Haptics and its Application in Multimodal User Interfaces

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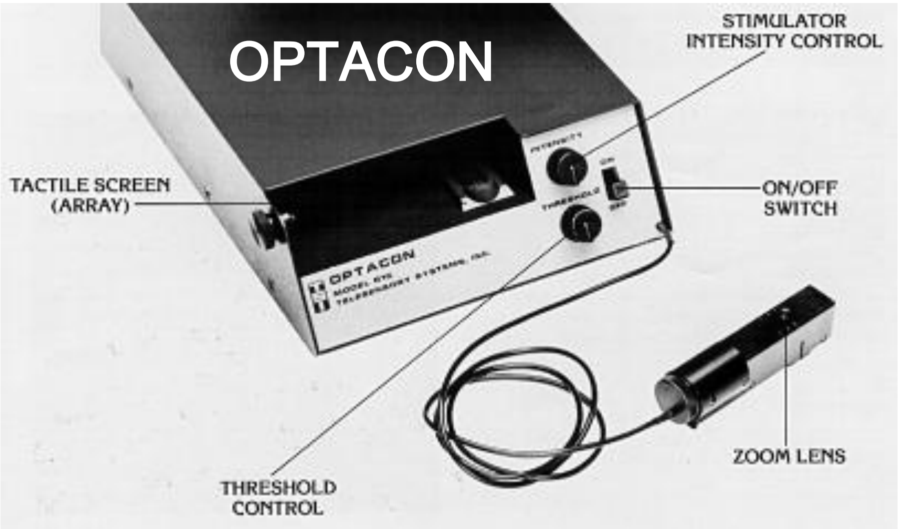
Touch & High Information Transfer Rate

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

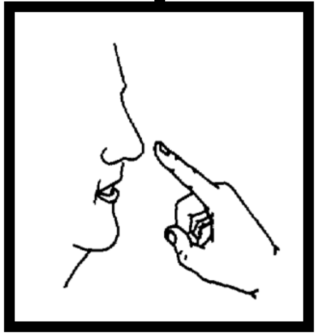
haptics

HAPTICS

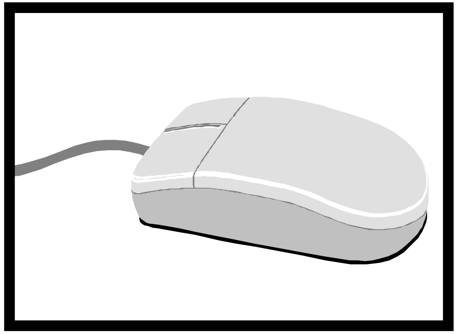
Sensing

Manipulation

Tactile
(vibration, texture)

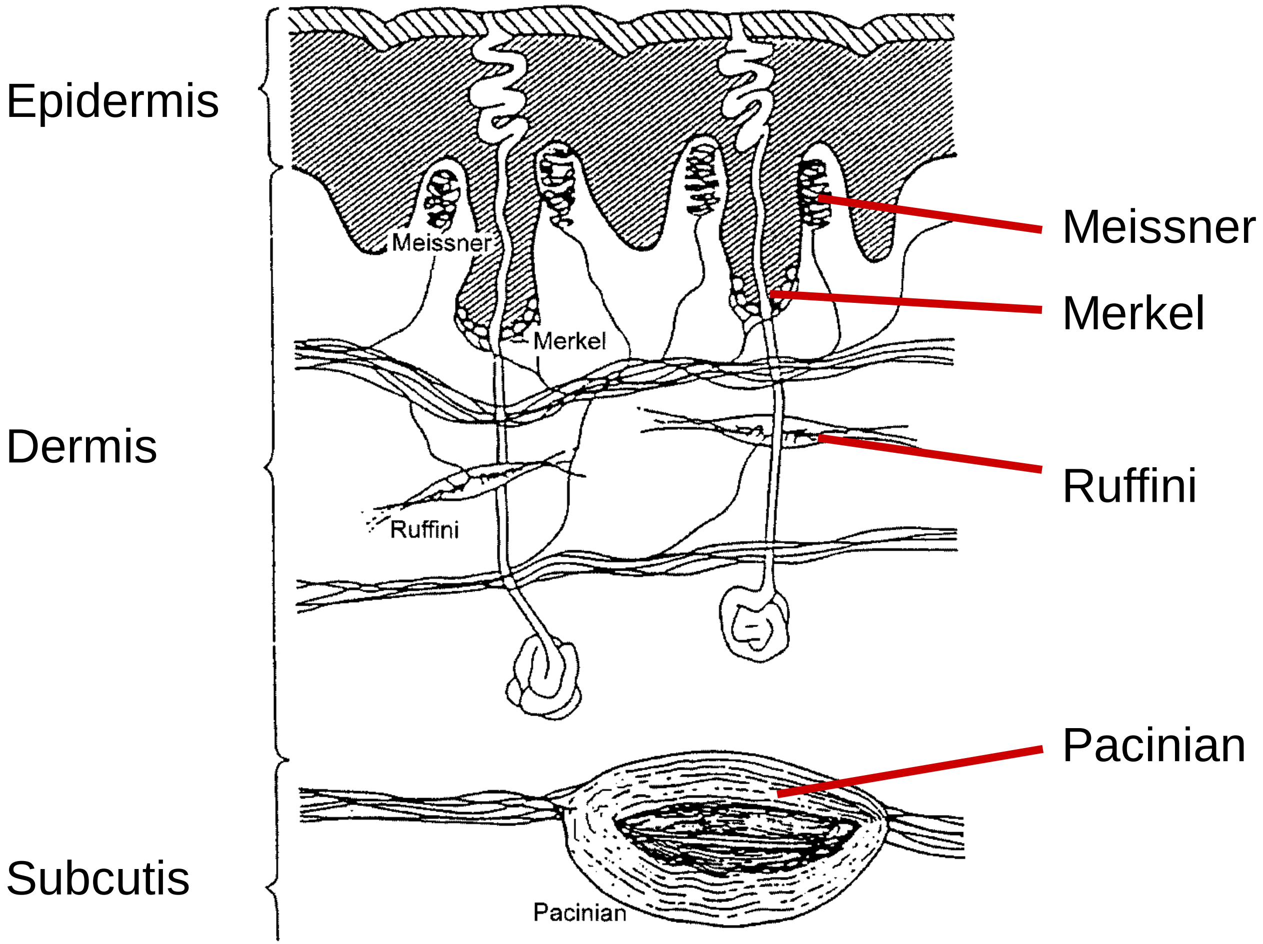


Kinesthetic
(position / force)



Tactile Sensing

through skin mechanoreceptors with specialized endings

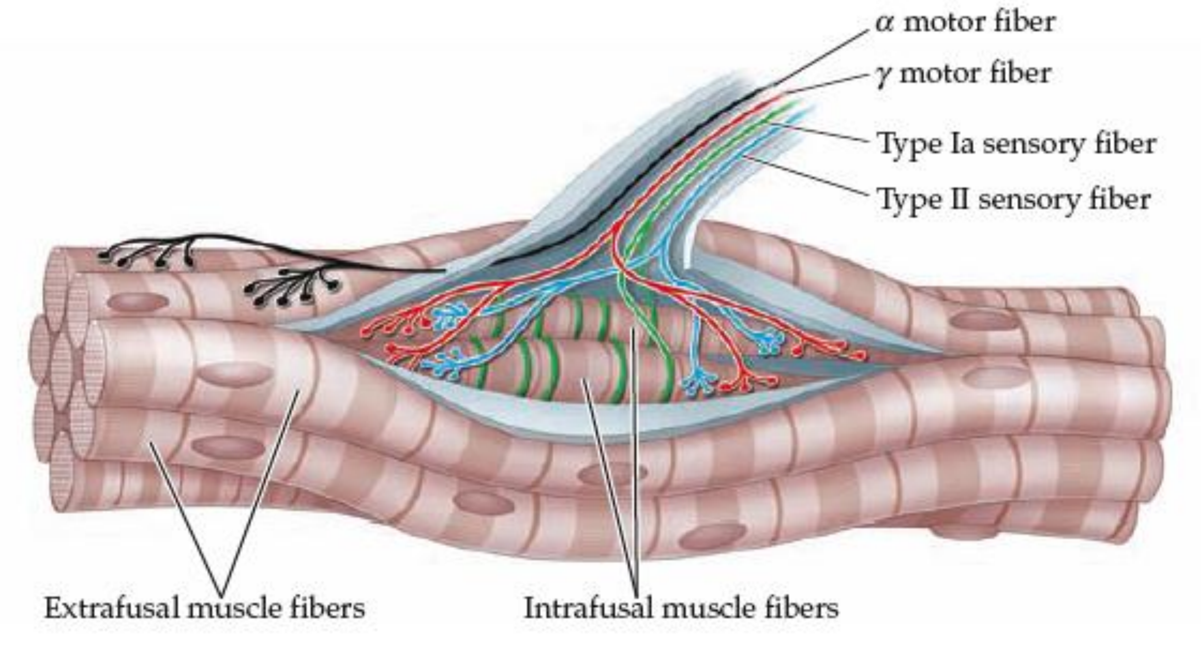


(Johannson & Valbo, 1983)

