Haptics and its Application in Multimodal User Interfaces

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Touch & High Information Transfer Rate

Blind and deaf people have been using touch to substitute vision or hearing for a very long time, at high information rate.

12 bits/sec

92 words/min
Being Deafferented
HAPTICS

Sensing
- Tactile (vibration, texture)
- Kinesthetic (position / force)

Manipulation
Tactile Sensing
through skin mechanoreceptors with specialized endings

Epidermis

Dermis

Subcutis

Meissner

Merkel

Ruffini

Pacinian

(Johannson & Valbo, 1983)
Kinesthetic Sensing (force + position) through receptors in muscles, tendons and joints

*Muscle spindle* embedded in extrafusal fibers contains intrafusal fibers. When intrafusal fibers contract, the spindle fires, conveying information about rate of change in fiber length.

*Tendon organ* ⇒ muscle tension

*Joint receptor* ⇒ joint angles (esp. extreme)

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**Slide courtesy of Prof. Roberta Klatzky, Carnegie Mellon University**
State of the Art

HAPTIC TECHNOLOGIES
Tactile Stimulators (& Applications)

- Pacinian Corpuscle
- Meissner & Merkel Cells
- Normal Force Load Cell
- Lateral Force Load Cell
- Lateral PaD by Northwestern
Popularity of Vibrations

[Graph showing sensitivity vs. frequency]
Kinesthetic (Force) Displays

**PHANToM™ by SensAble Technologies**

**Haptic Rendering**

**Omega™ by Force Dimension**

**The Mini-stick**
Custom designed by Dov Adelstein

**The µHaptic Device**
designed by Curt Salisbury

**The Maglev**
designed by Ralph Hollis
Force Feedback Is Intuitive

People understand force feedback without prior training. In many scenarios, force feedback is superior to vibration feedback.

Force feedback on a touchscreen: The technology is available today!
Piezoelectric Actuator Technology

1. Normal displacement – keyclick
2. Friction coefficient $\mu$ – texture / 3D features
3. Static lateral force – force well for buttons
(Piezo 1) Keyclick Feedback on Touchscreens

Real Keys

Virtual Keys
(Piezo 2) Surface Friction Display

Principle of Operation

- Ultrasonic bending waves in a sheet of glass create a “squeeze film” of air underneath a human fingertip.

- The squeeze film affects slipperiness of the surface. Controlling this in conjunction with fingertip movement serves as a tactile display.

Photo courtesy of Prof. Ed Colgate, Northwestern University
From 2D Force to 3D Feature

Lateral force can create the illusion of 3D surface features
(Piezo 3) Active Surface Force Display

Feeling force on a touchscreen without moving the finger

LateralPaD by Northwestern

Photo courtesy of Prof. Ed Colgate, Northwestern University
Electrovibration

TeslaTouch by Disney

Figure 11: Left: different textures produce different sensations, e.g. simulated corduroy. Right: a racing track where friction increases as the car “squeaks” around corners.

Figure 12: A visual star field in concert with a tactile layer conveying radiation intensity.
Thermal Display (very new…)

PI Control → A/D → D/A → Bipolar Power Supply & Voltage Amplifier

Thermistor 1
Thermistor 2
Peltier device
Index finger

Real material
Simulated material

Real
Simulated

Slide courtesy of Dr. Lynette Jones, MIT
HAPTICS IN MULTIMODAL USER INTERFACES
1. Haptic Cuing of Visual Attention

(Haptics-e, 2003; Transportation Research, 2005)
Valid vs. Invalid cues

- **Valid cue:**
  \[
  \text{haptically-cued } Q = \text{ visual-change } Q
  \]

- **Invalid cue:**
  \[
  \text{haptically-cued } Q \neq \text{ visual-change } Q
  \]
Results from One Participant

Results from All Participants

Valid Cues:
RT↓ 1630 ms (40.6%)

Invalid Cues:
RT↑ 781 ms (18.9%)
Baseline Initial Saccades

With Haptic Cueing (75% Validity)

Overall, RT decreased by 445 ms with valid cues, and increased by 242 ms with invalid cues. (* both changes are statistically significant.)
Summary of Haptic Cueing Studies

- Haptic cueing of visual attention works
- Participants tend to look where the haptic cue directs them, effortlessly, without much training
- When asked to deliberately suppress haptic cues, participants reported that it was hard
- *Haptic spatial cues are natural and effective in a multimodal system*
2. Visuohaptic 3D Watermarking

- With anticipated availability of haptic devices, the need may soon rise to protect 3D visuohaptic data and rendering methods.
- Of the three requirements of robustness, imperceptibility and capacity, we focused on maximize watermark capacity to improve robustness while guaranteeing imperceptibility.
- New 3D visuohaptic watermarking schemes were developed to take advantage of the different sensory capabilities of vision and touch.

Overview: Roughness-Adaptive 3D Visuohaptic Watermarking

- For 3D visual watermarking, we developed a roughness-adaptive scheme that adaptively selected watermark strengths based on local surface roughness.
- We extended the roughness-adaptive approach from visual to visuohaptic watermarking.
- The watermark strengths are based on human detection thresholds for watermarks.
Stimuli

Rendering

- Visual: TFT LCD 19” monitor
- Haptic: a custom force display
Procedure

- Three conditions: visual, haptic, & visuohaptic
- On each trial, the participant looked at (or touched) 3 surfaces; only 1 was watermarked
- The participant’s task was to judge which surface was different
Human Watermark Detection Thresholds
Summary of Visuohaptic Watermarking

- The difference in visual and haptic watermark detection thresholds can be explored to maximize watermark strengths depending on local surface roughness.
- Watermarking capacity can be increased by hiding watermarks in both visual and haptic channels.
- Watermark robustness is consequently improved.
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