rigid body motion in scene

- Simple because it’s symmetrical
- Horrible when it’s not

### 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 square of motion
  - Typically very small motion

Prox

length I, force \( \propto \dot{I} \)

Impacts

- Methods exist for managing collision detection in a scene
- 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

Impacts (2)

- Hard to do with phantom equipment
  - Insufficient force delivered too slowly
- Specialist hardware is common
  - virtual Chanbara
  - No FF, just impact

Deformable objects

- Rigid box replaced by spring model
  - Constants to model desired behaviour
- Not very realistic

Sprung polygon surface

Surface deformation
- Responds to applied force
- Complex behaviour

- Modelled in many ways
- Spring-connected polygons is common
  - Relatively easy to model
  - Not necessarily very realistic
  - Essential to design polygon mesh well
**Sprung polygon box**
- Edges and faces are different
- Edges relatively rigid
- Faces more deformable

**StoraEnso simulation**
- Polygon model is real engineering simulation

**Sprung polygon surface**
- For good realistic modelling need:
  - correct polygons and enough of them
  - correct spring qualities
  - correct level of propagation through mesh
- Produces big mathematical problem
  - Defining the spring qualities
- Well known problem in engineering:
  - Finite Element method

**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 Phong shading models
  - Make them look smooth
- Want same effect in surface haptics

**Smooth surface**
- Friction: static then dynamic
‘Real’ surfaces

- In our scene surfaces are not 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

A real surface

A real surface (2)

- Proxy moves on polygon surface
  - Computes surface properties
  - Adds fictional forces to physical tip

- Physical tip ‘feels’ interpolated normal
  - Interpolated like phong shading model

Surface haptics

- Surface properties
  - Modelled using complex polygon sets
  - Can apply ‘surface textures’ producing variable surface friction(s)

Summary: ‘Scene’ modelling

- Movable objects
  - Having mass distribution - complex behaviour

- Surface properties
  - Friction qualities vary across materials

- Deformable objects
  - Complex shapes
  - Deformation affects friction properties

- Big computational problem!

Haptic ‘Visualization’
Virtual Prototyping

‘Fictional’ Forces

- Derived from physical models
  - Vital for physical data visualization
- Physical model derived from real-world situations:
  - Physics
  - Chemistry
  - Engineering

Physical model: Discrete properties

- Probing electrostatic properties
  - Forces derived from physical effect
  - Well quantified methods
- E.g. Chemical forces
- Well-characterized potentials:
  - E.g. Lennard-Jones ‘6-12’ potential
  - More complex potentials (molecular mechanics)

Chemical interactions

- Total force found by summing partial forces

‘Molecule on a stick’

1,2-Dichloroethane

- Consider rotation around central axis
More worthwhile example: Protein-Ligand docking

Protein-Ligand docking

- Simple forces not good enough:
  - Need more complex functions
  - Computationally very expensive
  - Makes it hard to calculate in real time
    - Impossible at the moment
  - Need a method which provides easier mathematics
    - Must still give good quality results
    - Real-time updates

Volume haptics

- Whole (quite new) area of research:
  - Examining data volumes through haptics
- Volumes of data can have material properties
  - Density
  - Tensile properties
  - Viscosity
  - Velocity
- Can map those into haptic forces

Probing volume data

- Can map those into haptic forces
  - As it moves through the data
    - Dependent on data, speed, probe type
- Many methods, e.g.
  - Direct physical properties
  - Identification of surfaces
- Goal, to perceive data types at a point
- Example: Protein-ligand docking

Volume haptics (2)

- Create fictional forces for virtual probe
  - As it moves through the data
  - Dependent on data, speed, probe type
- Many methods, e.g.
  - Direct physical properties
    - Field strength dependent on atom type
  - Identification of surfaces
- Goal, to perceive data types at a point
- Example: Protein-ligand docking

Protein-Ligand docking with volume effects

- Current exjobb project at NVIS
- Protein Ligand interaction can be modelled by a potential field
  - Field strength dependent on atom type
  - Compute force on each atom in ligand from local, atom-type-specific field
- Maths much simpler than before:
  - Can calculate forces on ligand in real time
Medical work

- Volume haptics is very interesting for medical work
- Volume data is commonplace:
  - CT (X-Rays) data
  - MRI data
- Tissue types show well-defined property differences in the data

Gamma knife

- Recent Exjobb project at ITN
  - Collaboration with hospital in Stockholm
  - And with Elektra
- Treatment planning for brain tumours:
  - using precise radiation treatment
  - Requires exact location of tumour tissue

Brain tumour data

- Brain tissues:
  - Grey matter
  - White matter
  - Fluid
  - Tumour

Gamma Knife Application

Mastoidectomy
**Mastoidectomy (2)**

**Visualization of fluid data**
- Interaction with a fluid simulation output data
- Volume containing:
  - Density
  - Velocity
  - Viscosity
  - Vorticity
- Use ‘paddle’ probe to feel vorticity

**Haptic fluid flow probe**

**Visualization for the blind**
- Graphical visualization of limited use to the visually impaired
- Haptic interaction can improve that
- Rendered images can be interpreted through the haptic interaction
  - Edge sharpness → contrast
  - Colours → roughness of the surface
  - Shininess → dynamic/static friction

**Haptic rendering process**

**Output geometry**
### Summary

- In addition to scene objects can use simulated data through fictional forces
- These forces provide a means to probe data through the sense of touch
- Valuable addition to visual cues representing data values in display
- Can combine both for a very powerful interactive 'visualization' system