Slide courtesy of Prof. Roberta Klatzky, Carnegie Mellon University 5

Kinesthetic Sensing (force + position)

through receptors in muscles, tendons and joints

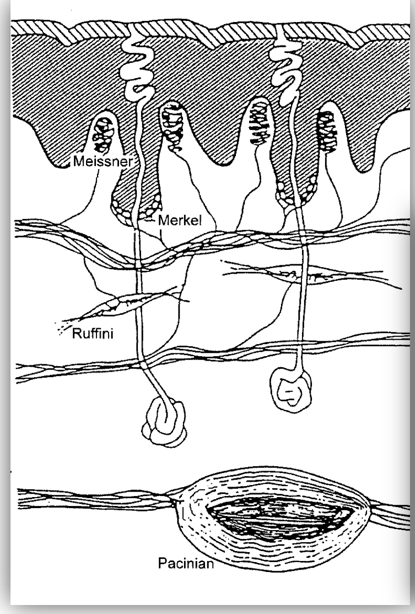


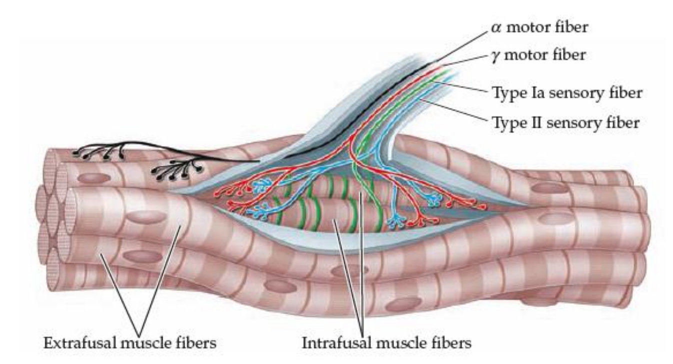
Muscle spindle embedded in extrafusal fibers contains intrafusal fibers. When intrafusal fibers contract, the spindle fires, conveying information about rate of change in fiber length.

Tendon organ ⇒ muscle tension

Joint receptor ⇒ joint angles (esp. extreme)

Slide courtesy of Prof. Roberta Klatzky, Carnegie Mellon University

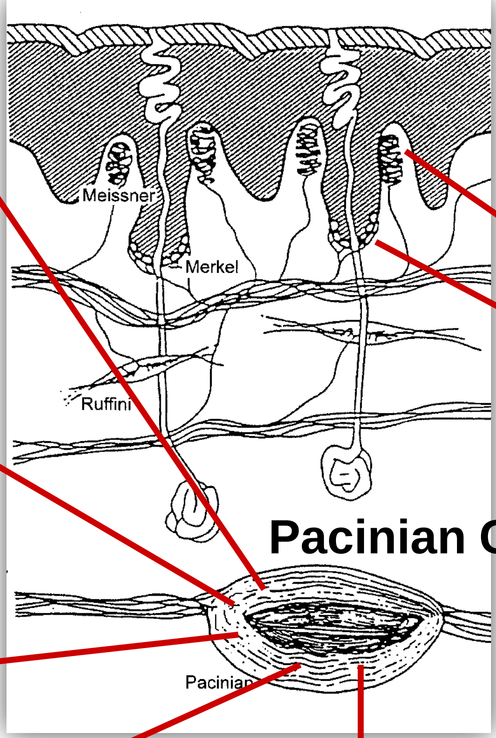




State of the Art

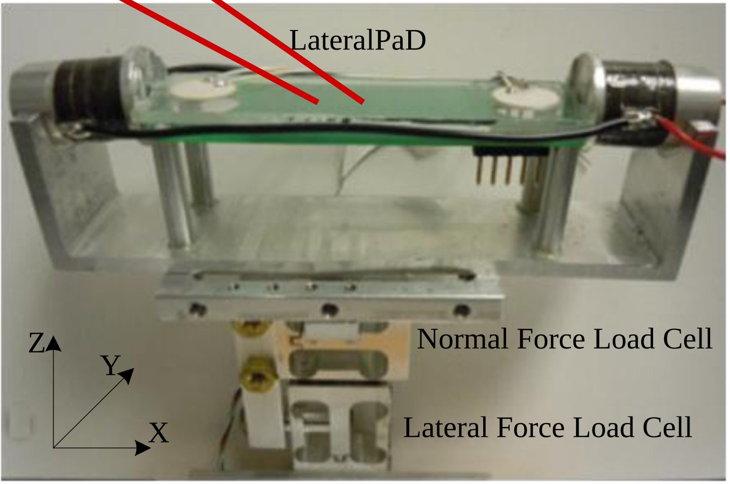
HAPTIC TECHNOLOGIES

Tactile Stimulators (& Applications)



Meissner & Merkel Cells

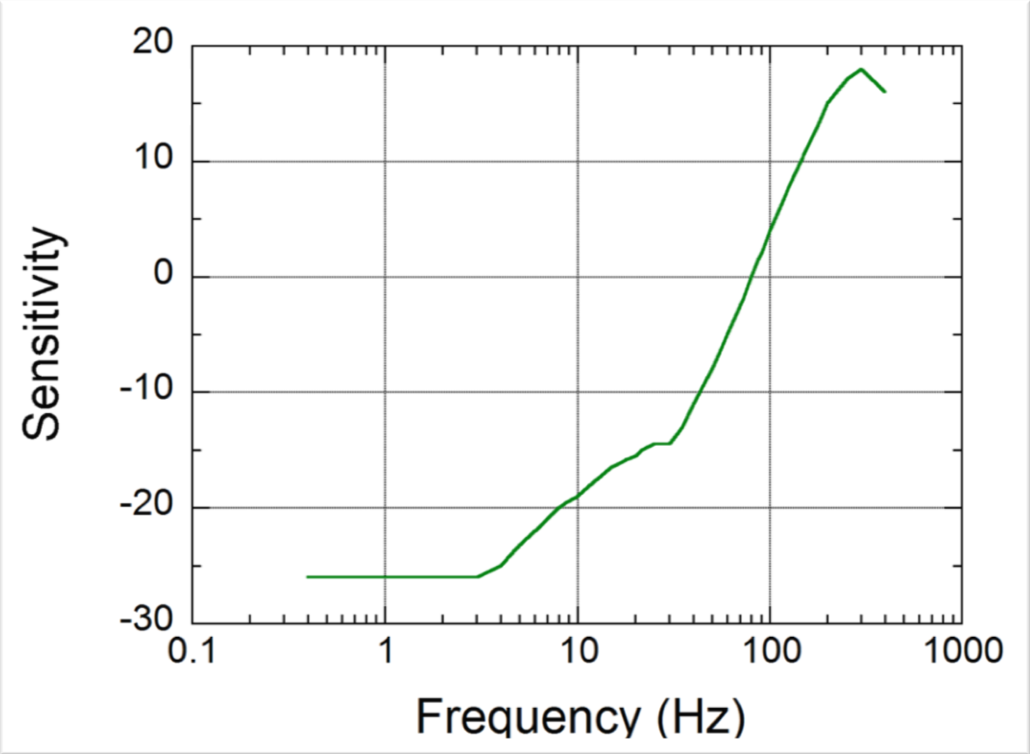
Pacinian Co



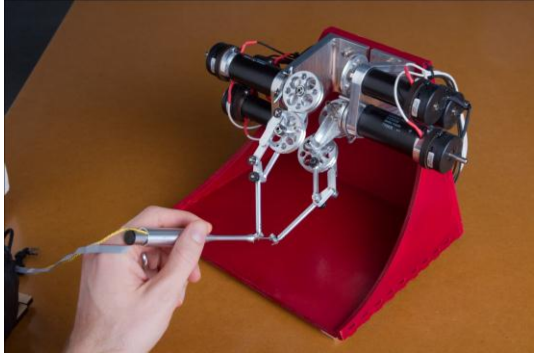
LateralPaD by Northwestern

Popularity of Vibrations

TouchSense® 1000
Haptic System Overview

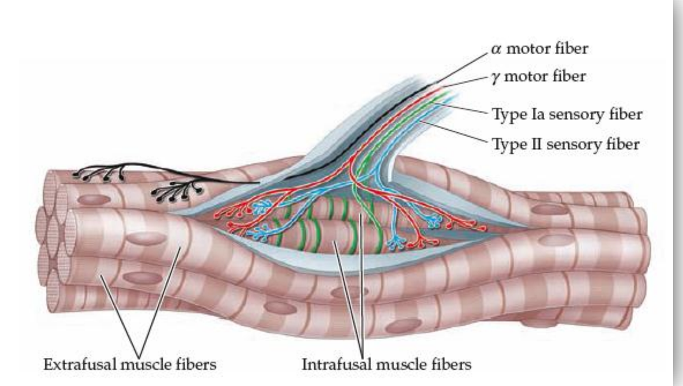


Kinesthetic (Force) Displays

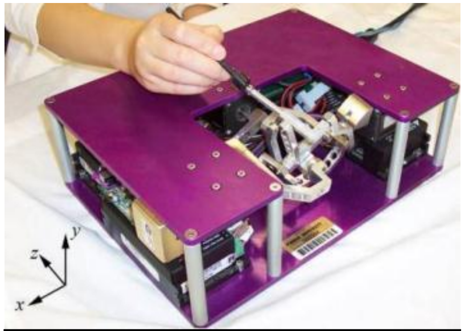


The μHaptic Device
designed by
Curt Salisbury

PHANToM™ *by*
SensAble Technologies



Omega™ *by*
Force Dimension



The Mini-stick
Custom designed by
Dov Adelstein

The Maglev
designed by
Ralph Hollis

Haptic
Rendering

Force Feedback Is Intuitive

People understand force feedback without prior training.

