Module 13

Haptic / tactile displays
Haptic / Tactile rendering

• Haptic rendering
  – Force based rendering (Kinesthetic stimuli)
  – Force feedback on surgical probe

• Tactile rendering

• Touch based rendering (Cutaneous stimuli)
  – Vibrational feedback on touchscreen / keyboard
Haptic display

- Single point of contact
- 3 DoF

- Equivalent to feeling and exploring a 3D object through a stylus in the real world.
Haptic display

- Significantly more complex than visual rendering
  > Bilateral process: display (rendering) cannot be divorced from manipulation
  > Tracking the inputs of the user as well as displaying the haptic response

- Computationally demanding due to the high sampling rates required.
  > Requires signals to be refreshed faster than 1 ms.
  > Vibration \( \approx 1000 \text{ kHz} \) is required
    - to simulate fast motion over fine texture,
    - for sharp, impulsive rendering of a changing contact condition.
Model of haptic device

Virtual coupler
- Mechanical (Spring) model
- Electrical (Admittance / Impedence) model

Source: Basdogan, et al.
Rendering 3D objects

Source: Basdogan, et al.
Schematic

Source: Basdogan, et al.
Rendering 3D objects

\[ \vec{F} = k \Delta \vec{x} \]

Source: Basdogan, et al.

HIP: Haptic Interface Point
IHIP: Ideal Haptic Interface Point
Also known as Surface Contact Point (SCP)
Effect of sampling

Update (sampling) rate: ~ 1 kHz

Note: energy gain / loss (hysteresis)

Source: Basdogan, et al.
Ambiguity
Synchronization with visual feedback

- Visual feedback dominates
- In a psychological experiment
  - Delaying haptic feedback had no effect on either performance or the participant’s perception of task difficulty,
  - Nor did keeping it in real time aid participants when visual feedback was delayed
Geometric models

- **Surface Model**
  - Polygonal surfaces
  - Parametric surfaces
    - B-Splines
    - Implicit surfaces
      - Defined by a function
        - $f(x) = 0$: on the surface, $f(x) < 0$: inside, $f(x) > 0$: outside

- **Volumetric model**
  - Use of “voxels”
  - Stacked “Slices” (as in CT-Scan)

Add surface details (e.g. Texture) for more realistic feeling
Extensions

- 6 DoF rendering
  - Add torques
  - More suitable for deformable objects

- Full-hand interaction
Vibro-tactile perception

<table>
<thead>
<tr>
<th>End Organ</th>
<th>SA I (NP III)</th>
<th>RA (FA I, NP I)</th>
<th>SA II (NP II)</th>
<th>PC (FA II, P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory Adaptation</td>
<td>Merkel Disk</td>
<td>Meissner Corpuscle</td>
<td>Ruffini Ending</td>
<td>Pacinian Corpuscle</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>Fast</td>
<td>Slow</td>
<td>Fast</td>
</tr>
<tr>
<td>Receptive Field</td>
<td>Small</td>
<td>Small</td>
<td>Large</td>
<td>Large</td>
</tr>
<tr>
<td>Frequency Range (Hz)</td>
<td>&lt; 5</td>
<td>3–100</td>
<td>15–400</td>
<td>10–500</td>
</tr>
<tr>
<td>Perceiving Property</td>
<td>Pressure, Fine Details</td>
<td>Flutter</td>
<td>Stretch</td>
<td>Vibration</td>
</tr>
</tbody>
</table>

4-channel theory of tactile perception for Glabrous (non-hairy) skin
Can the user perceive a vibro-tactile cue?

- **Absolute (detection) threshold:**
  - The weakest stimulus intensity that can be perceived by humans
  - Depends on channel and frequency
- **U-shaped curve for variation with frequency for every channel**
- **These absolute thresholds are affected by ... body site, stimulus waveform, skin temperature, the presence of other masking stimuli, and age**
  - Contact area and duration have additive effects
- **A stimulus may be perceived by multiple channels**
Can the user distinguish between the different vibrotactile cues?

• Discrimination threshold
  - The smallest difference between two stimuli that leads to reliable discrimination
  - Recall weber law: \( \Delta p = k \frac{\Delta S}{S} \)
    - \( k \) = Weber constant

• Typical values of \( k \)
  - 10-30\% for vibration intensity
  - 15-30\% for vibration frequency
  - 20-30\% change required for robust discrimination
How strong does a vibrotactile cue feel?

- Perceptual strength of a stimulus $I$
  \[ \psi(I) = k \cdot I^e \]
  - Steven's law
  - $e = 0.35 - 0.86$,
  - Depends on stimulation conditions, stimulus frequency

- Both amplitude and frequency affect the perceived pitch of a vibration

- Identical sensation contours
How good are users at judging the timing of vibrotactile cues?

- High temporal acuity.
  - We can distinguish successive pulses with a time gap as small as 5 ms
    - Better than that for vision (25 ms)
    - Worse than auditory acuity (0.01 ms)

- Further temporal variations can be brought into by changing its amplitude over time (envelop)
  - Rhythm
Can vibro-tactile cues elicit any other perceptual effects?

- Frequency
  - Very slow frequency (< 3 Hz): slow kinesthetic motion
  - Low frequency (10 – 70 Hz): Rough motion / fluttering
  - High frequency (100 – 300 Hz): Smooth vibration
- Qualitative difference for two ranges
  - 40 – 100 Hz
  - 100 – 250 Hz
- In practical vibro-tactile displays
  - Low frequency vibrations are used to modulate high-frequency vibrations to provide different cues
Multiple body sites

- Can a user distinguish vibrotactile cues applied to neighboring locations on the body?
  - Recall
    - Two point threshold: 4 – 45 mm
    - Localization threshold: 2 – 12 mm
    - Depend on part of the body
  - The localization accuracy of 250-Hz vibrotactile stimuli around the waist was
    - 74% with 12 equidistant tactile actuators (tactors),
    - 92% with 8 tactors
    - 97% with 6 tactors

- Intuitive mapping
  - A tap on the left shoulder makes one to turn right
Vibro-tactile actuators

- Linear Electromagnetic Actuators
  - Same principle as audio-speaker
  - Very small ~ 1 cm
- Rotary Electromagnetic Actuators
  - A dc motor with an off-centre load
- Nonelectromagnetic Actuators
  - Piezo-electric
Vibro-tactile displays

• Monolithic display
  – The whole device vibrates as a whole

• Localized display
  – Many displays are integrated in the device (or a suit)
  – Contact points of individual displays are important
Applications

• Physical information delivery
  - Material property (texture)
    • Virtual texture of fabric on screen
    • Virtual ride on a gravel road
  - Contact Location
    • Body contact in a VR environment

• Abstract information delivery
  - Communication for physically challenged
    • OPtical to TActile CONverter (Optacon)
  - Navigation aid
    • For visually challenged, helicopter pilots
  - Human-Machine Interaction
    • Mobile devices
References

- Basdogan, et al. 3 DOF Haptic rendering