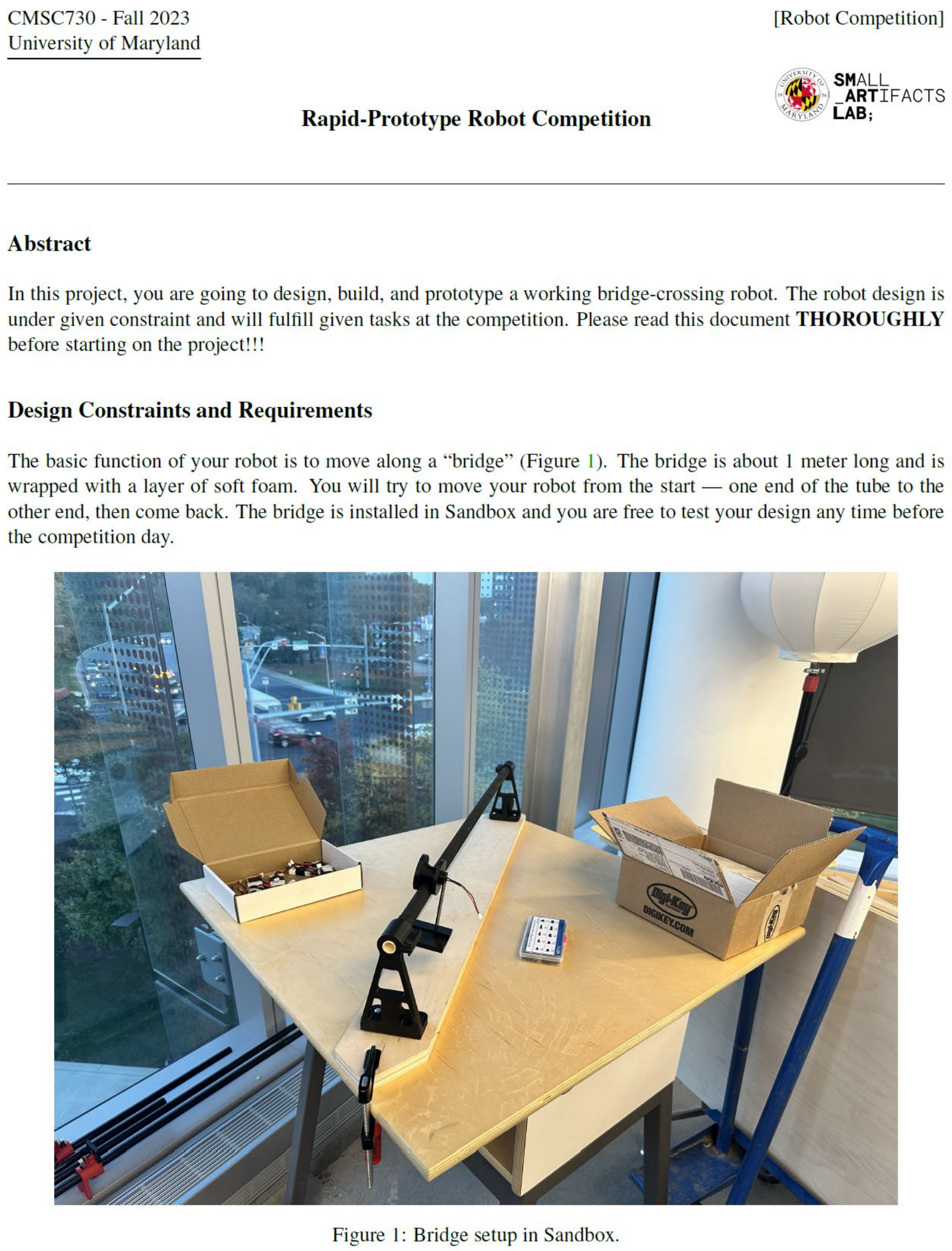
Robot Competition



CMSC730 - Fall 2023
University of Maryland

[Robot Competition]

SMALL _ARTIFACTS LAB;

Rapid-Prototype Robot Competition

Abstract

In this project, you are going to design, build, and prototype a working bridge-crossing robot. The robot design is under given constraint and will fulfill given tasks at the competition. Please read this document **THOROUGHLY** before starting on the project!!!

Design Constraints and Requirements

The basic function of your robot is to move along a "bridge" (Figure 1). The bridge is about 1 meter long and is wrapped with a layer of soft foam. You will try to move your robot from the start — one end of the tube to the other end, then come back. The bridge is installed in Sandbox and you are free to test your design any time before the competition day.

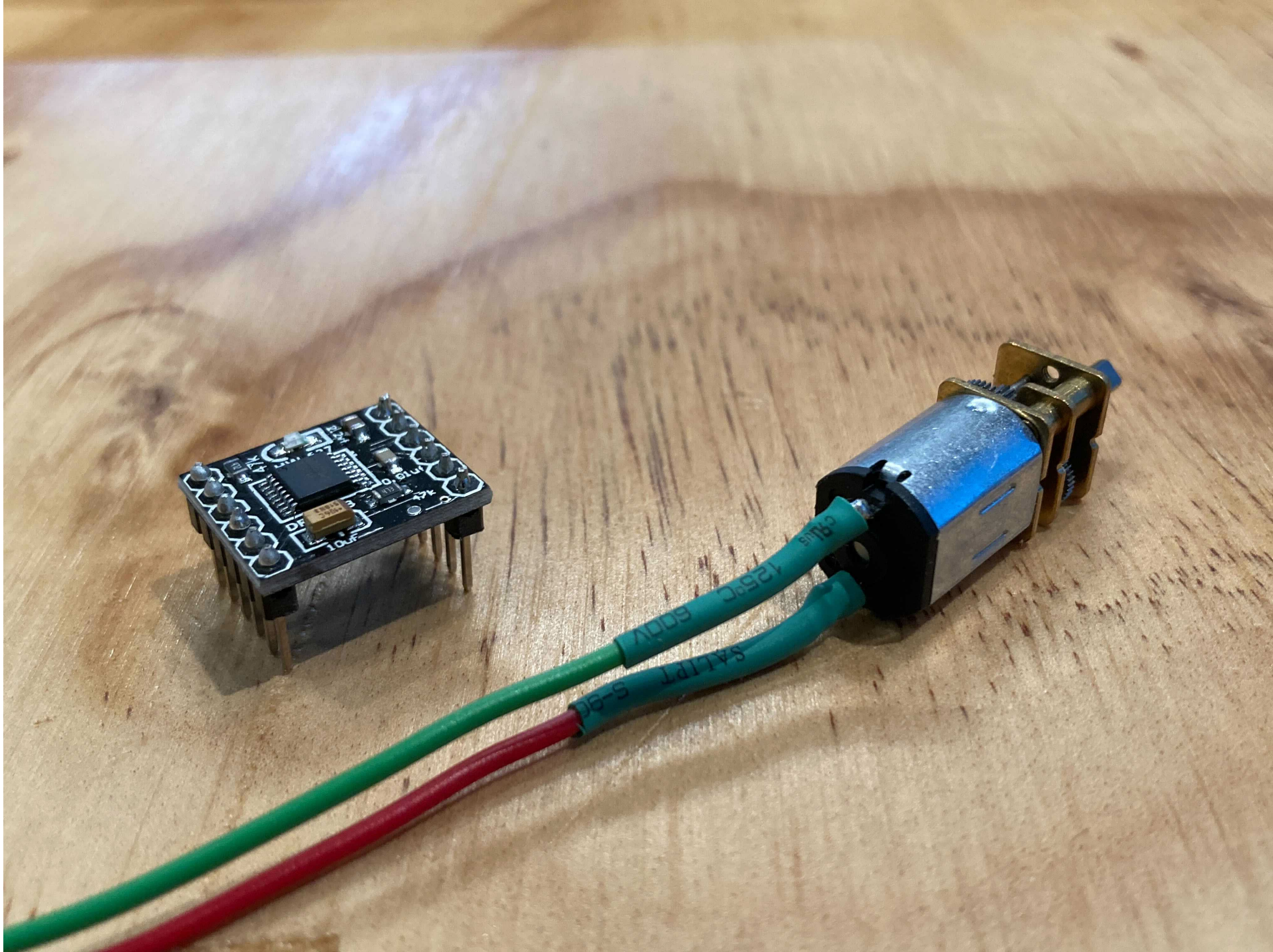
Figure 1: Bridge setup in Sandbox.

