Lecture 12: Human haptic perception and Tactile devices

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types of haptic sensing

**cutaneous/tactile**
Related to the skin.

**kinesthesia/proprioception/force**
A sense mediated by end organs located in muscles, tendons, and joints. Stimulated by bodily movements.

Johansson and Westling
types of haptic sensing

**tactile**
- spatial form (SA I)
- texture (SA I, PC)
- movement (RA)
- flutter (RA)
- vibration (PC)

**stereognosis**
(SA I, Proprioceptors)

**pain**
- pricking pain (A δ)
- burning pain (C fiber)

**muscle force**
(Golgi tendon organs)

**temperature**
- cold (A δ)
- warm (C fiber)

**body position/movement**
(SA II, joint afferents, muscle spindles)
sensory homunculus

mapping the human somatosensory cortex
(Kandel, Schwartz and Jessel)
active vs. passive touch

• Active touch
  – Focus on the object

• Passive touch
  – Focus on the sensation experienced

• Try it

• Is active touch better?
  – Purposiveness vs. movement over skin
    – In 3D, yes

• How is this important to haptic device design?
mechanoreception
mechanoreceptive afferents

classified by depth:
I: closer to skin surface
II: deeper beneath surface

classified by rate of adaptation:
rapidly adapting = phasic
slowly adapting = tonic

classified by sending modality:
e.g., receptor structure
cross section of glabrous skin
Merkel (SA I)

- Shape: disk
- Location: near border between epidermis & dermis
- Type: SA I
- Best Frequencies: 0.3-3 Hz
- Stimulus: pressure

- form and texture perception
- low-frequency vibrations
Ruffini (SA II)

- static and dynamic skin deformation
- skin stretch

**Shape:** many-branched fibers inside a roughly cylindrical capsule

**Location:** dermis

**Type:** SA II

**Best Frequencies:** 15-400 Hz

**Stimulus:** stretching of skin or movement of joints
Meissner (RA I)

**Shape:** stack of flattened cells, with a nerve fiber winding its way through

**Location:** in dermis just below epidermis

**Type:** RA I

**Best Frequencies:** 3-40 Hz

**Stimulus:** taps on skin

- motion, slip/grip
- dynamic skin deformation
Pacinian Corpuscle (PC / RA II)

**Shape:** layered capsule surrounding nerve fiber

**Location:** deep in skin

**Type:** PC

**Best Frequencies:** 10 to >500 Hz

**Stimulus:** rapid vibration

• high frequency vibration

• gross pressure changes
# cutaneous mechanoreceptors

<table>
<thead>
<tr>
<th></th>
<th>Receptor</th>
<th>Diam.</th>
<th>Density (Fibers/cm²)</th>
<th>Response</th>
<th>Percep. Function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SA I</strong></td>
<td>Merkel</td>
<td>2mm</td>
<td>100</td>
<td>curvature</td>
<td>form &amp; texture</td>
</tr>
<tr>
<td></td>
<td>Meissner</td>
<td>5 mm</td>
<td>150</td>
<td>motion</td>
<td>motion &amp; grip control</td>
</tr>
<tr>
<td><strong>RA</strong></td>
<td>Ruffini</td>
<td>8mm</td>
<td>20</td>
<td>stretch</td>
<td>hand shape, lateral force</td>
</tr>
<tr>
<td><strong>SA II</strong></td>
<td>Pacinian</td>
<td>Hand</td>
<td>20</td>
<td>vibration</td>
<td>tools &amp; probes</td>
</tr>
</tbody>
</table>
kinesthesia
kinesthetic sensing

perception of limb movement & position, force

• muscle receptors (muscle spindles and Golgi tendon organs)

• joint receptors (in capsules and ligaments of joints)

• skin receptors (slowly adapting cutaneous mechanoreceptors that measure skin stretch): Ruffini endings, Merkel Cells in hairy skin
force sensing

- Resolution 0.06 N
- Grasping force: 400 N!
- Which of the following objects weighs about one Newton?

automobile, Isaac Newton, bowling ball, baseball, a dime
proprioception

• derived from Latin, *proprius*, meaning “belonging to one's own self”

• in general, it provides a sense of static position and movement of the limbs and body in relation to one another and the world

• in much of the literature, proprioception is defined as the perception of positions and movements of the body segments in relation to each other (without aid of vision, touch, or the organs of equilibrium). This is in contrast to *exteroception*.
## Just Noticeable Differences at Joints

<table>
<thead>
<tr>
<th>Joint</th>
<th>Just Noticeable Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal-InterPhalangeal (PIP) Joint</td>
<td>~2.5°/*6.8°</td>
</tr>
<tr>
<td>MetaCarpalPhalangeal (MCP) Joint</td>
<td>~2.5°/*4.4°</td>
</tr>
<tr>
<td>Wrist</td>
<td>2.0°</td>
</tr>
<tr>
<td>Elbow</td>
<td>2.0°</td>
</tr>
<tr>
<td>Shoulder (front)</td>
<td>0.8°</td>
</tr>
<tr>
<td>Shoulder (side)</td>
<td>0.8°</td>
</tr>
</tbody>
</table>


Movement and position threshold can depend on velocity and whether muscle is contracted.

\[
\begin{array}{c|c|c|c|c|c|c}
\text{Angular velocity (deg/sec)} & 0.000 & 1.750 & 3.500 & 5.250 & 7.000 \\
\hline
\text{Index finger} & 0.01 & 0.10 & 1.00 & 10.00 & 100.00 \\
\end{array}
\]

Index finger

- Elbow relaxed
- Elbow contracting

Jones, 2000
Two-point discrimination experiment

The two-point discrimination test seeks to determine the distance between two contact points at the threshold of when they are perceived as a single contact point vs. two separate contact points.