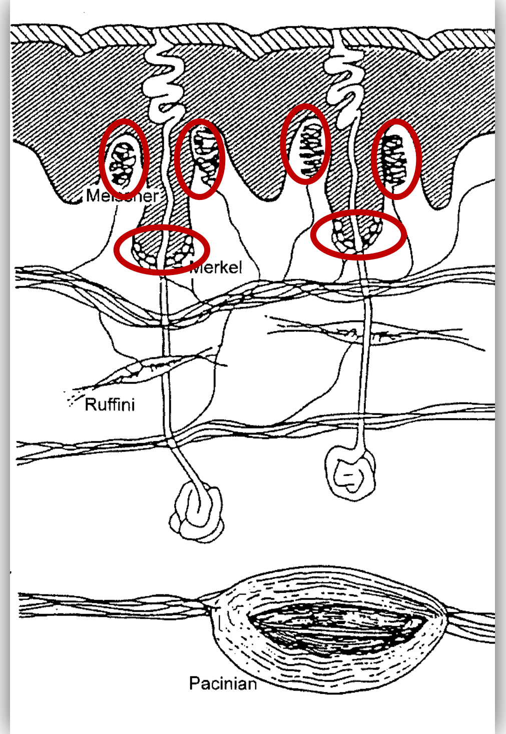
In many scenarios, force feedback is superior to vibration feedback.

Force feedback on a touchscreen :

The technology is available today!

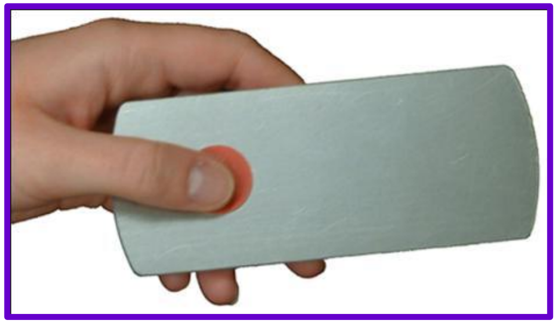
Piezoelectric Actuator Technology

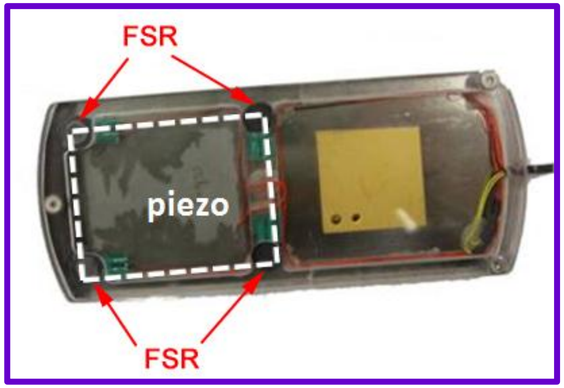
Surface / Fingertip Haptics

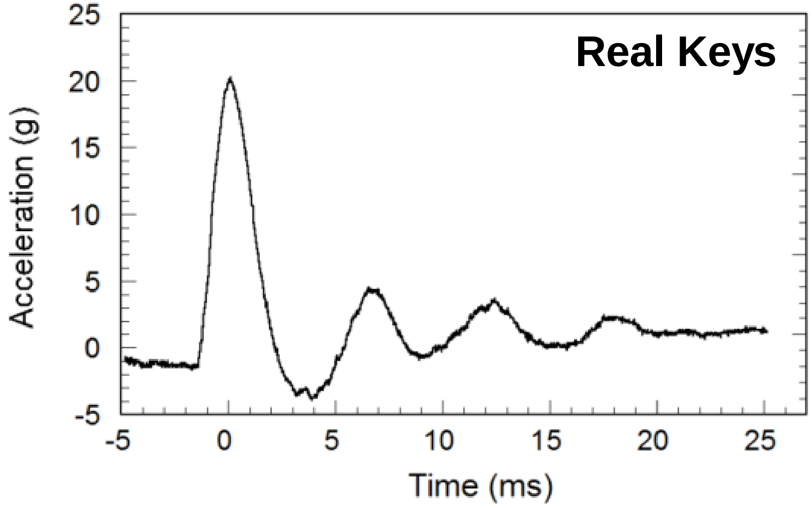


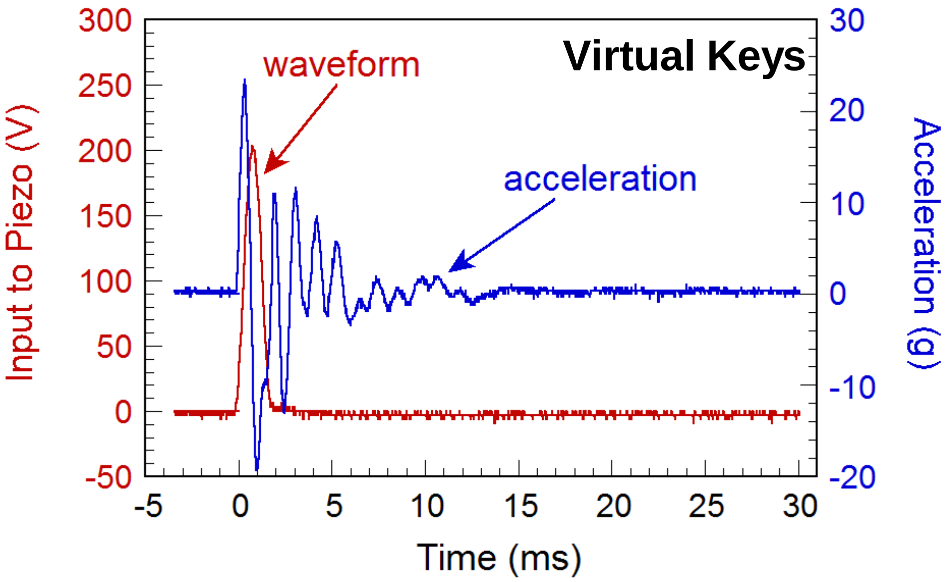
1. Normal displacement
   – keyclick
2. Friction coefficient μ
   – texture / 3D features
3. Static lateral force
   – force well for buttons

(Piezo 1) Keyclick Feedback on Touchscreens







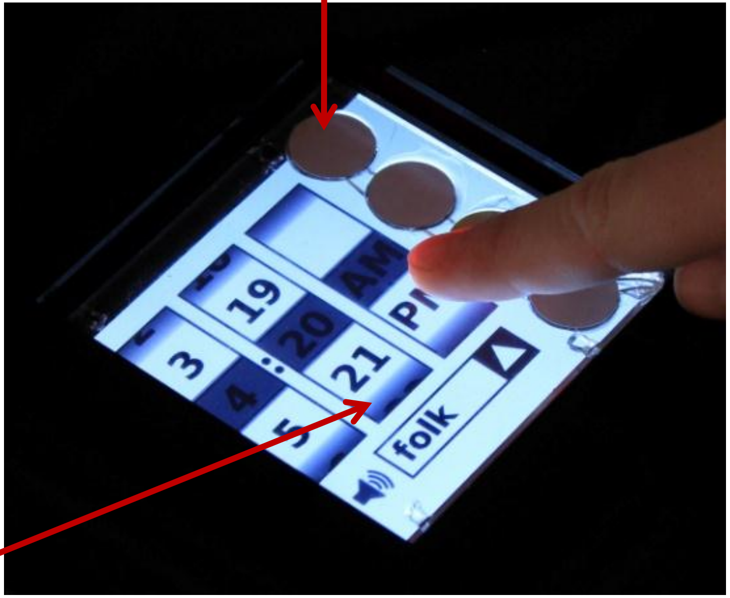


(Piezo 2) Surface Friction Display

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.