Robot Competition

Tube

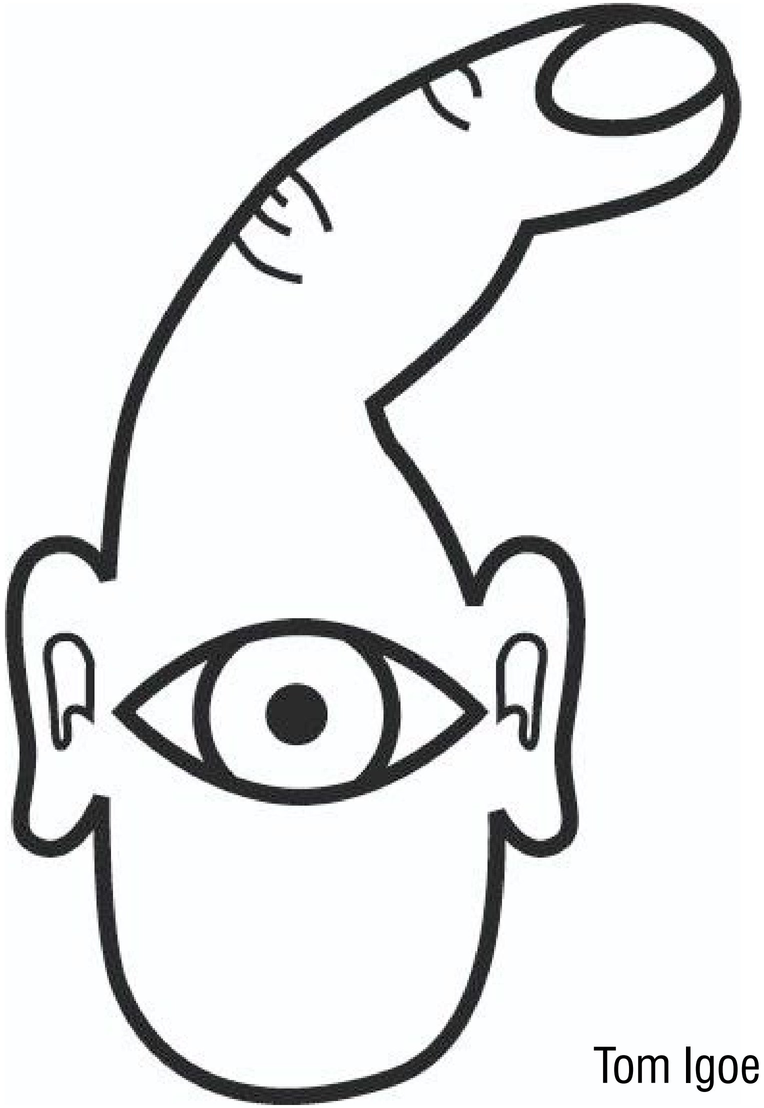
Robot Competition

Motor



Intro to Haptics

CMSC730 | Huaishu Peng | Fall 2023



Touch

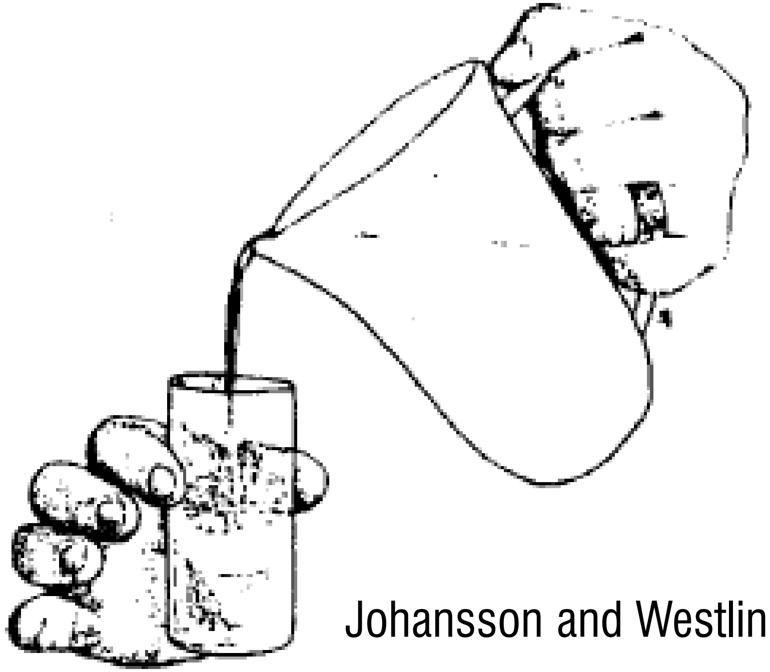
distributed
narrow
active
physical

Sight

centralized
broad
passive
cognitive

Tom Igoe

What is haptic



Cutaneous

Temperature
Texture
Slip
Vibration
Force

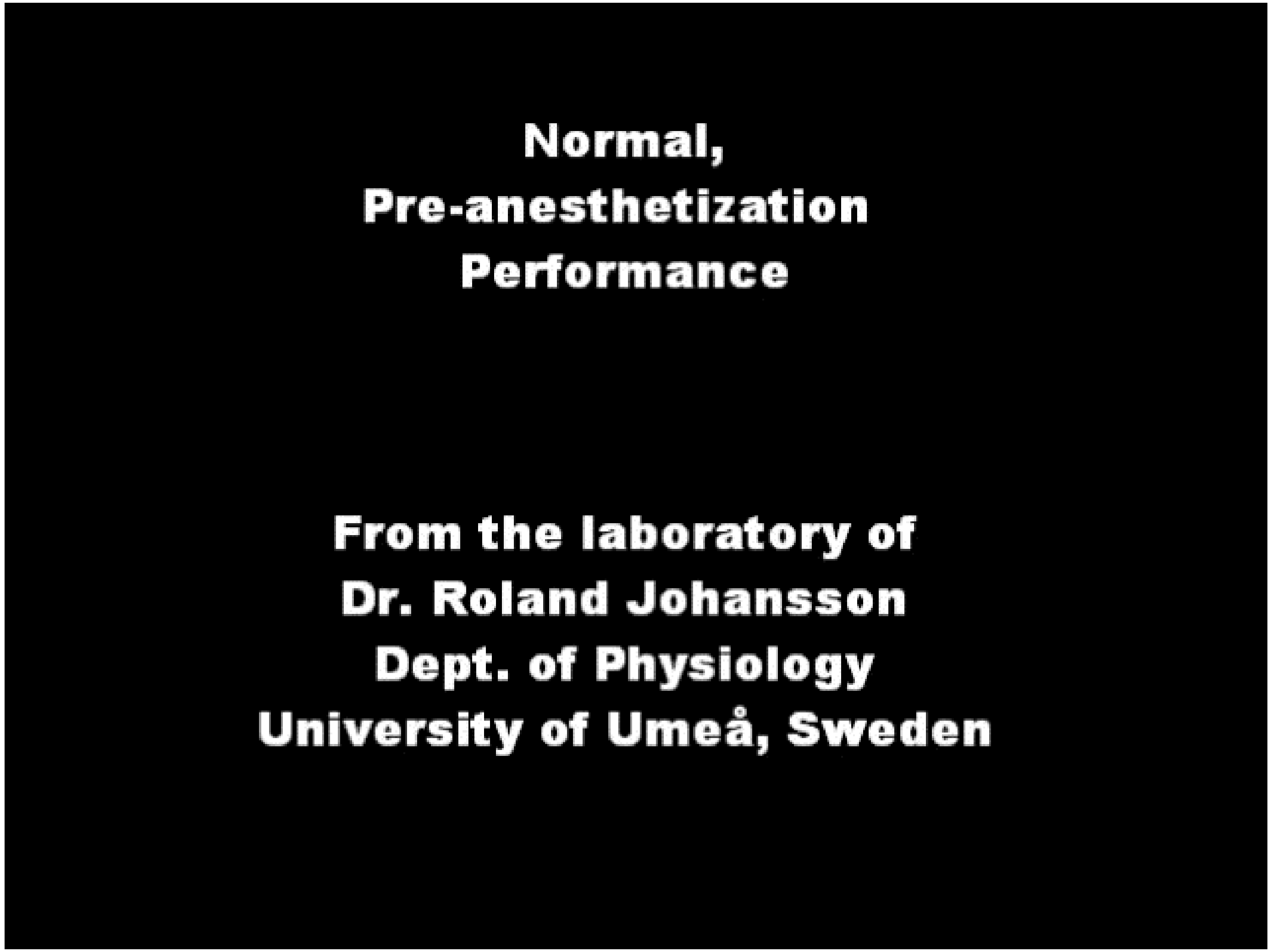
Kinesthesia

Location/configuration
Motion
Force
Compliance

Johansson and Westling

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

Cutaneous

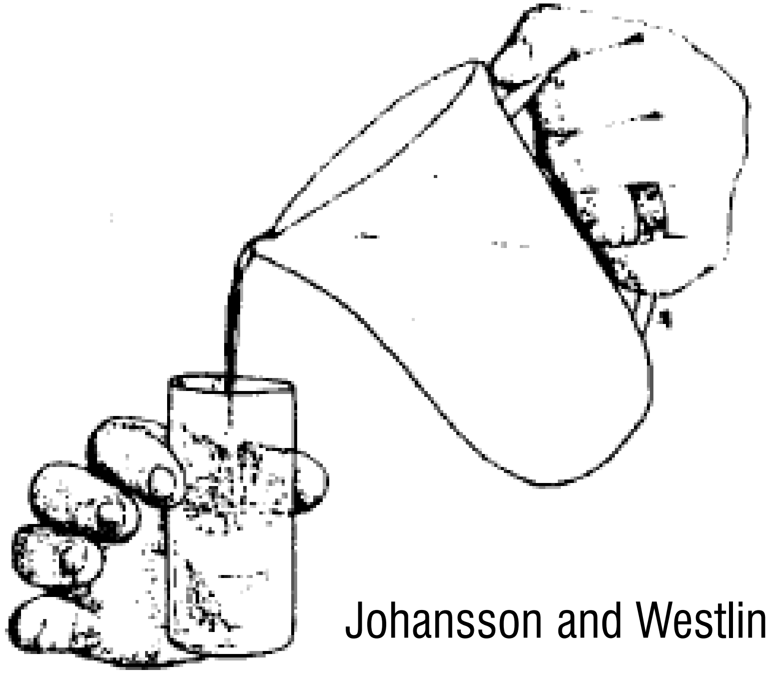


Normal,
Pre-anesthetization
Performance

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

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

What is haptic

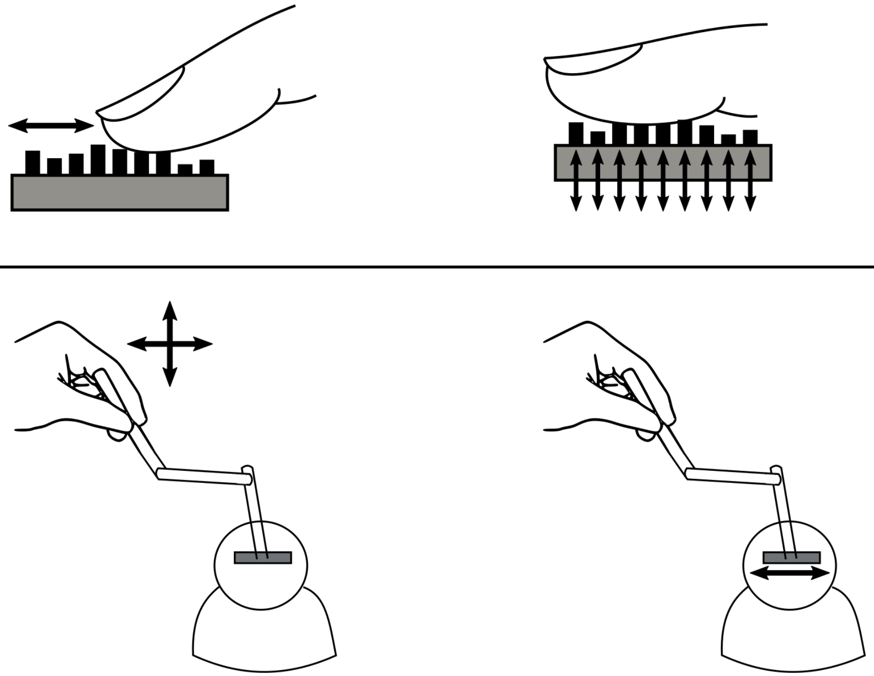


Cutaneous
Temperature
Texture
Slip
Vibration
Force

Kinesthesia
Location/confi
guration
Motion Force
Compliance

Johansson and Westling

kinesthetic vs. tactile devices



Active

Passive

Cutaneous

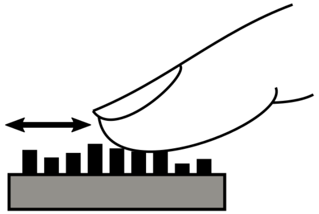
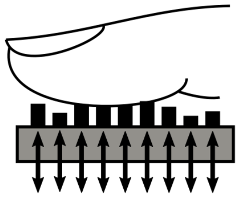
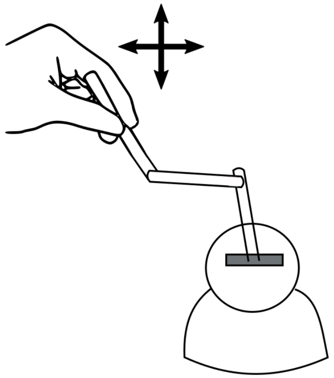
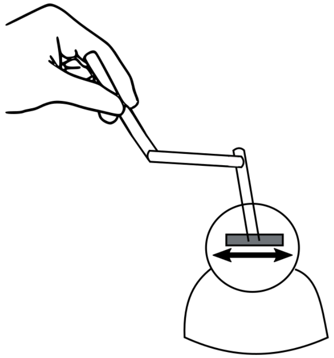
Tactile haptic devices
stimulate the skin

Kinesthetic

Kinesthetic haptic devices
display forces or motions
through a tool

Rodríguez, José-Luis, Ramiro Velázquez, Carolina Del-Valle-Soto, Sebastián Gutiérrez, Jorge Varona, and Josué Enríquez-Zarate. "Active and passive haptic perception of shape: Passive haptics can support navigation." Electronics 8, no. 3 (2019): 355.

kinesthetic vs. tactile devices

	Active	Passive	
Cutaneous Tactile haptic devices stimulate the skin			Tactile haptic devices can more easily be wearable
Kinesthetic Kinesthetic haptic devices display forces or motions through a tool			Kinesthetic haptic devices are usually grounded

Rodríguez, José-Luis, Ramiro Velázquez, Carolina Del-Valle-Soto, Sebastián Gutiérrez, Jorge Varona, and Josué Enríquez-Zarate. "Active and passive haptic perception of shape: Passive haptics can support navigation." Electronics 8, no. 3 (2019): 355.