• Do in pairs
• Test (1) the tip of the index finger and (2) the inside of the forearm
• Method: apply contact points, move them closer together (or further apart) until two points feel like one (or one point feels like two), record the distance
• Enter the threshold at the URL provided
tactile haptic devices
tactile feedback

• goal is to stimulate the skin in a programmable manner to create a desired set of sensations

• sometimes distributed tactile feedback is provided

• tactile feedback is generated by a tactile device, sometimes called a tactile display

• not usually called a tactile interface

  why not?

• can aim to recreate real sensations, create novel ones, or communicate information
What does the human hand feel?

“Psychophysical Dimensions of Tactile Perception of Textures” by Okamoto et al., 2013
What does the human hand feel?

- Spatial distribution of SAI
- No temporal information

“Psychophysical Dimensions of Tactile Perception of Textures” by Okamoto et al., 2013
What does the human hand feel?

“Psychophysical Dimensions of Tactile Perception of Textures” by Okamoto et al., 2013

- Vibratory information
- FAI and FAII
What does the human hand feel?

- Mediated by skin of finger pad
- Skin stretch or adhesion

"Psychophysical Dimensions of Tactile Perception of Textures" by Okamoto et al., 2013
What does the human hand feel?

- Heat transfer property between texture and finger
- TRP ion-channels on free nerve endings

“Psychophysical Dimensions of Tactile Perception of Textures” by Okamoto et al., 2013
What does the human hand feel?

- Tactile cues
- Contact area between finger pad and object is important

“Psychophysical Dimensions of Tactile Perception of Textures” by Okamoto et al., 2013
Feeling through a tool

- Rigid link between surface and fingers
- No spatial cues available
  - Skin deformation from tool, not from surface
- Vibratory stimuli
- Warm/cool dimension cannot be conveyed
technologies and interaction modes

particle jamming
skin stretch
variable friction surfaces

Northwestern TPad (many publications):  
http://stage-admin.northbynorthwestern.com/story/more-than-a-feeling/

Disney’s TeslaTouch (Bau et al. 2011):  
https://www.youtube.com/watch?v=3I3MDNZk-3I
mid-air haptics

Ultrasonic haptics (Ultrahaptics):
https://www.youtube.com/watch?v=6lhQnWb44zk

Vortex haptics (Microsoft):
https://www.youtube.com/watch?v=b5vzvMCmiyQ
vibration feedback
eccentric mass motors

4 mm, ~0.6 g
7 mm, ~1 g
12 mm, ~1.2 g
20 mm, ~4 g
24 mm, ~2.8 g
45 mm, ~9.7 g
shaftless vibration motors

Three pole DC motor with eccentric coil

10 mm, ~0.8 g

www.precisionmicrodrives.com

8 mm, ~0.4 g  12 mm, ~0.9 g  12 mm, ~0.6 g
vibration motors
shaftless vibration motors

www.precisionmicrodrives.com
information display

Rotella et al. 2012
saltation illusion

Geldard and Sherrick 1972
Vibration Flow

Seo & Choi 2010

Kim et al. 2009
linear actuator: C2 Tactor

**SPECIFICATIONS: C-2 TACTOR**

- **Physical Description:** 1.2” diameter by 0.31” high
- **Weight:** 17 grams
- **Exposed Material:** anodized aluminum, polyurethane
- **Electrical Wiring:** Flexible, insulated, #24 AWG.
- **Skin Contactor:** 0.3” diameter, pre-loaded on skin
- **Electrical Characteristics:** 7.0 ohms nominal.
- **Insulation Resistance:** 50 megohm minimum at 25 Vdc, leads to housing.
- **Response Time:** 33 ms max
- **Transducer Linearity:** +/- 1 dB from sensory threshold to 0.04” peak displacement.
- **Recommended Drive:** Sine wave tone bursts 250Hz at 0.25A rms nominal, 0.5 A rms max for short durations.
- **Recommended Driver:** Bipolar, linear or switching amplifier, 1 W max, 0.5 W typical.

[www.eaiiinfo.com](http://www.eaiiinfo.com)
C2 Tactor application

Gurari et al. 2009
C2 Tactor application

**tactor mapping**

**tactor waistbelt**

**virtual prosthetic hand**

**envelope frequencies**

- Level 1
- Level 2
- Level 3

Cheng et al. 2012
another vibration actuator (voicecoil)
Voicecoil actuator

McMahan and Kuchenbecker 2009
Voicecoil actuator application
Vibrotactile Feedback

- Sensory substitution – vibrotactile feedback to replace force feedback

[Murray, Klatzky, Khosla., Psychophysical Characterization and Testbed Validation of a Wearable Vibrotactile Glove for Telemanipulation Presence, 12(2) 2003]
Vibrotactile + Force Feedback

[Kontarinis & Howe 1995]

[Utah Haptics]
vibrotactile feedback

advantages?

disadvantages?