Piezoelectric actuators excite the glass TPaD surface at resonance



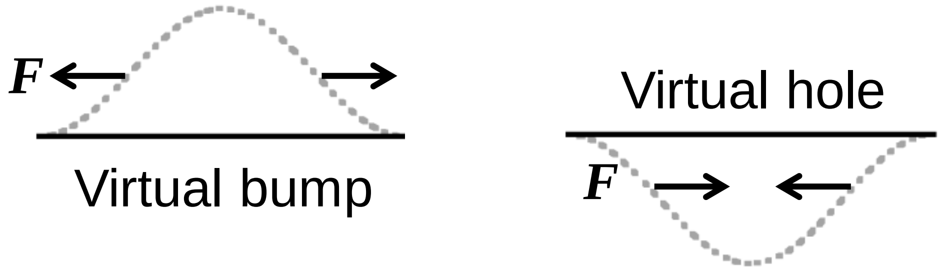
Graphical display is positioned underneath glass surface of TPaD

TPaD by Northwestern

Photo courtesy of Prof. Ed Colgate, Northwestern University

From 2D Force to 3D Feature

Lateral force can create the illusion of 3D surface features



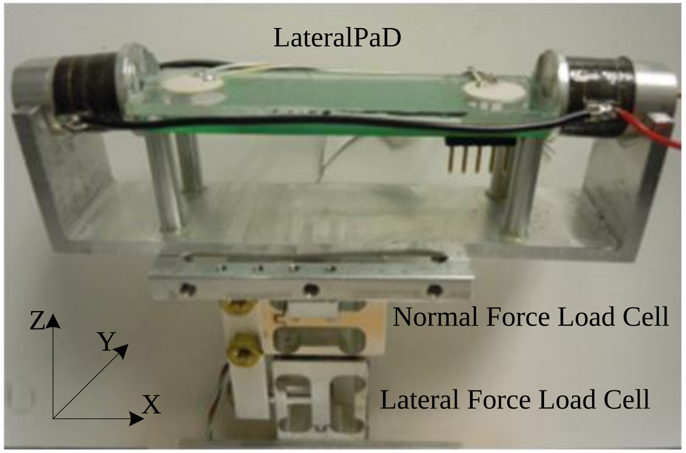
Flat surface

Virtual bump

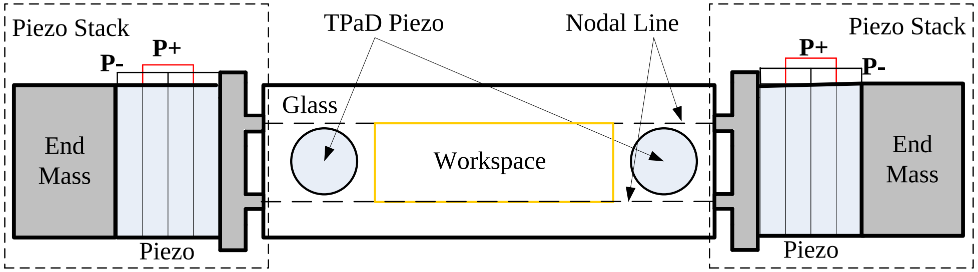
Virtual hole

(Piezo 3) Active Surface Force Display

Feeling force on a touchscreen without moving the finger



LateralPaD by Northwestern



Top view of the LateralPaD structure

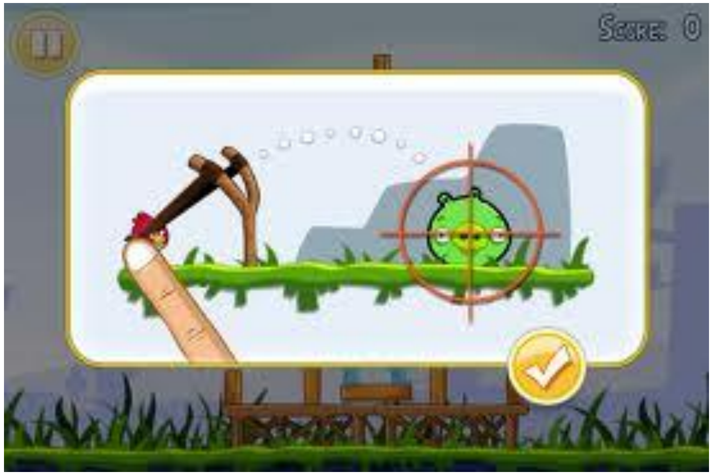
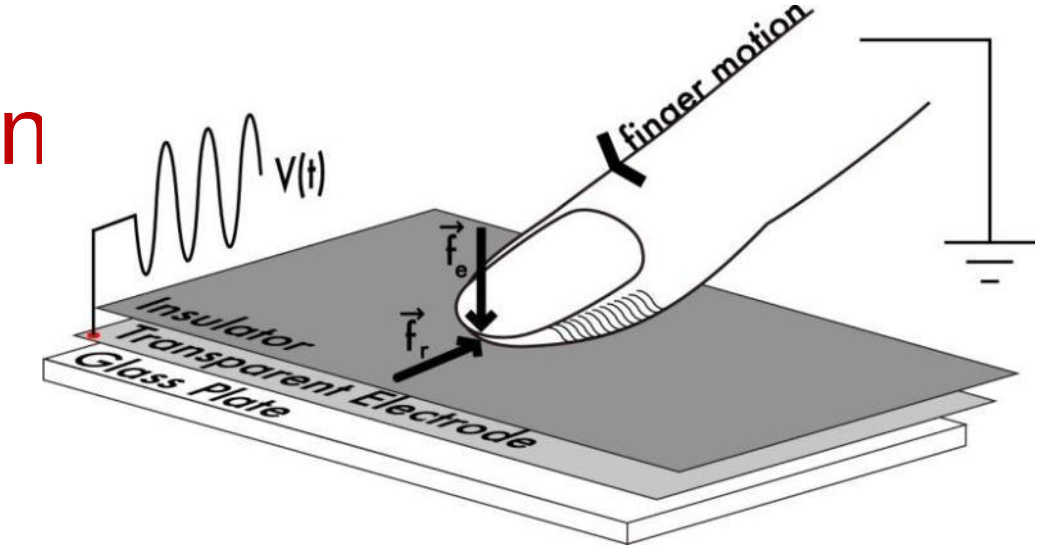


Photo courtesy of Prof. Ed Colgate, Northwestern University

Electrovibration



TeslaTouch by Disney

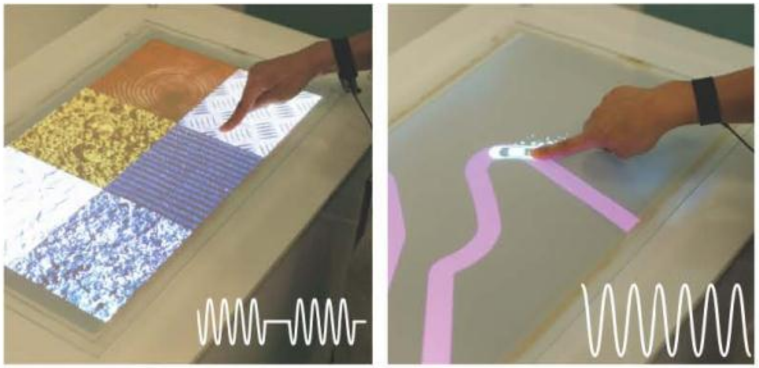
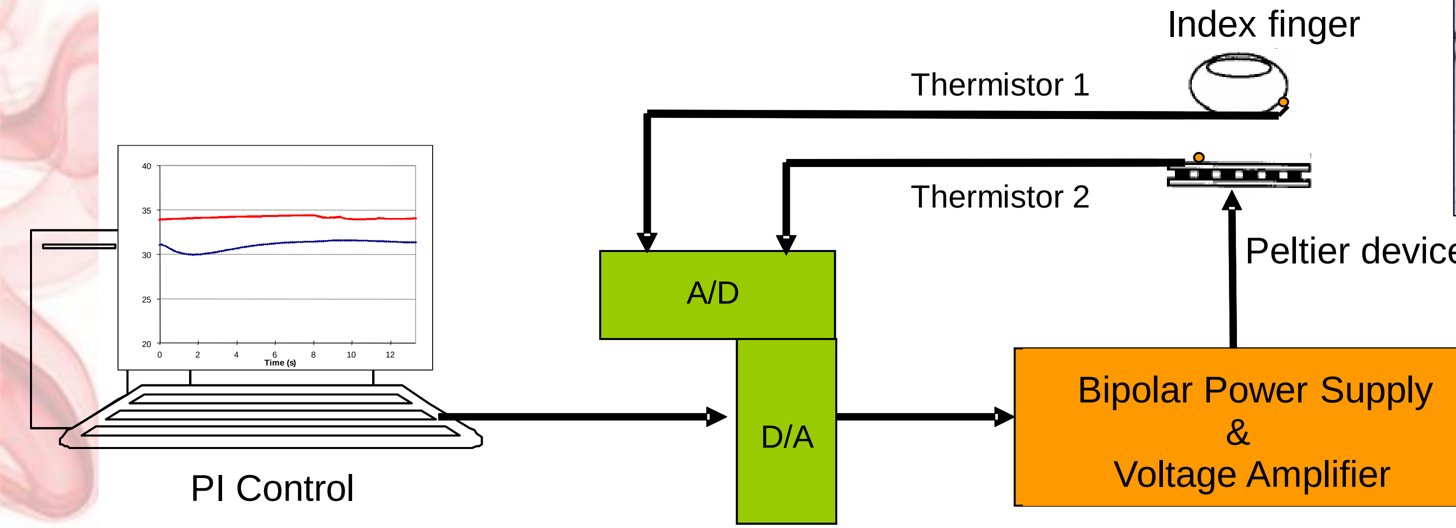


Figure 11: Left: different textures produce different sensations, e.g. simulated corduroy. Right: a racing track where friction increases as the car "squeaks" around corners.