Tactile (cutaneous) device basics

Tactile feedback

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

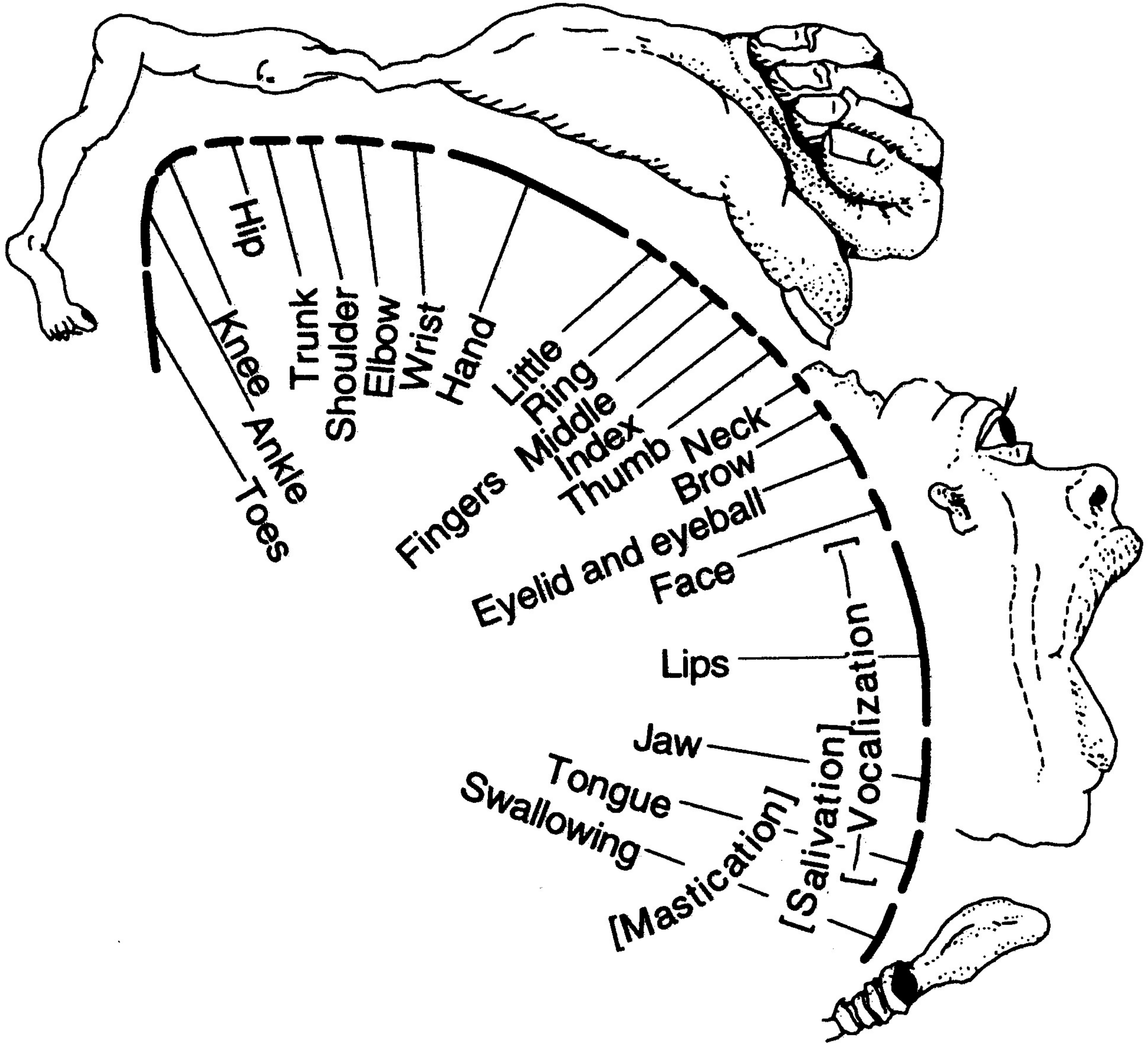
sometimes **distributed** tactile feedback is provided

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

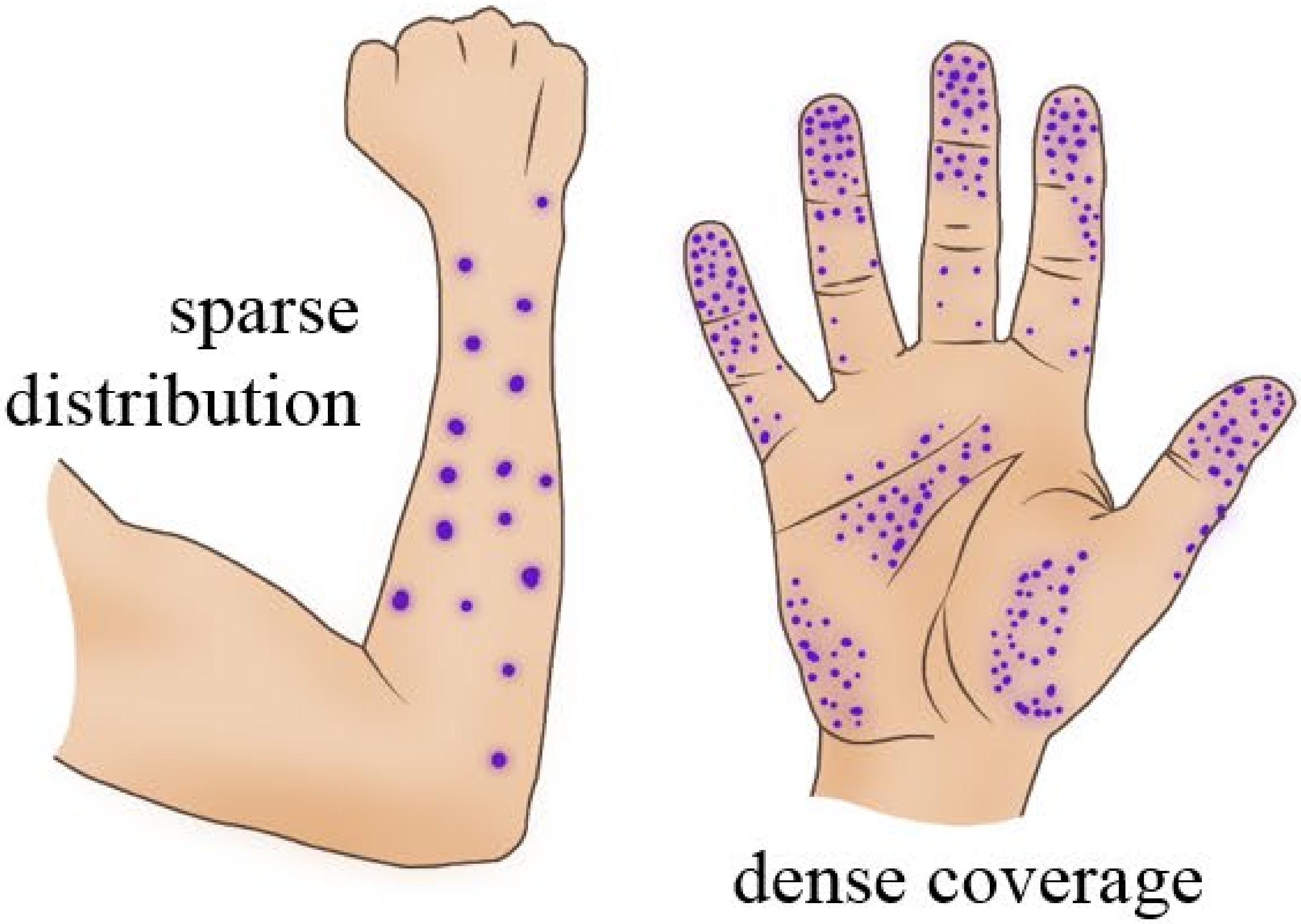
can aim to recreate real sensations, create novel ones, or communicate information

