Virtual Reality Technology and Programming

TNM053: Lecture 9: 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

delivering haptic sensations

Motor driven

Electromagnetic

Hydraulic

Gyroscopic

Fakespace Cybertouch

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 \(~1.3\) cm
- 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

![Phantom Desktop DOFs](image)

- Motors with Position sensors
- Pivot with position sensors
**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’

**Example application**

- 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
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

Bone drilling

Drilling in human bone

Pinning joint fractures

Working applications

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

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
  - $\pm 0.06\text{mm}$, $\pm 0.09^\circ$
- 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

**Delta Haptic Device**

- Torque delivered through ‘wrist’

**Sensor Arm - U. Tokyo**

- 6 DOF
  - Shoulder (3)
  - Elbow (1)
  - Wrist (2)
- All measured
- All force-enabled

**Sensor Glove - U. Tokyo**

- 20DOF
- Every finger joint
- +1 (sideways) for each digit
- All force-enabled

**Virtual Chanbara - U. Tokyo**

**Audience View**
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
- Current devices limited in range
  - Largest devices give ~1m movement
  - No (general) portable devices available

Virtual Reality Technology and Programming

TNM053:
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

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 movement
  - Typically very small movement

**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

- 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

Deformable objects

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

Sprung polygon surface

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 (materials) qualities
  - correct level of propagation through mesh
- Produces big mathematical problem
- Well known problem in engineering:
  - Finite Element method
- Even more complex with data volumes

### 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
- Motion

### ‘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**

**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
  - 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-Ray) data
  - MRI data
- Tissue types show well-defined property differences in the data
**Gamma knife**

- Recent exjobb project at ITN
  - Collaboration with Karolinska Institute in Stockholm
  - And with Elekta
- Treatment planning for brain tumours:
  - using precise radiation treatment
  - Requires exact location of tumour tissue

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**Brain tumour data**

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

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**Gamma Knife Application**

**Visualization of fluid data**

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

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**Haptic fluid flow probe**

**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