Figure 12: A visual star field in concert with a tactile layer conveying radiation intensity.

TeslaTouch (UIST 2010)

Thermal Display (very new…)



Index finger

Thermistor 1

Thermistor 2

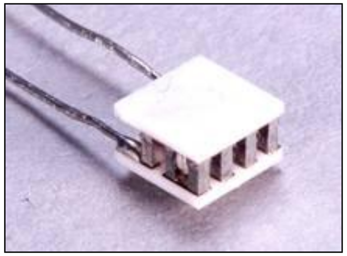
Peltier device

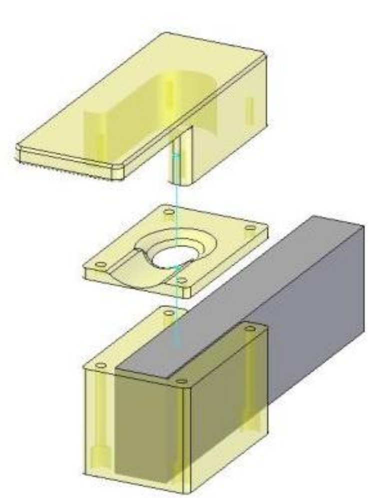
A/D

D/A

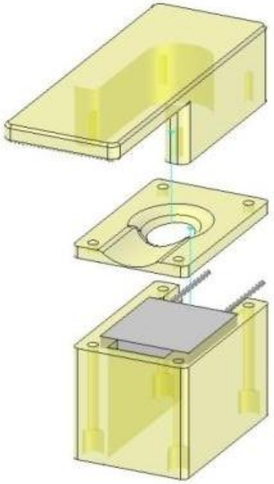
Bipolar Power Supply
&
Voltage Amplifier

PI Control

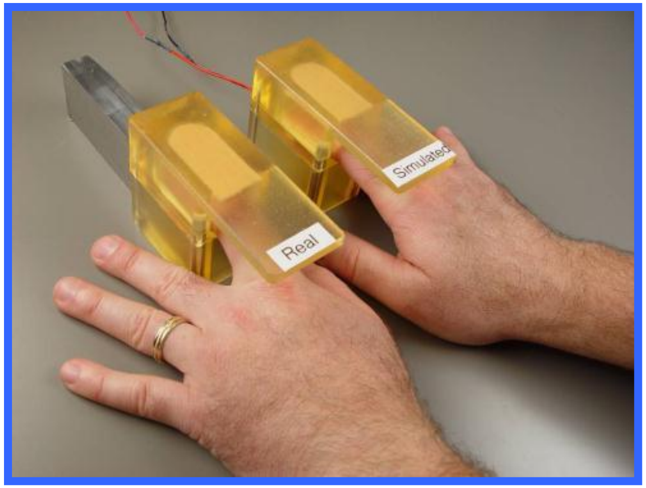




Real material



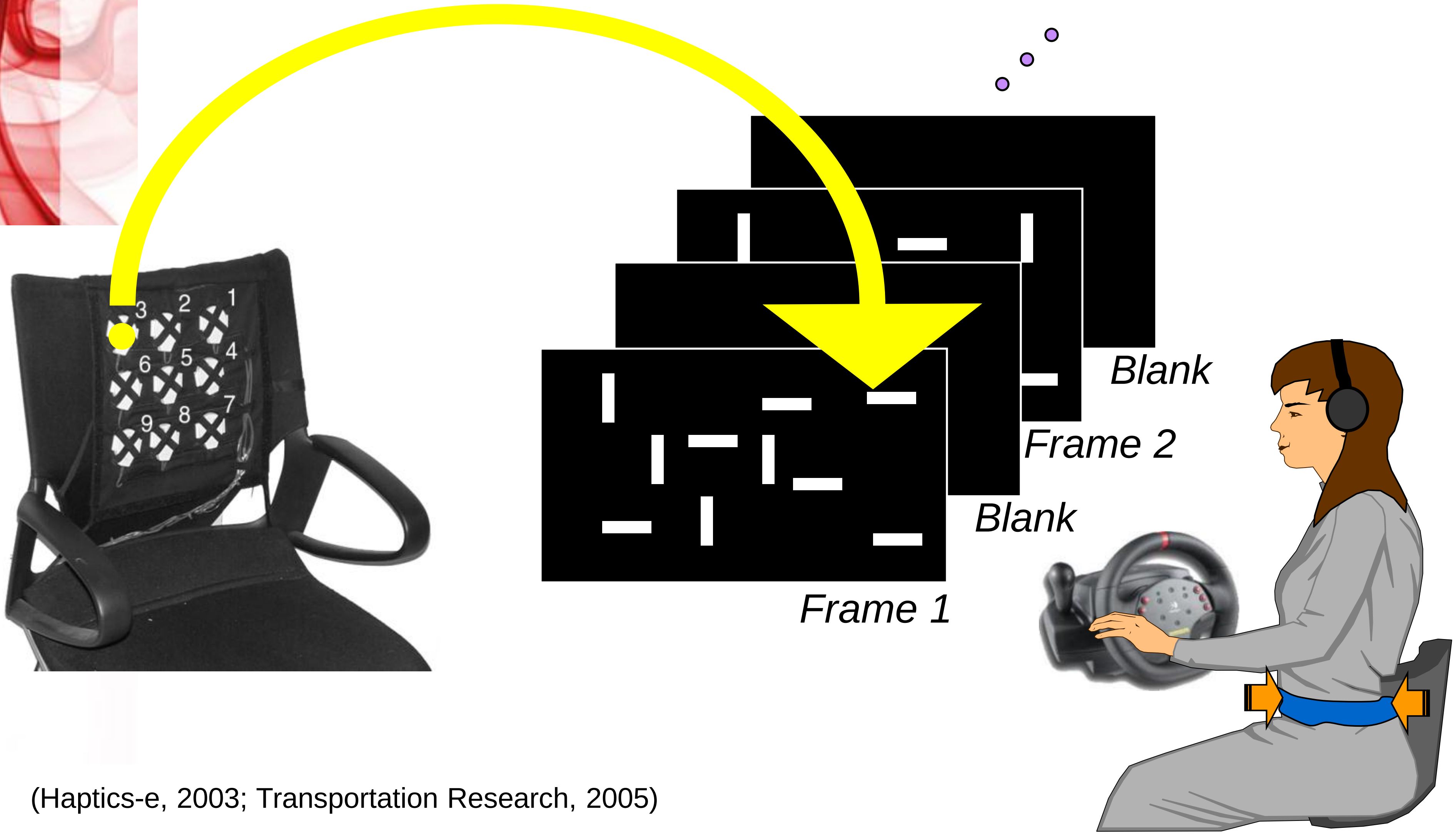
Simulated material



Slide courtesy of Dr. Lynette Jones, MIT

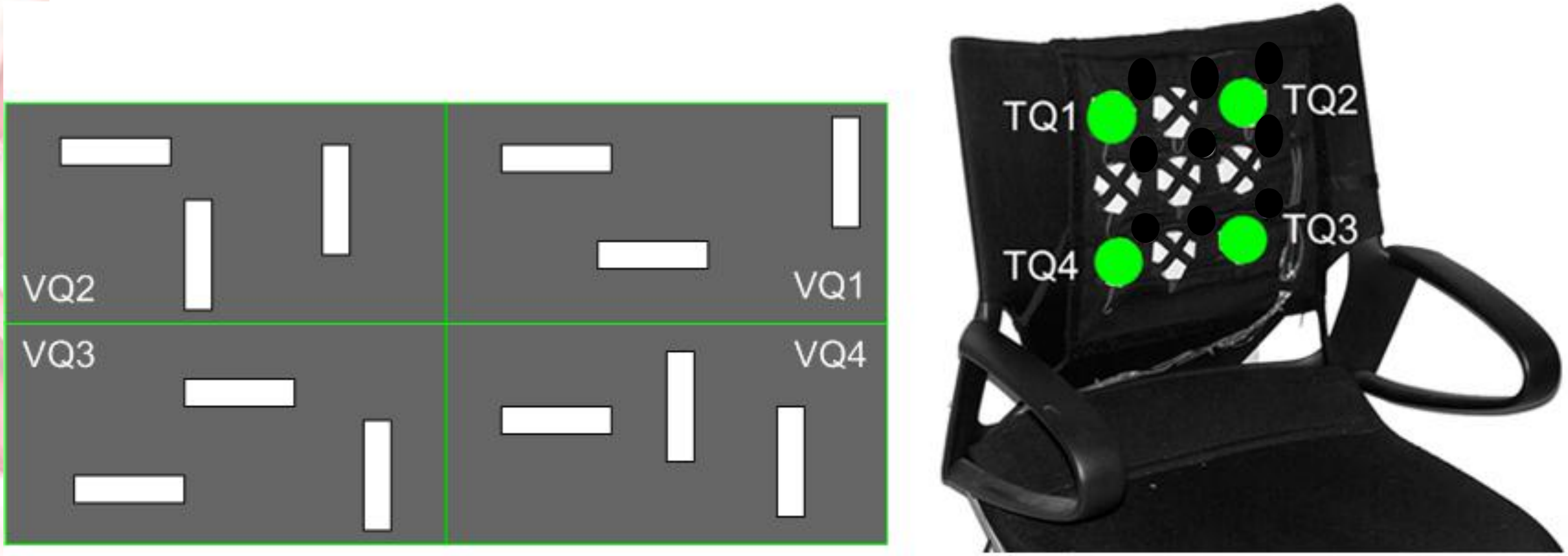
HAPTICS IN MULTIMODAL USER INTERFACES

1. Haptic Cuing of Visual Attention



(Haptics-e, 2003; Transportation Research, 2005)