Sensory homunculus

mapping the human somatosensory cortex

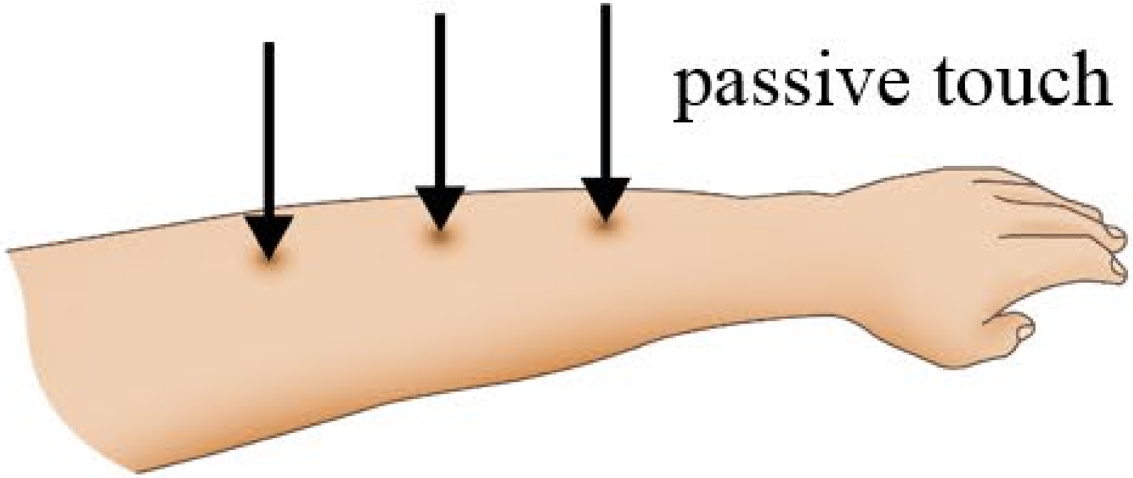


Arms vs fingertips



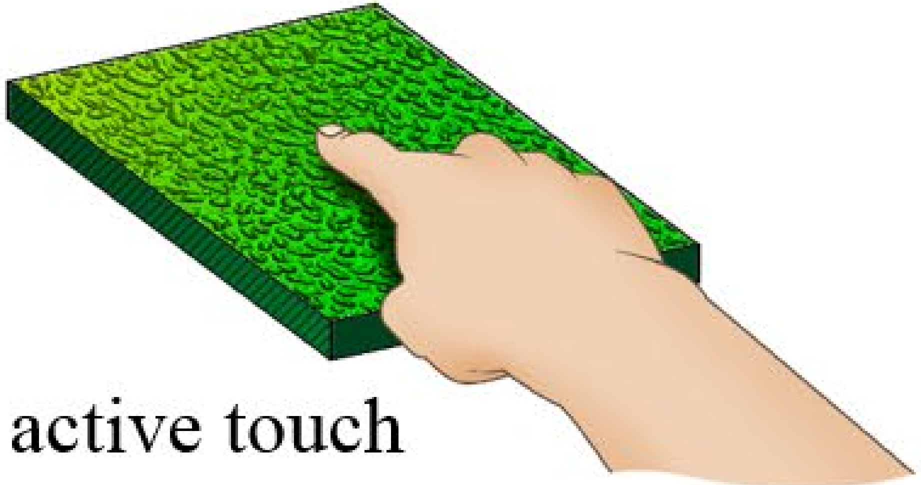
Images courtesy Even Pezent

Active vs. passive touch



Passive touch

Focus on the sensation experienced

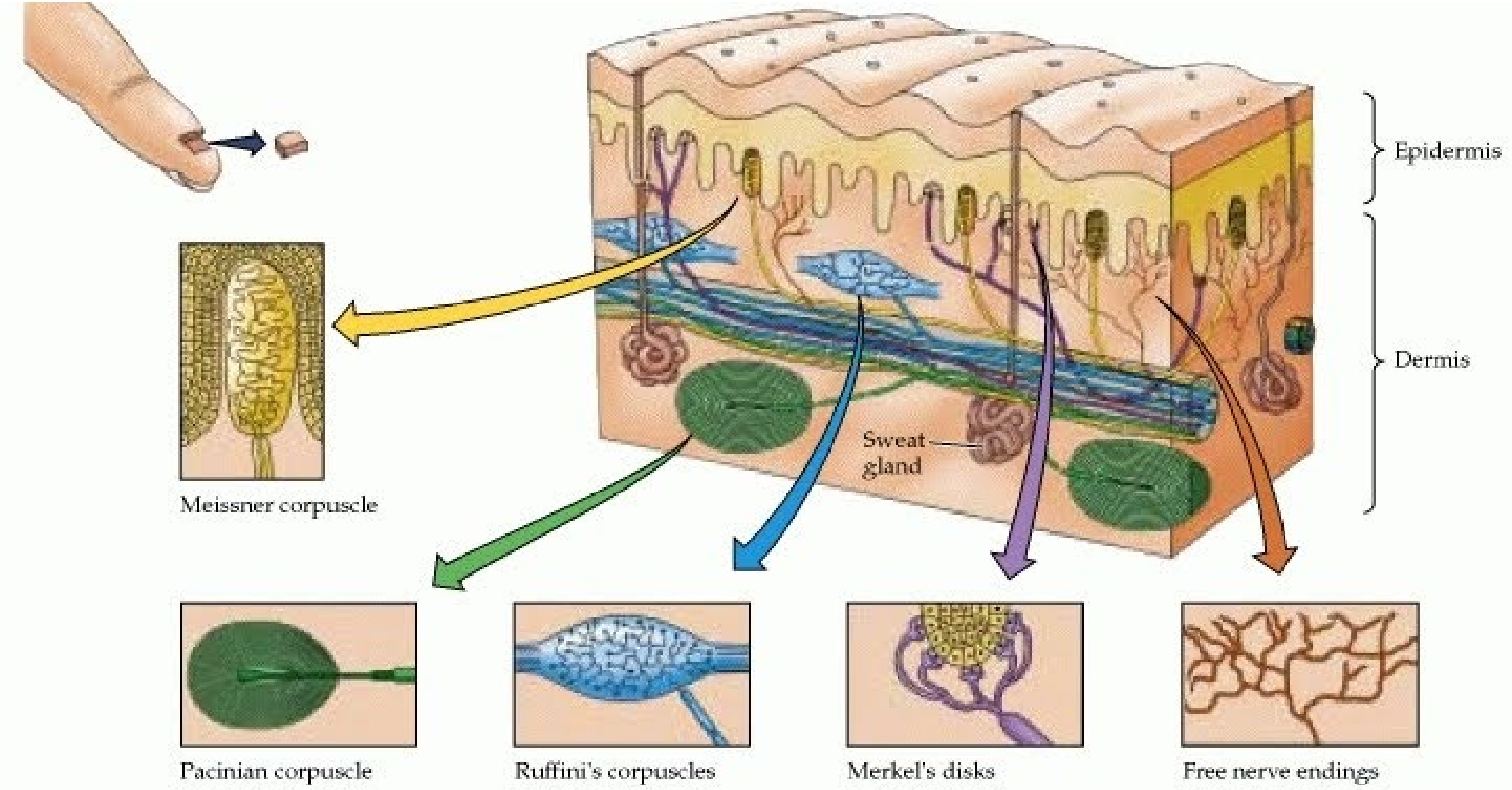


Active touch

Focus on the object

Images courtesy Even Pezent

Mechanoreception



Mechanoreceptive afferents

classified by depth:

I: closer to skin surface

II: deeper beneath surface response

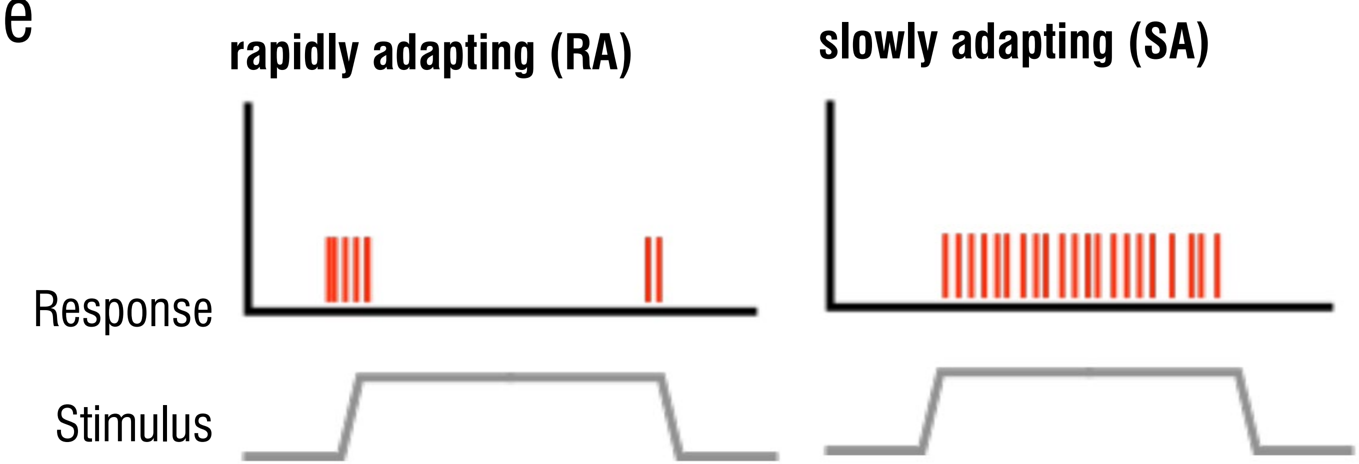
classified by rate of adaptation:

rapidly adapting = phasic

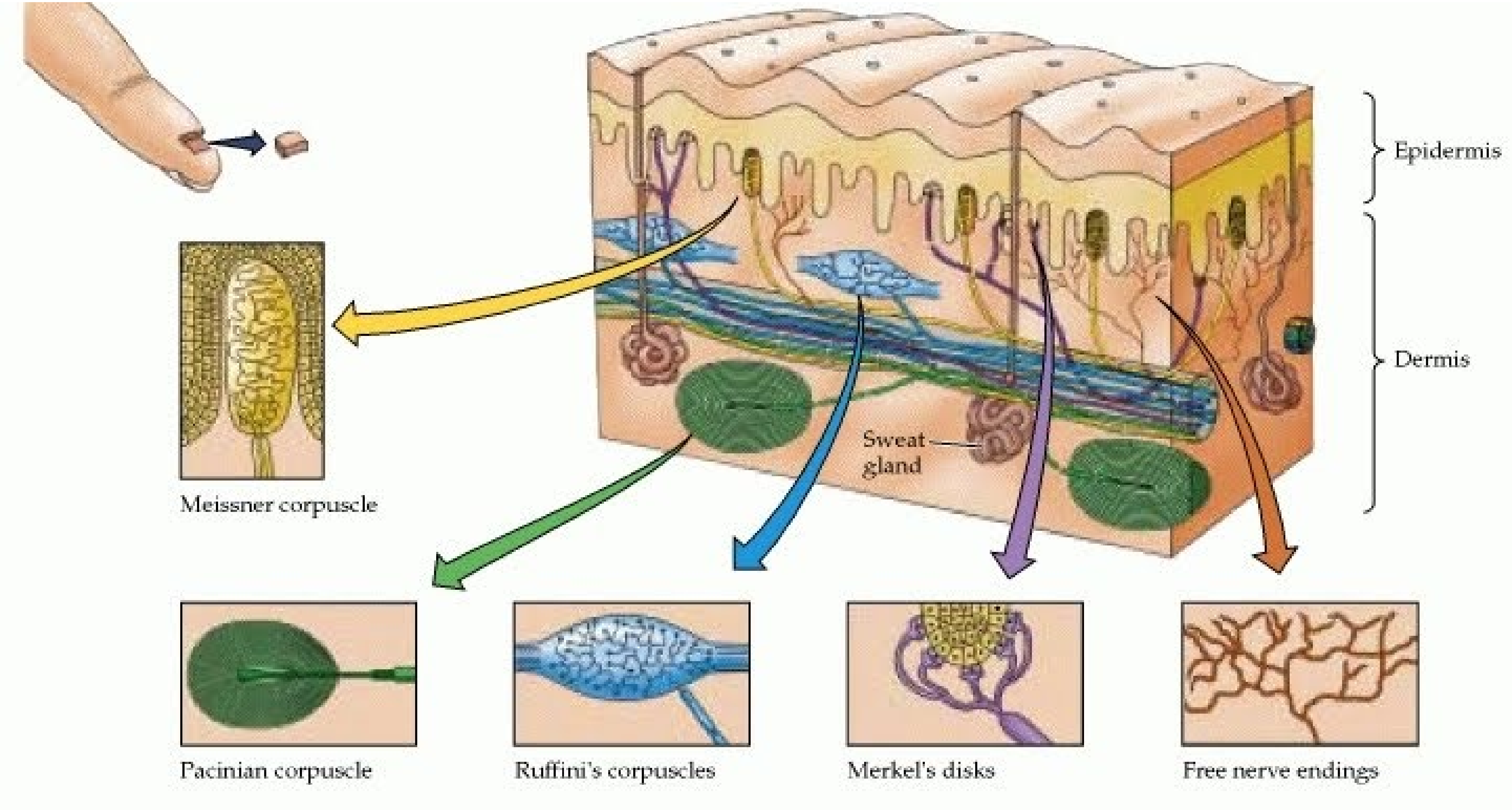
slowly adapting = tonic

classified by sensing modality:

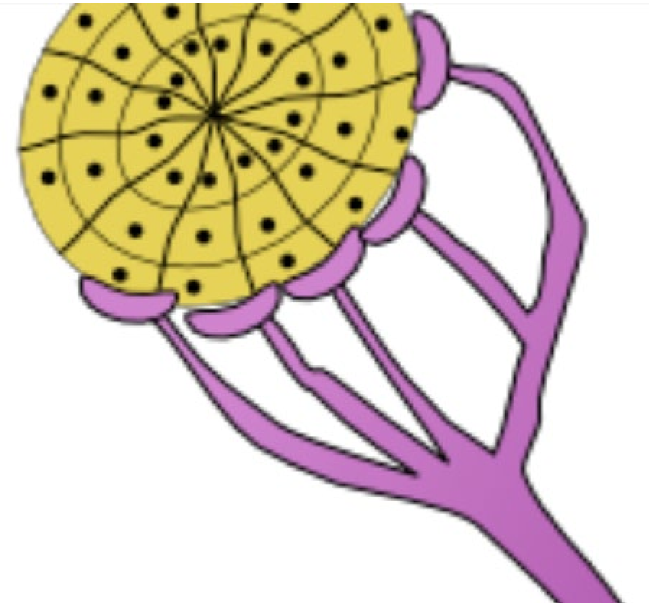
e.g., receptor structure



Cross section of glabrous skin



Merkel (SA I)

