Intro to Haptics

CMSC730 | Huaishu Peng | Fall 2022
5 Senses

- Sight
- Hear
- Smell
- Taste
- Touch
Sight vs Touch

Sight
- centralized
- broad
- passive
- cognitive

Touch
- distributed
- narrow
- active
- physical

Tom Igoe
What is haptic

The haptic senses work together with the motor control system to:
- Coordinate movement
- Enable perception

Cutaneous
Temperature
Texture
Slip
Vibration
Force

Kinesthesia
Location/configuration
Motion
Force
Compliance

Johansson and Westling
Normal,
Pre-anesthetization
Performance

From the laboratory of
Dr. Roland Johansson
Dept. of Physiology
University of Umeå, Sweden

Cutaneous

https://www.youtube.com/watch?v=0LfJ3M3Kn80
What is haptic

Cutaneous
- Temperature
- Texture
- Slip
- Vibration
- Force

Kinesthesia
- Location/configuration
- Motion Force
- Compliance

Johansson and Westling
kinesthetic vs. tactile devices

<table>
<thead>
<tr>
<th></th>
<th>Active</th>
<th>Passive</th>
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</thead>
<tbody>
<tr>
<td><strong>Cutaneous</strong></td>
<td>Tactile haptic devices</td>
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<td>display forces or motions</td>
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<td>stimulate the skin</td>
<td>stimulate the skin</td>
</tr>
</tbody>
</table>

| **Kinesthetic**       | Kinesthetic haptic devices    | Kinesthetic haptic devices    |
|                      | display forces or motions     | display forces or motions     |
|                      | through a tool                | through a tool                |

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<tbody>
<tr>
<td>Tactile haptic devices</td>
<td>Kinesthetic haptic</td>
</tr>
<tr>
<td>can more easily be</td>
<td>devices are usually</td>
</tr>
<tr>
<td>wearable</td>
<td>grounded</td>
</tr>
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</table>

Tactile (cutaneous) device basics
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
Sensory homunculus

mapping the human somatosensory cortex
Arms vs fingertips

sparse distribution

dense coverage

Images courtesy Even Pezent
Active vs. passive touch

**Passive touch**
Focus on the sensation experienced

**Active touch**
Focus on the object
Mechanoreceptive afferents

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

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

classified by sensing modality:
e.g., receptor structure
Cross section of glabrous skin

Epidermis

Dermis

Meissner corpuscle

Pacinian corpuscle

Ruffini's corpuscles

Merkel's disks

Free nerve endings

Sweat gland
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)

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

**SA I**

**RA**

**SA II**

**PC**
Thermal sensing

separate warm and cold receptors whose firing rate depends on magnitude of difference w.r.t body temperature

both slowly adapting (SA) and rapidly adapting (FA) characteristics, so depends on both T and dT/dt

perception strongly affected by body temperature versus temperature at surface of skin (aluminum feels cooler at room temperature than wood) -- an important component of material identification

What does the human hand feel?

What does the human hand feel?

Spatial distribution of SA I
No temporal information

What does the human hand feel?

- Friction (Moist/Dry, Sticky/Slippery)
- Hardness (Hard/Soft)
- Warmness (Warm/Cold)
- Fine roughness (Rough/Smooth)
- Macro roughness (Uneven, Relief)

Vibratory information
RA I and RA II

Pacinian corpuscle (FA-II) sensitivity to vibrations and Meissner (FA-I) sensitivity to small features

Peak sensitivity around 300 Hz.

Able to detect bumps of a few microns under ideal conditions

What does the human hand feel?

Mediated by skin of finger pad
Skin stretch or adhesion

What does the human hand feel?

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

What does the human hand feel?

Tactile cues
Contact area between finger pad and object is important

Different technologies and interaction modes mapping

Skin-Stretch/dragging Mechanism
Skin-Stretch/dragging Mechanism

Skin Drag Displays
Skin-Stretch/dragging Mechanism

Figure 1: Skin drag displays drag a tactor over the wearer’s skin in order to communicate a spatial message, (a) e.g. write a ‘C’ on the user’s arm. (b) Our self-contained prototype.

Figure 5: (a) A motor using a worm drive actuates the rotation of the diaphragm. (b) All components rotate with the diaphragm, e.g., 45° counterclockwise.
Skin-Stretch/dragging Mechanism
Practical jamming

Haptic Jamming: A Deformable Geometry, Variable Stiffness Tactile Display using Pneumatics and Particle Jamming
Variable friction surfaces

Ultrasonic vibration could reduce the coefficient of friction of sandpaper; the same principle is here applied to glass.
Variable friction surfaces reported that dragging a dry finger over a conductive surface covered with a thin insulating layer and excited with a 110 V signal, created a characteristic “rubbery” feeling…called electrovibration.
Mid-air haptics

Ultrasonic haptics
Mid-air haptics

Ultrasonic haptics

Student Innovation Contest

Submission deadline: Friday July 29, 2022 11:59pm AoE (Anywhere on Earth)

Acceptance notification: Wednesday August 3, 2022

Submission of Project Video: Tuesday October 25, 2022 11:59pm AoE

Presentation of final demo: At the in-person UIST conference in Bend, Oct 29 - November 2, 2022

Apply here: SIC registration page.

In the UIST Student Innovation Contest (aka the "SIC"), we explore how novel input, interaction, actuation, and output technologies can augment interactive experiences! This year, in partnership with UCL we are seeking students who will push the boundaries of input and output techniques with the ultrasound haptics/levitation toolkit. Join the UIST SIC team and turn your ideas into reality! Meet amazing people! Win fabulous prizes! You can apply here: https://forms.gle/cSgRyiVLQ114Lnp3A.
Mid-air haptics

Vortex haptics

AirWave: Using Air Vortex Rings for Non-Contact Haptic Feedback
Mid-air haptics

Vortex haptics

Figure 2: (left) Volume of air moved by speaker equals the volume of the slug used to model the vortex formation. (right) Vortex ring is a toroid where air flows around the circular axis as the entire toroid travels along its perpendicular axis.

Figure 3: Vortex generator prototype and vortex ring formation process. (a) As the slug of air is pushed out of the aperture, the boundary layer starts to curl outwards as it exits, then (b) vorticity increases until pinch-off, causing the vortex to detach. (c) AirWave prototype filled with fog to visualize a vortex ring shortly after pinch-off.
Vibration feedback
eccentric rotating mass motors (ERM)
Shaftless vibration motors

K. J. Kuchenbecker
Shaftless vibration motors

Frequency and magnitude are often coupled.
Linear resonant actuator (LRA)
Linear resonant actuator

**MagnetIO:** Passive yet Interactive Soft Haptic Patches Anywhere

Alex Mazursky, Shan-Yuan Teng, Romain Nith, Pedro Lopes
Recap

Haptic concept
Types of haptic
Tactile feedback and Mechanoreception
Examples of tactile devices

We thank Allison M. Okamura @ Stanford University for the lecture material
Optional readings

Ubicomp 13
Gupta et.al.

UIST 10
Bau et.al.