Valid vs. Invalid cues



(a) visual stimuli on computer screen

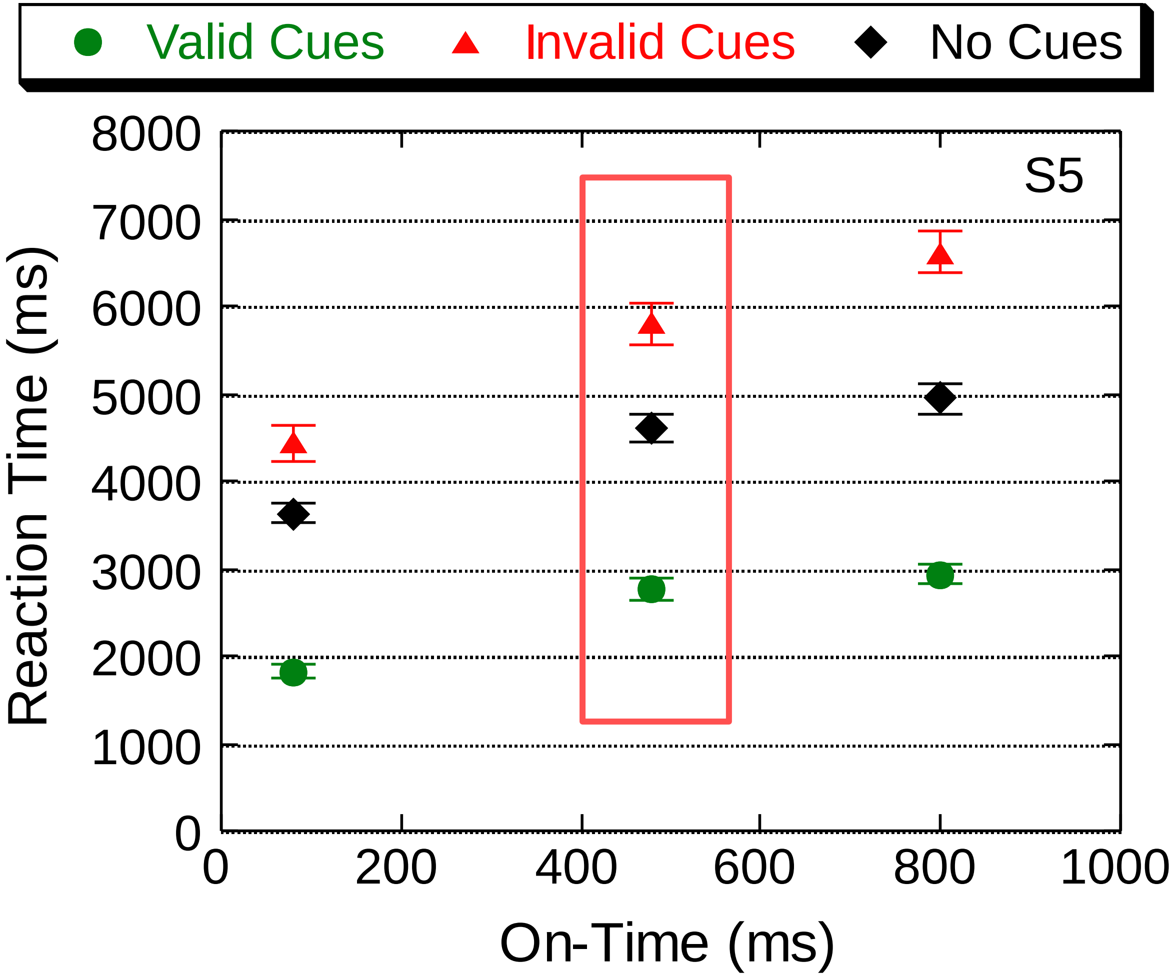
(b) tactor array on chair

- Valid cue:

  haptically-cued Q = visual-change Q
- Invalid cue:

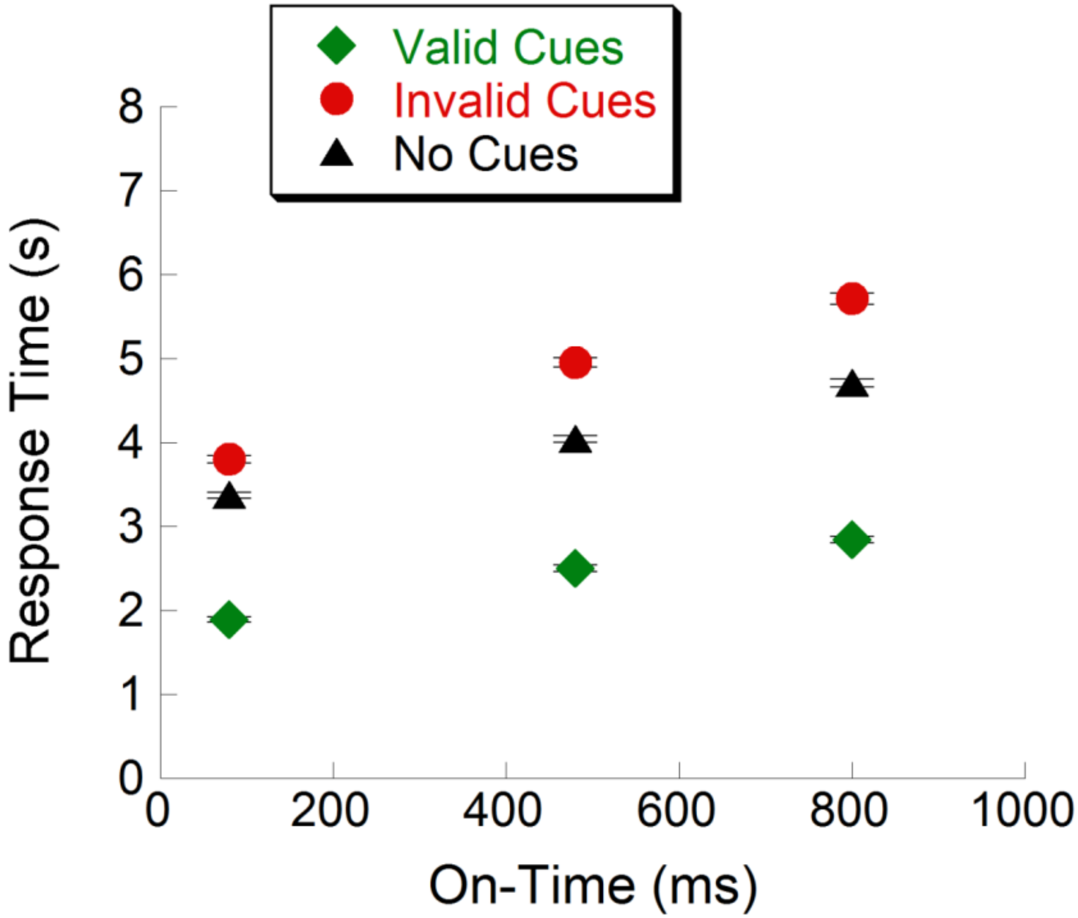
  haptically-cued Q ≠ visual-change Q

Results from One Participant



Tan, Gray, Young, Irawan, "Haptic cueing of a visual change-detection task: Implications for multimodal interfaces," *HCI International 2001*.