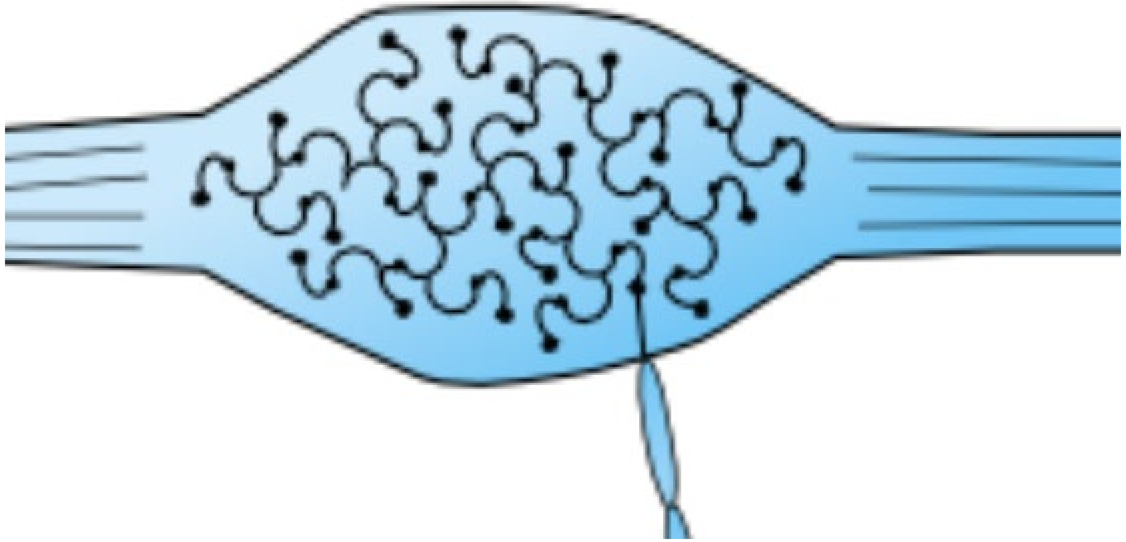


form and texture perception

low-frequency vibrations

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

Ruffini (SA II)

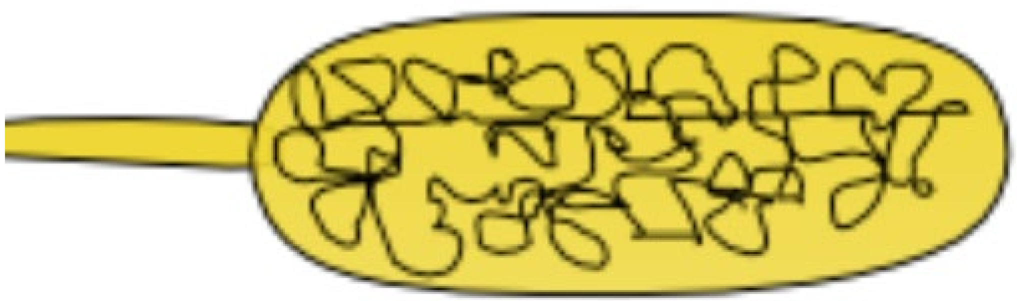


static and dynamic skin deformation

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)

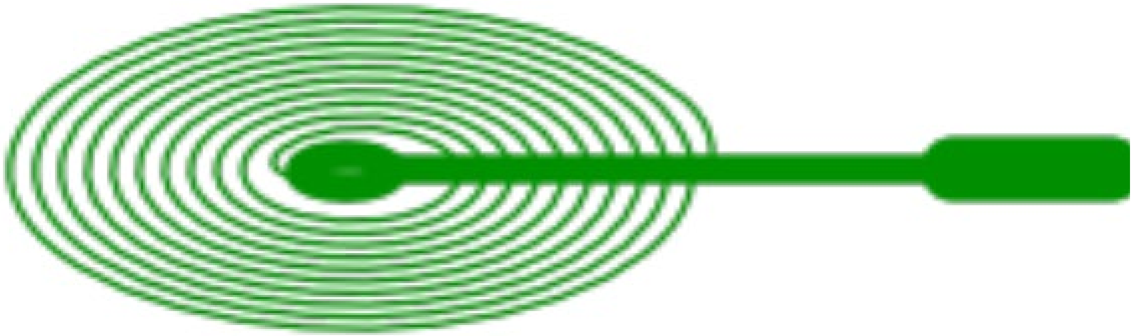


motion, slip/grip

dynamic skin deformation

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

Pacinian Corpuscle (PC / RA II)



high frequency vibration

gross pressure changes

Shape: layered capsule surrounding nerve fiber
Location: deep in skin
Type: PC
Best Frequencies: 10 to >500 Hz
Stimulus: rapid vibration

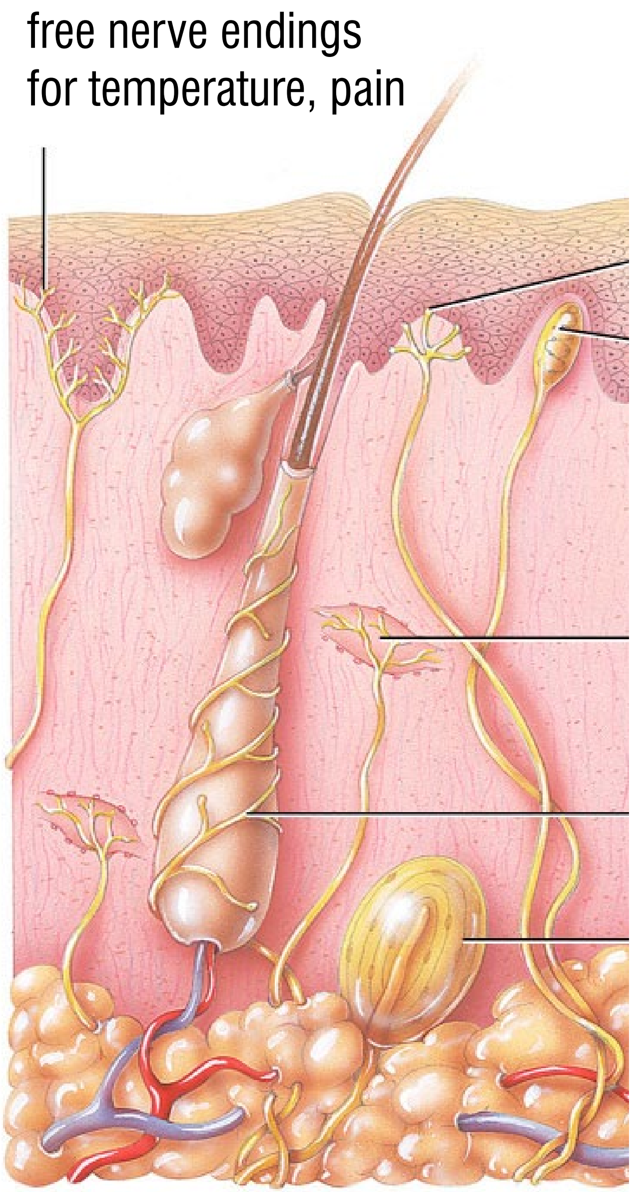
	Receptor	Diam.	Density (Fibers/cm^2)	Response	Percep. Function
SA I	Merkel	2mm	100	curvature	form & texture
RA	Meissner	5 mm	150	motion	motion & grip control
SA II	Ruffini	8mm	20	stretch	hand shape, lateral force
PC	Pacinian	Hand	20	vibration	tools & probes

Thermal sensing

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

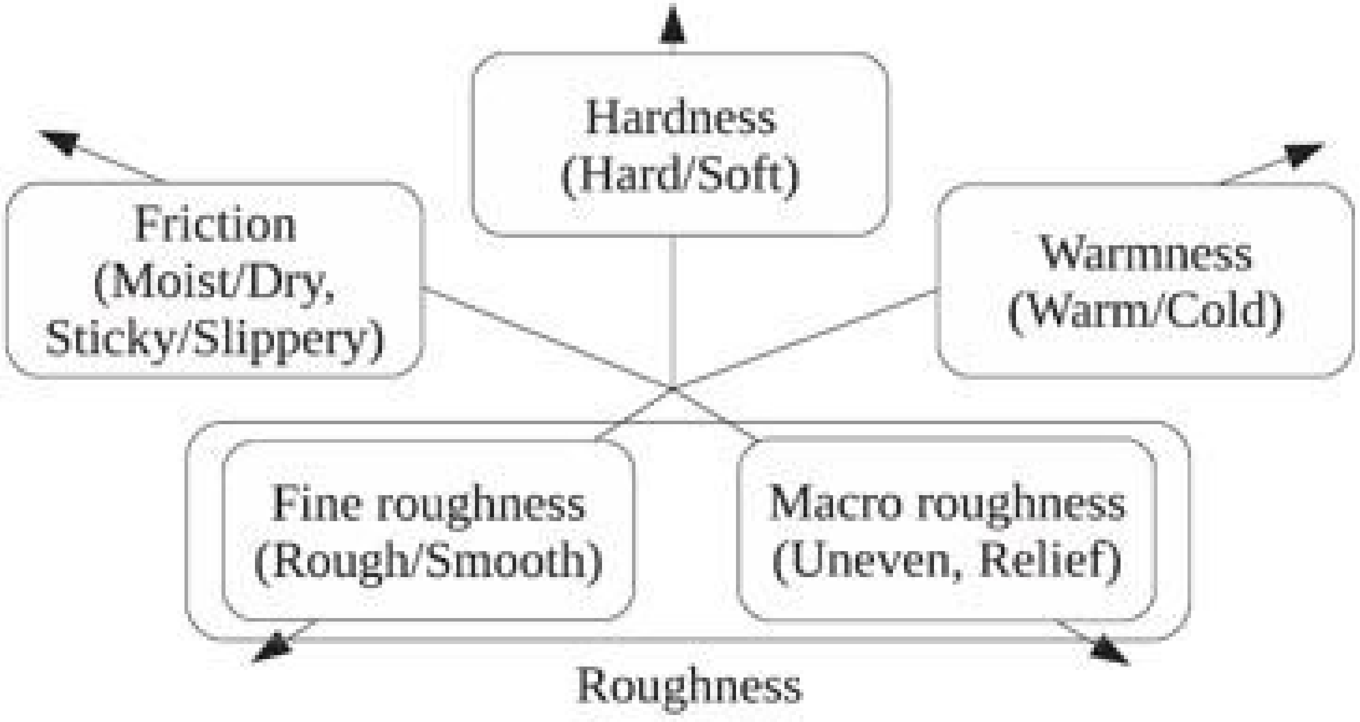
both slowly adapting (SA) and rapidly adapting (FA) characteristics, so depends on both T and dT/dt

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



R.K. Adair. A model of the detection of warmth and cold by cutaneous sensors through effects on voltage-gated membrane channels, PNAS 1999 96 (21).

What does the human hand feel?