Results from All Participants



Valid Cues:
RT↓ 1630 ms (40.6%)

Invalid Cues:
RT↑ 781 ms (18.9%)

Eyetracker POR Data

ISCAN Eyetracker

Visual Scene

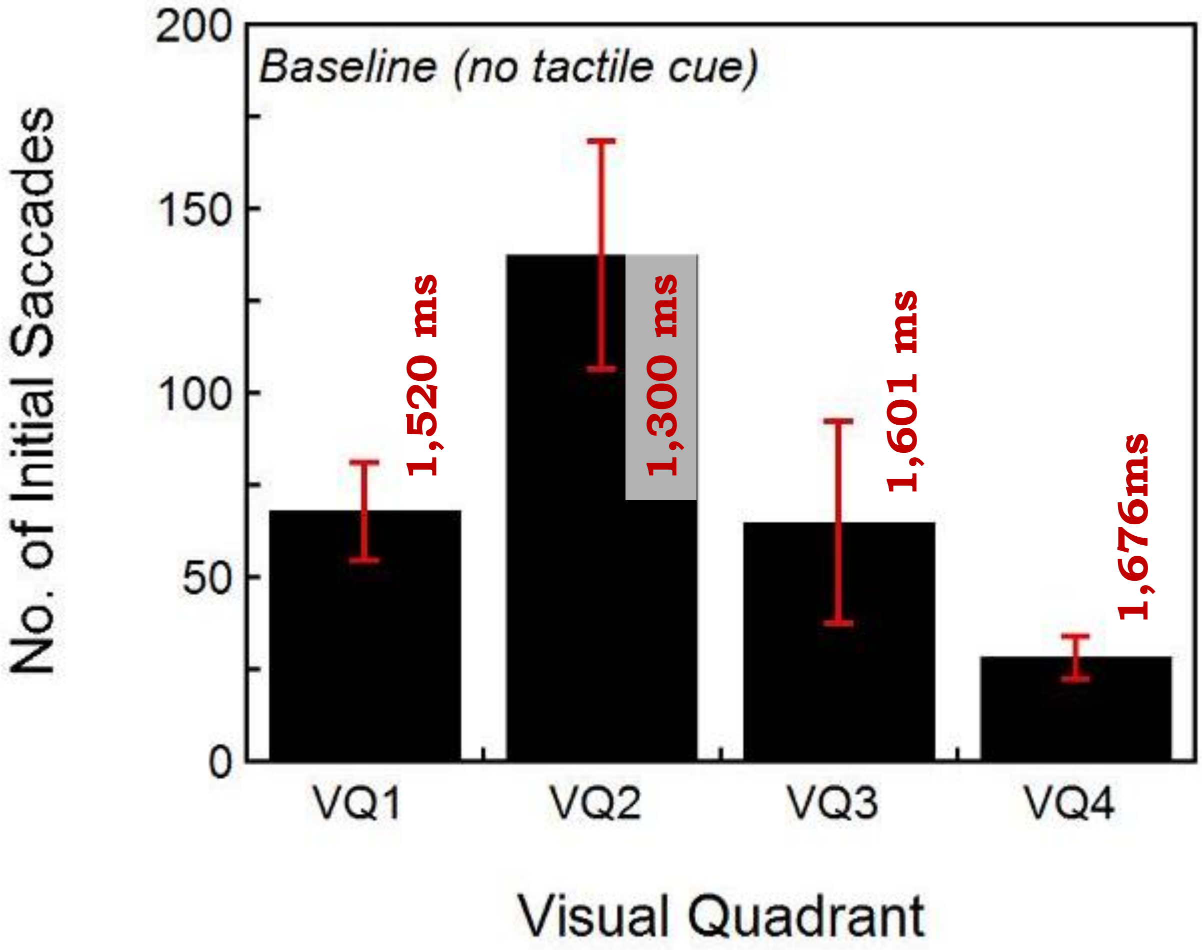
Tactor Driver Box

Head & Chin Stabilizer

Haptic Back Display

Q2 Q1
Q3 Q4

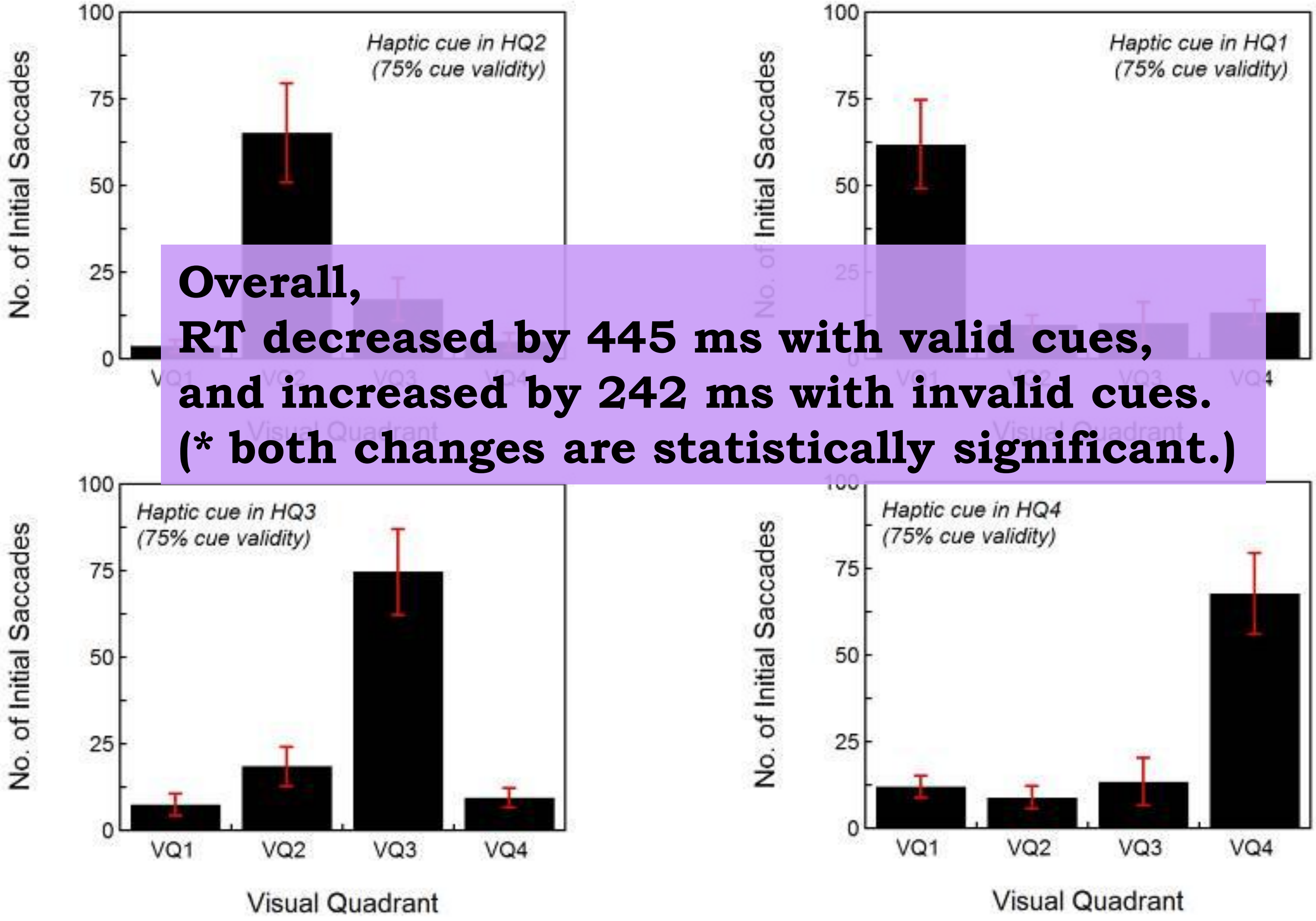
Baseline Initial Saccades



haptics

Jones, Gray, Spence, & Tan, "Directing visual attention with spatially informative and spatially noninformative tactile cues," *Experimental Brain Research*, 2008.

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.)

haptics

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

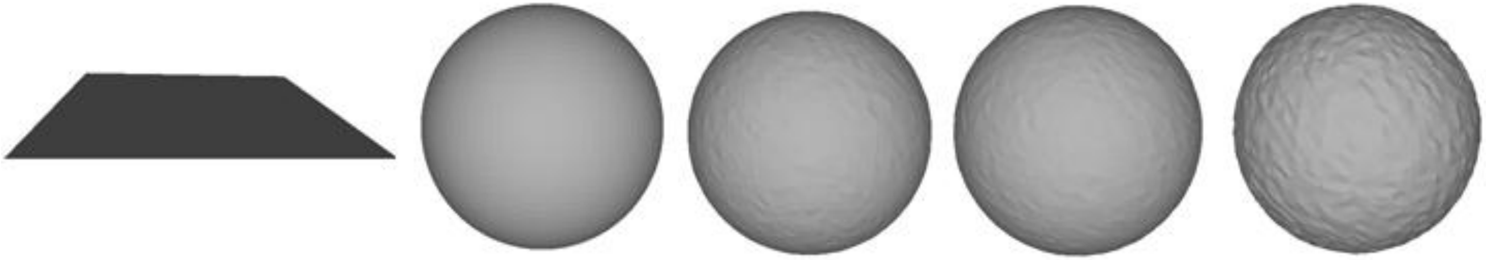
- With anticipated availability of haptic devices, the need may soon rise to protect 3D visuohaptic data and rendering methods
- Of the three requirements of robustness, imperceptibility and capacity, we focused on maximize watermark capacity to improve robustness while guaranteeing imperceptibility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

Kim, Barni, & Tan, “Roughness-adaptive 3D watermarking based on masking of surface roughness,” *IEEE Transactions on Information Forensic and Security*, 2010.

Overview: Roughness-Adaptive 3D Visuohaptic Watermarking

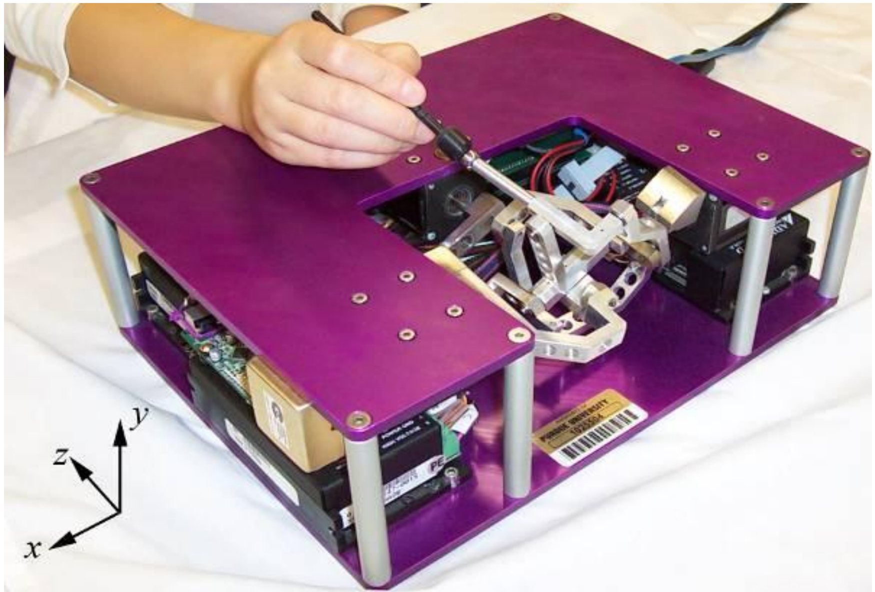
- For 3D visual watermarking, we developed a roughness-adaptive scheme that adaptively selected watermark strengths based on local surface roughness
- We extended the roughness-adaptive approach from visual to visuohaptic watermarking
- The watermark strengths are based on human detection thresholds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

Stimuli



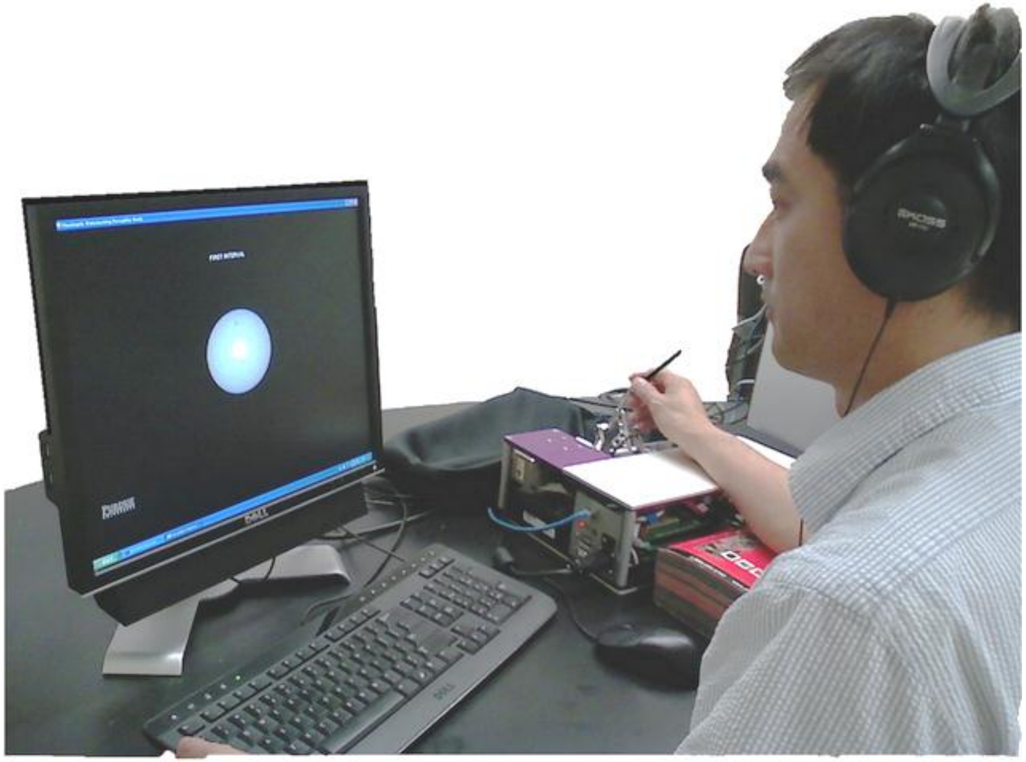
Rendering

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

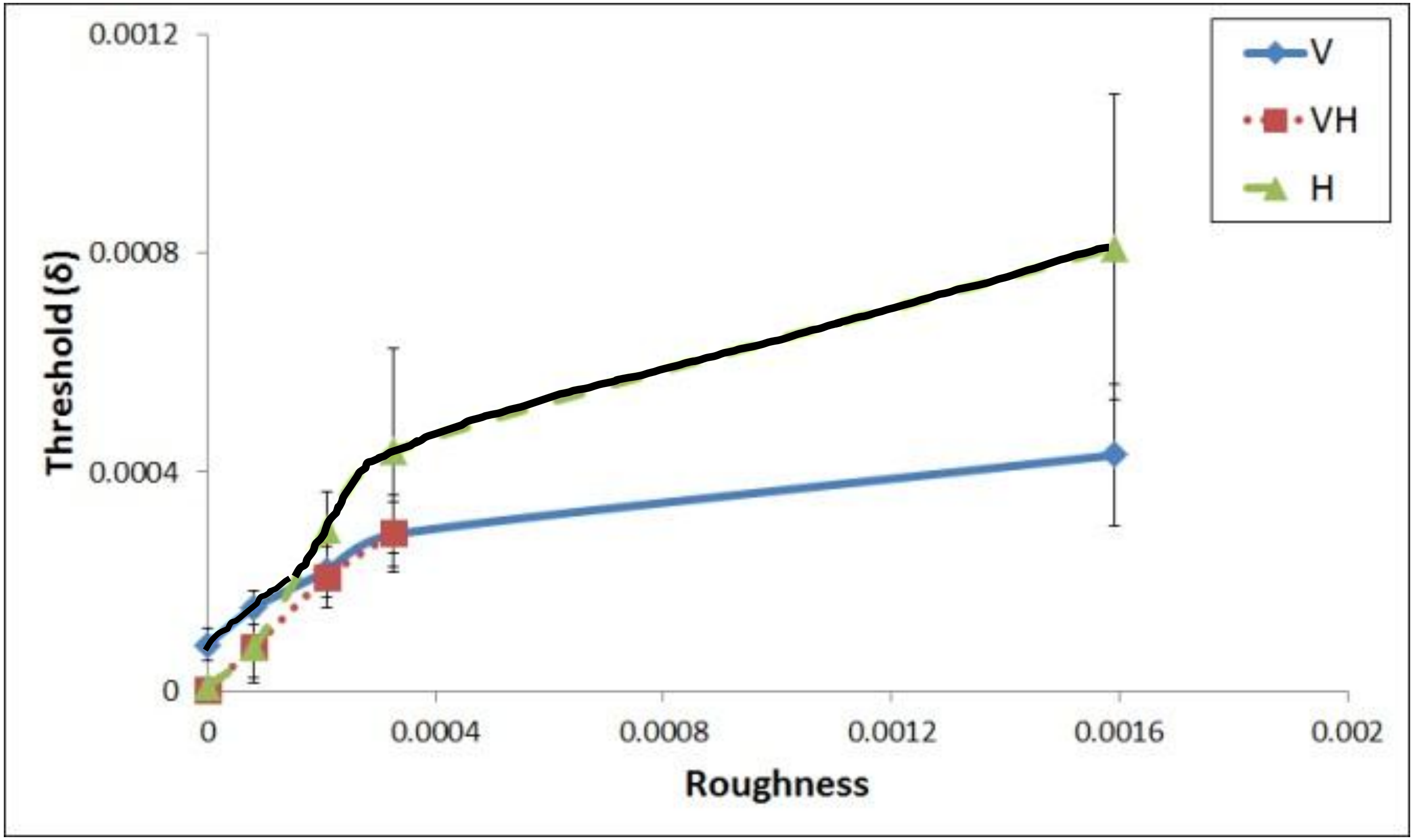


Procedure

- 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



haptics

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

Acknowledgments

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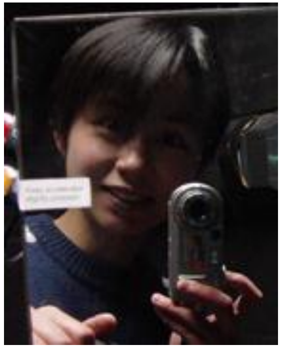

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