Hardness
(Hard/Soft)

Friction
(Moist/Dry,
Sticky/Slippery)

Warmness
(Warm/Cold)

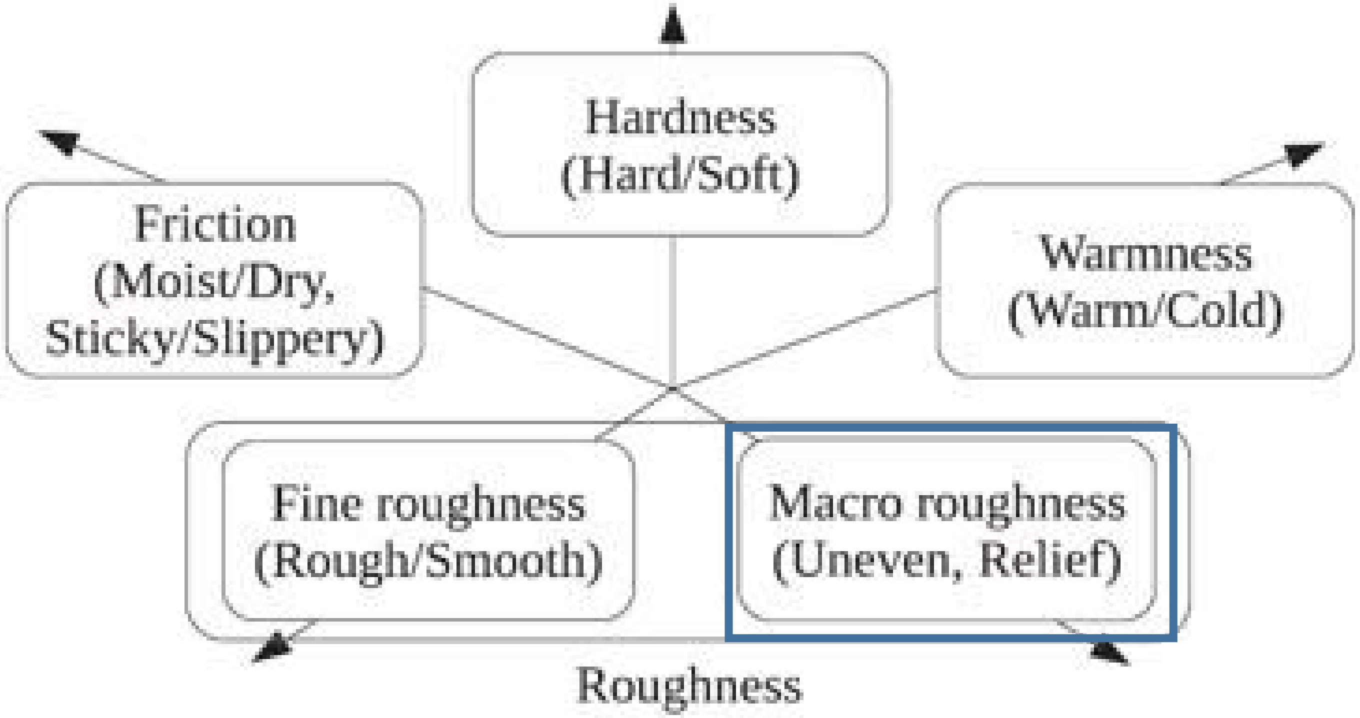
Fine roughness
(Rough/Smooth)

Macro roughness
(Uneven, Relief)

Roughness

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

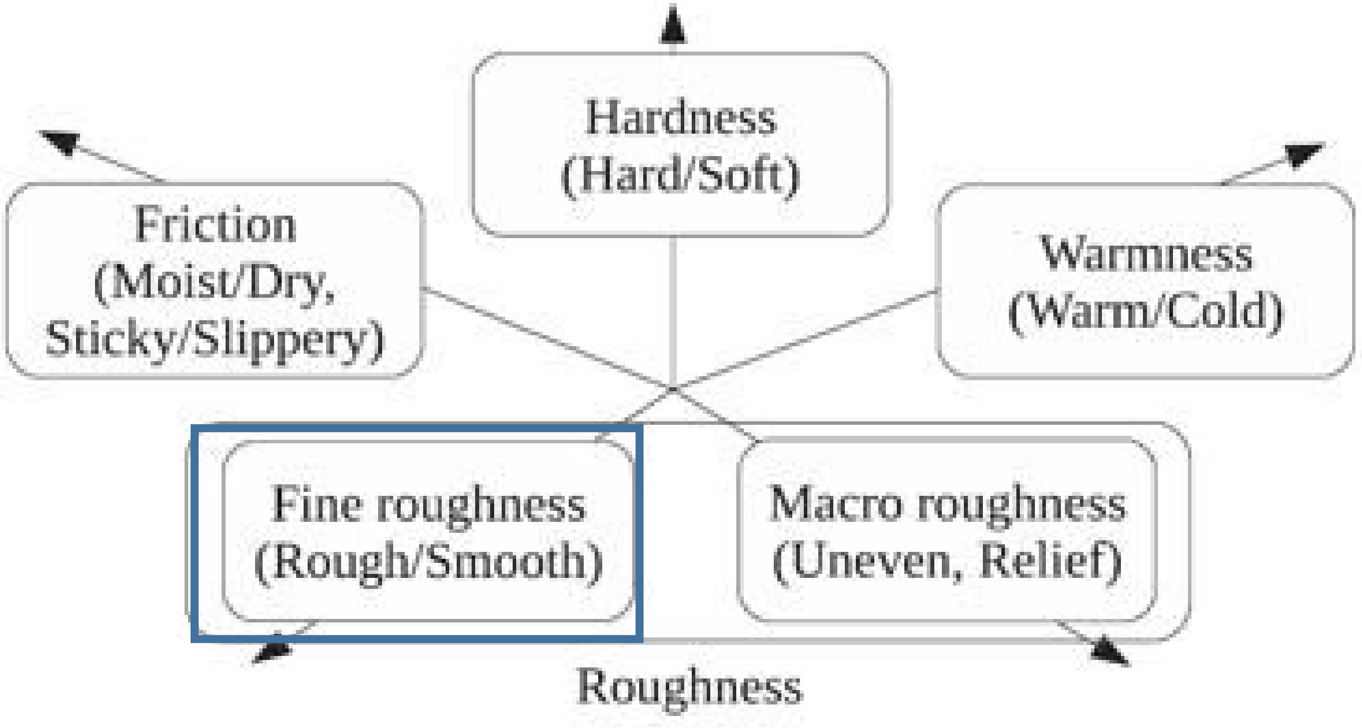
What does the human hand feel?



Spatial distribution of SA I
No temporal information

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

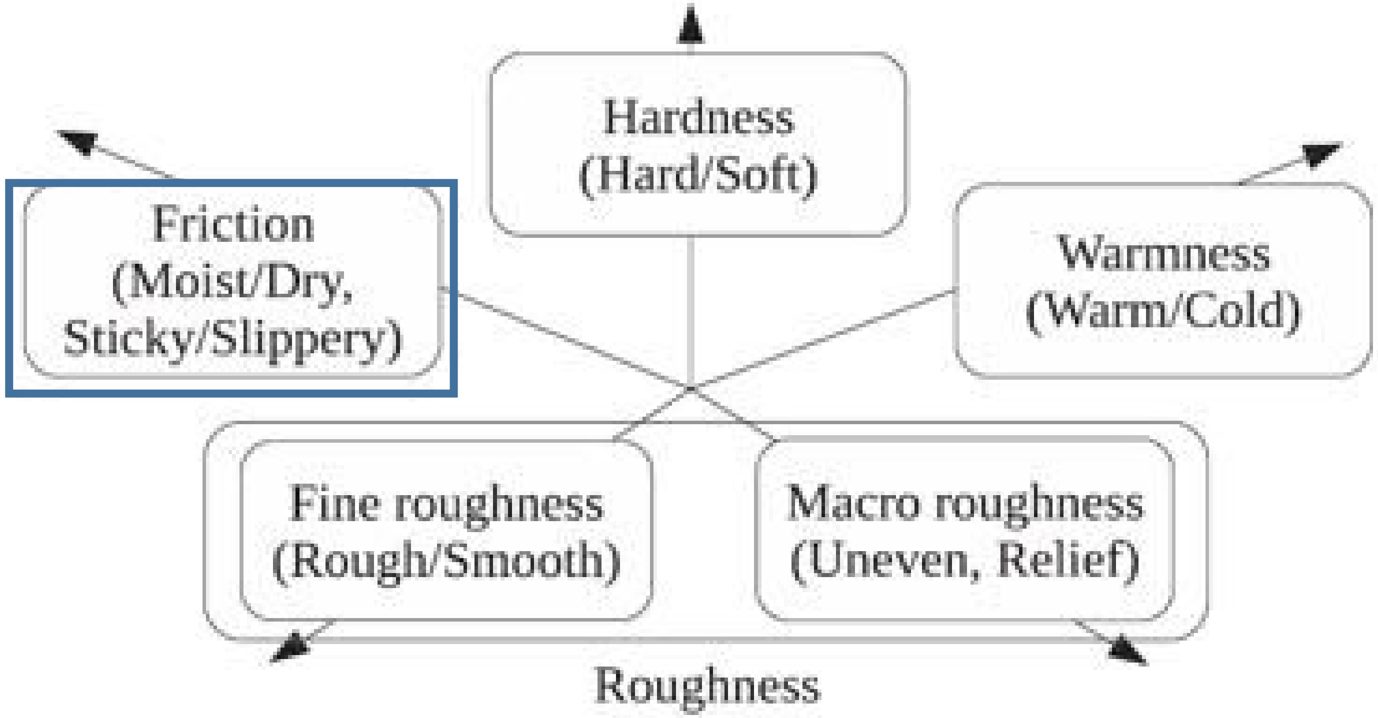
What does the human hand feel?



Vibratory information
RA I and RA II

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

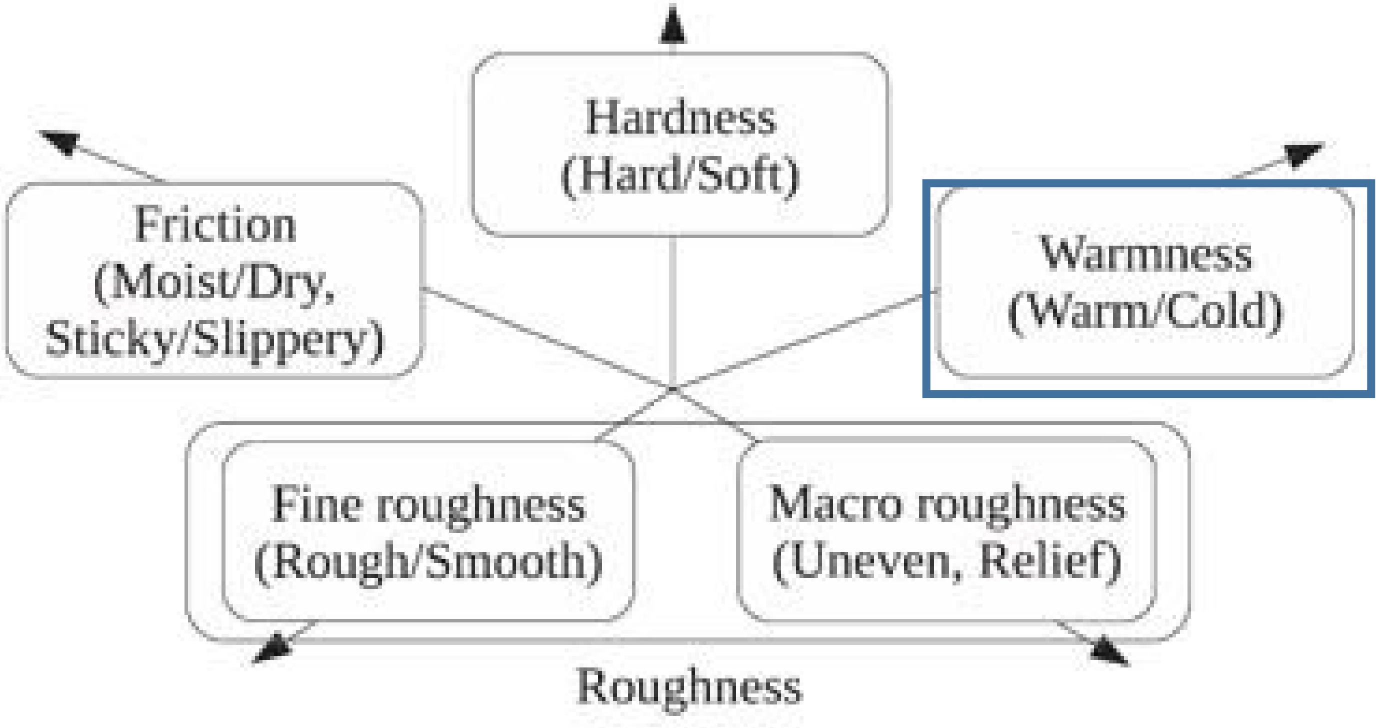
What does the human hand feel?



Mediated by skin of finger pad
Skin stretch or adhesion

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

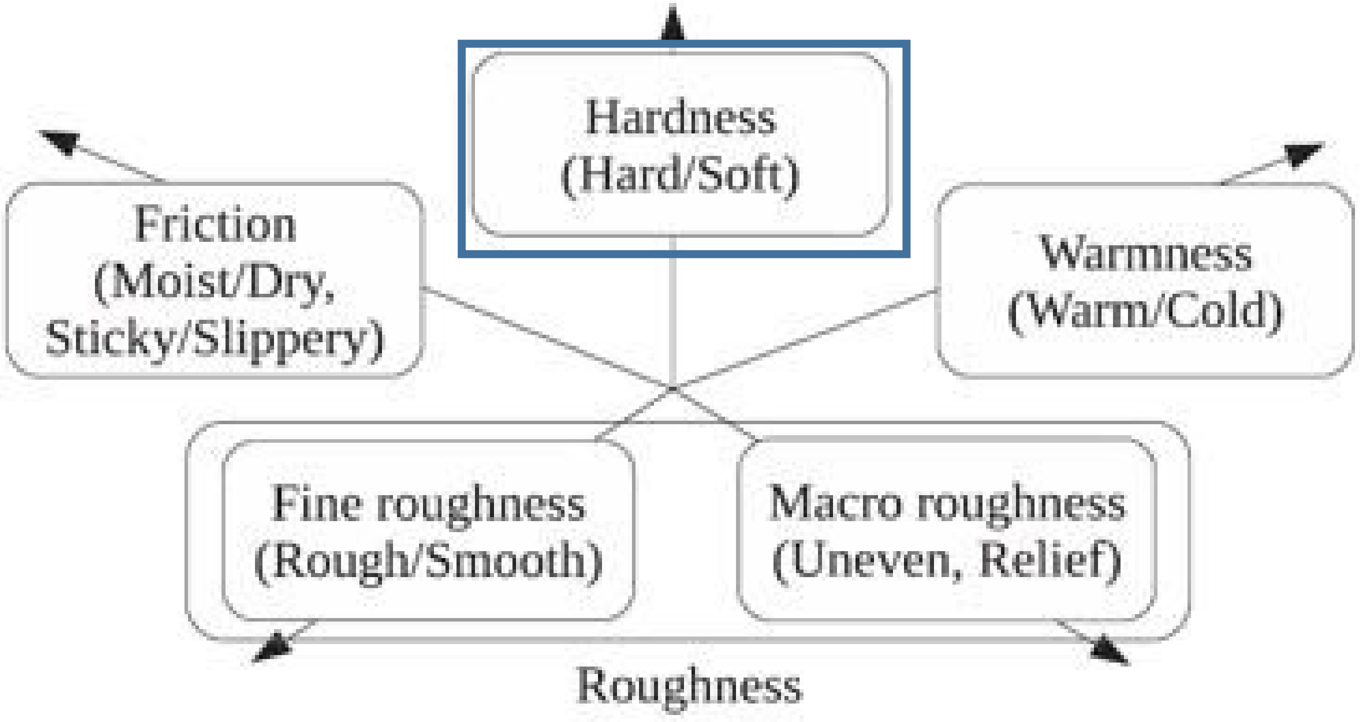
What does the human hand feel?



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

Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

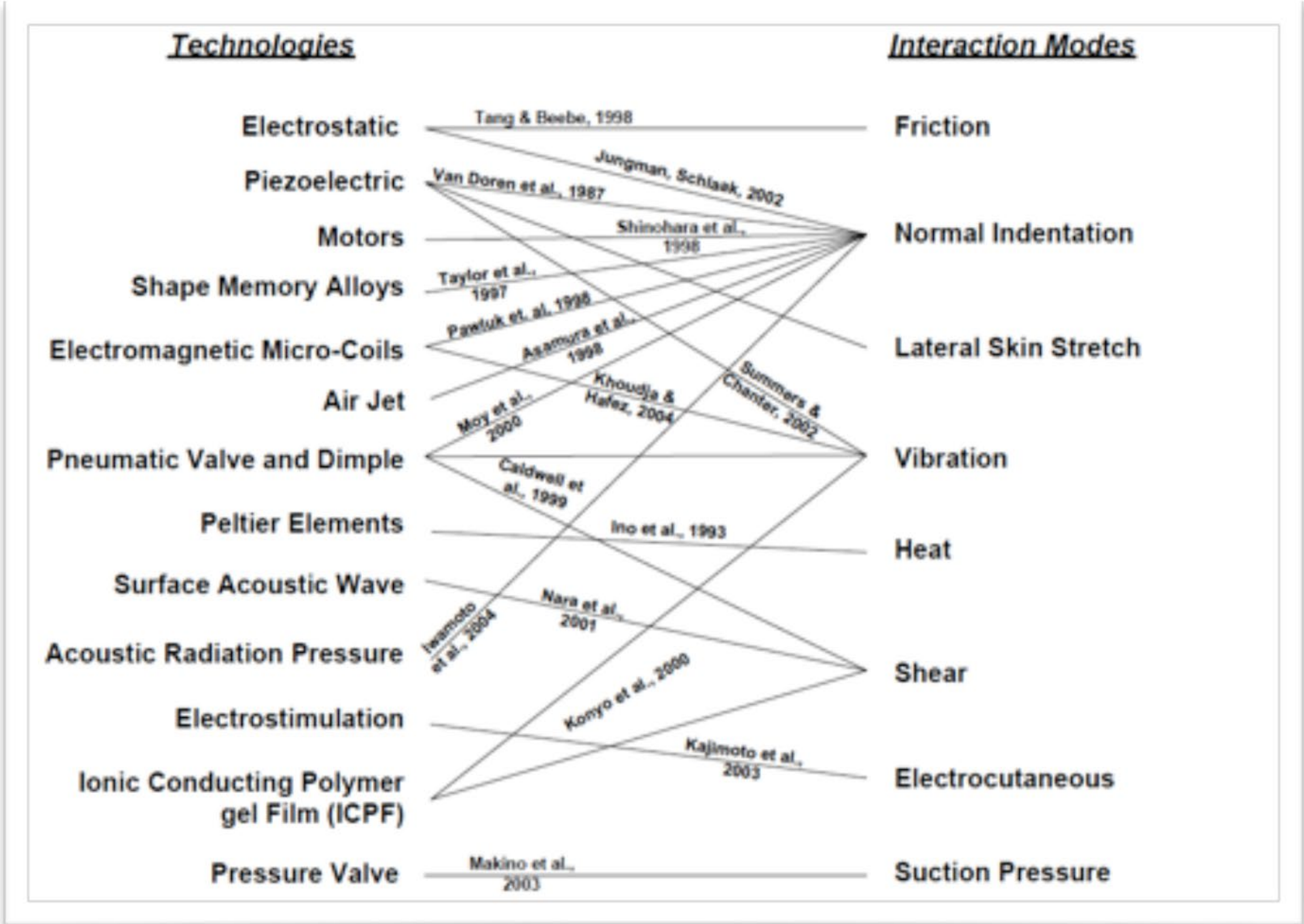
What does the human hand feel?



Tactile cues
Contact area between finger pad and object is important

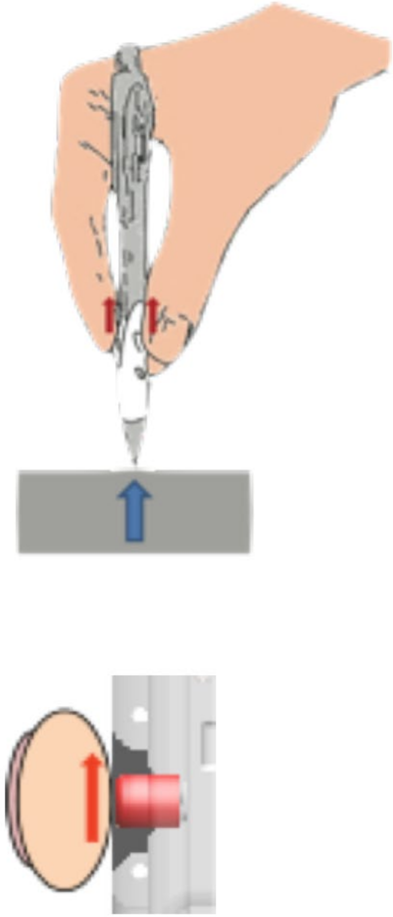
Okamoto, Shogo, Hikaru Nagano, and Yoji Yamada. "Psychophysical dimensions of tactile perception of textures." *IEEE Transactions on Haptics* 6, no. 1 (2012): 81-93.

Different technologies and interaction modes mapping

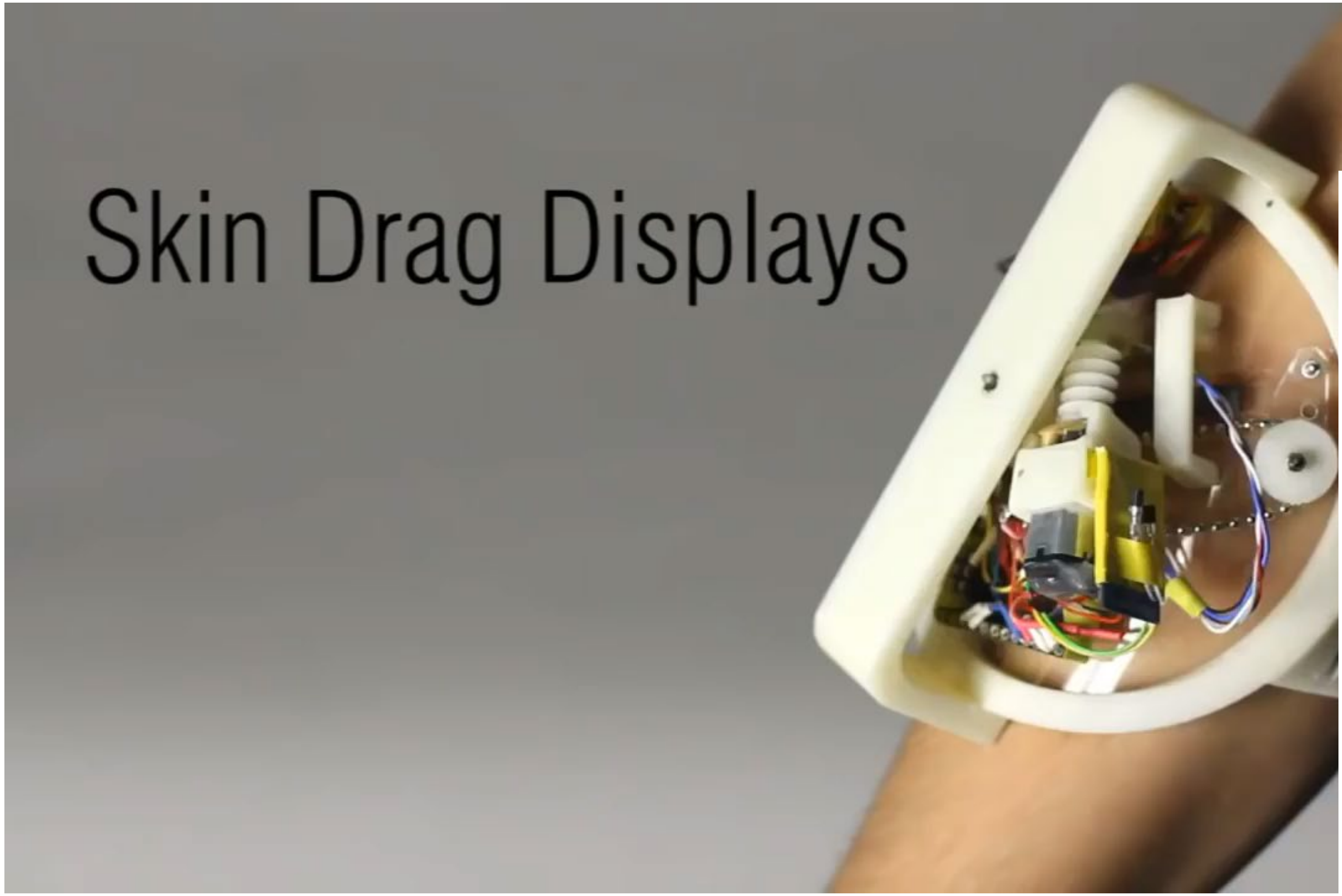


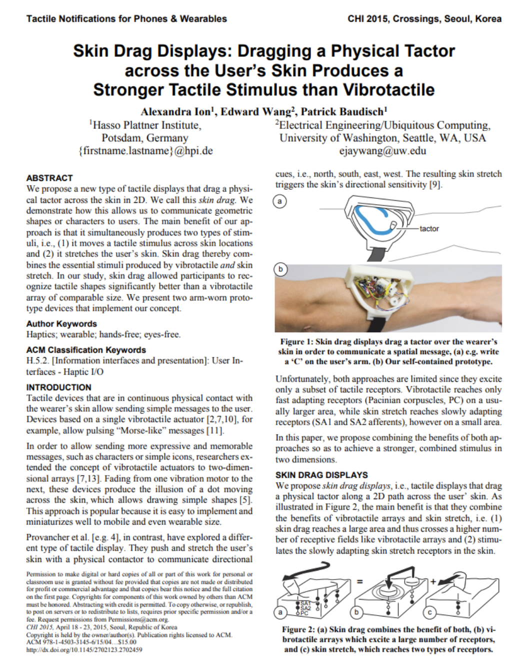
Jerome Pasquero, Survey on Communication through Touch, Technical Report: TR-CIM 06.04, 2006

Skin-Stretch/dragging Mechanism



Skin-Stretch/dragging Mechanism





Skin Drag Displays: Dragging a Physical Tactor across the User's Skin Produces a Stronger Tactile Stimulus than Vibrotactile

Alexandra Ion[1], Edward Wang[2], Patrick Baudisch[1]
[1]Hasso Plattner Institute,
Potsdam, Germany
{firstname.lastname}@hpi.de
[2]Electrical Engineering/Ubiquitous Computing,
University of Washington, Seattle, WA, USA
ejaywang@uw.edu

ABSTRACT

We propose a new type of tactile displays that drag a physical tactor across the skin in 2D. We call this *skin drag*. We demonstrate how this allows us to communicate geometric shapes or characters to users. The main benefit of our approach is that it simultaneously produces two types of stimuli, i.e., (1) it moves a tactile stimulus across skin locations and (2) it stretches the user's skin. Skin drag thereby combines the essential stimuli produced by vibrotactile *and* skin stretch. In our study, skin drag allowed participants to recognize tactile shapes significantly better than a vibrotactile array of comparable size. We present two arm-worn prototype devices that implement our concept.

Author Keywords
Haptics; wearable; hands-free; eyes-free.

ACM Classification Keywords
H.5.2. [Information interfaces and presentation]: User Interfaces - Haptic I/O

INTRODUCTION

Tactile devices that are in continuous physical contact with the wearer's skin allow sending simple messages to the user. Devices based on a single vibrotactile actuator [2,7,10], for example, allow pulsing "Morse-like" messages [11].

In order to allow sending more expressive and memorable messages, such as characters or simple icons, researchers extended the concept of vibrotactile actuators to two-dimensional arrays [7,13]. Fading from one vibration motor to the next, these devices produce the illusion of a dot moving across the skin, which allows drawing simple shapes [5]. This approach is popular because it is easy to implement and miniaturizes well to mobile and even wearable size.

Provancher et al. [e.g. 4], in contrast, have explored a different type of tactile display. They push and stretch the user's skin with a physical contactor to communicate directional cues, i.e., north, south, east, west. The resulting skin stretch triggers the skin's directional sensitivity [9].

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.

Unfortunately, both approaches are limited since they excite only a subset of tactile receptors. Vibrotactile reaches only fast adapting receptors (Pacinian corpuscles, PC) on a usually larger area, while skin stretch reaches slowly adapting receptors (SA1 and SA2 afferents), however on a small area.

In this paper, we propose combining the benefits of both approaches so as to achieve a stronger, combined stimulus in two dimensions.

SKIN DRAG DISPLAYS

We propose *skin drag displays*, i.e., tactile displays that drag a physical tactor along a 2D path across the user' skin. As illustrated in Figure 2, the main benefit is that they combine the benefits of vibrotactile arrays and skin stretch, i.e. (1) skin drag reaches a large area and thus crosses a higher number of receptive fields like vibrotactile arrays and (2) stimulates the slowly adapting skin stretch receptors in the skin.

Figure 2: (a) Skin drag combines the benefit of both, (b) vibrotactile arrays which excite a large number of receptors, and (c) skin stretch, which reaches two types of receptors.

CHI 2015, April 18 - 23, 2015, Seoul, Republic of Korea

ACM 978-1-4503-3145-6/15/04…$15.00
http://dx.doi.org/10.1145/2702123.2702459

CHI 15
Ion et.al.

Skin-Stretch/dragging Mechanism

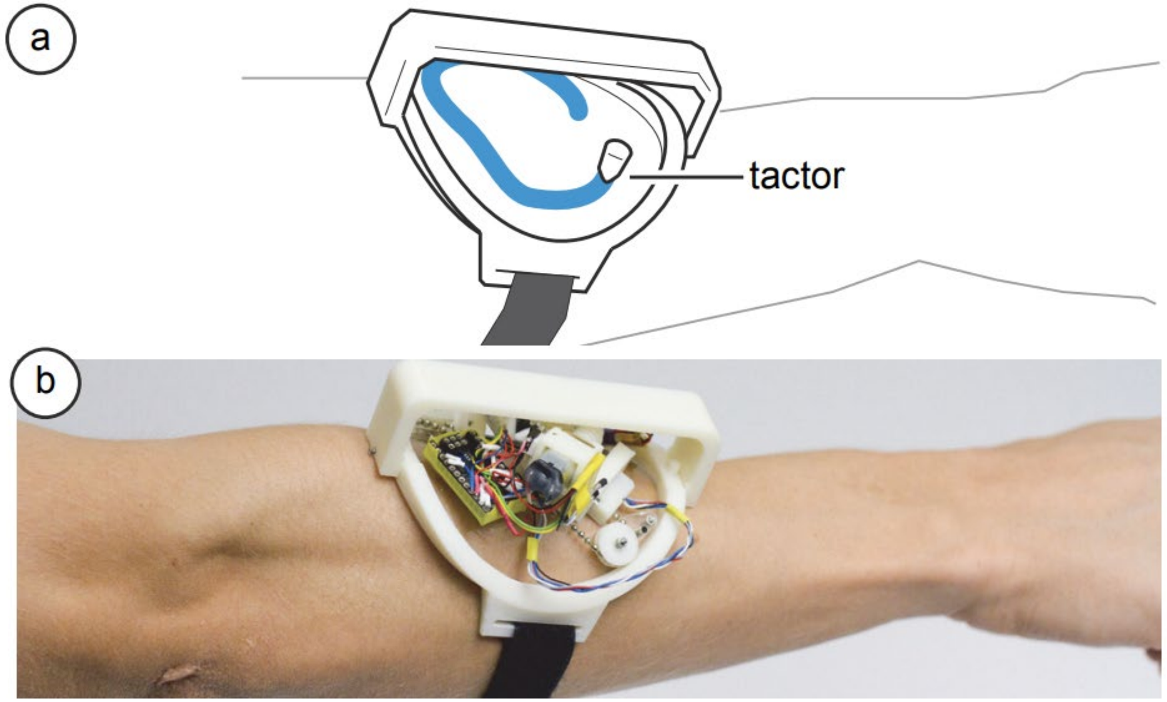


Figure 1: Skin drag displays drag a tactor over the wearer’s skin in order to communicate a spatial message, (a) e.g. write a ‘C’ on the user’s arm. (b) Our self-contained prototype.

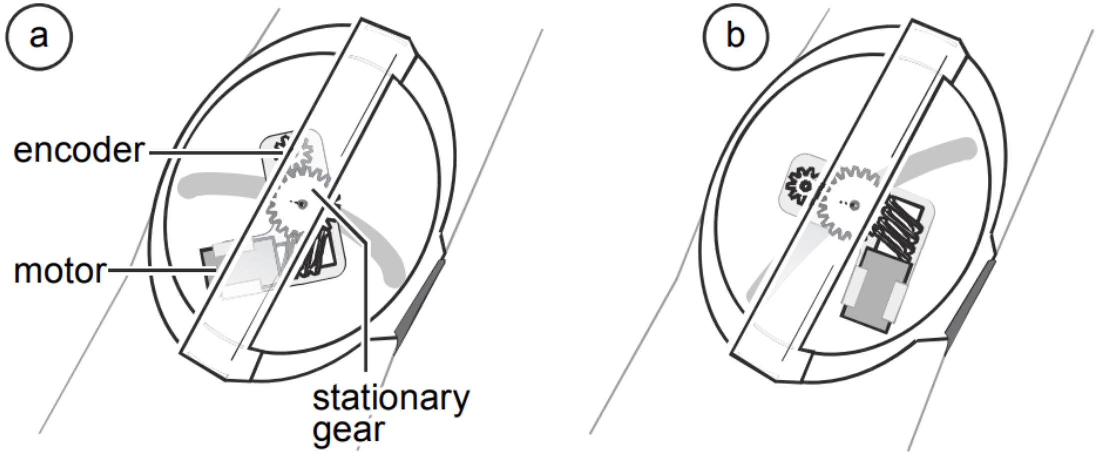


Figure 5: (a) A motor using a worm drive actuates the rotation of the diaphragm. (b) All components rotate with the diaphragm, e.g., 45° counterclockwise.

Skin-Stretch/dragging Mechanism


Haptics on Skin
CHI 2017, May 6–11, 2017, Denver, CO, USA

tactoRing: A Skin-Drag Discrete Display

Seungwoo Je[1] **Brendan Rooney**[2] **Liwei Chan**[3] **Andrea Bianchi**[1]

[1]Department of Industrial Design,
KAIST, Daejeon, Korea
{Seungwoo_je, andrea}@kaist.ac.kr

[2]Department of Mathematical Sciences,
KAIST, Daejeon, Korea
brooney@kaist.ac.kr

[3]Computer Science, National Chiao
Tung University, Hsinchu, Taiwan
liweichan @cs.nctu.edu.tw

ABSTRACT

Smart rings are an emerging wearable technology particularly suitable for discrete notifications based on haptic cues. Previous work mostly focused on tactile actuators that stimulate only specific skin receptors on the finger, resulting in limited information expressiveness. We propose *tactoRing*, a novel tactile display that, by dragging a small tactor on the skin around the finger, excites multiple skin areas resulting in more accurate cue recognition. In this paper we present the hardware and a perception study to understand the ability of users to recognize eight distinct points around the finger. Moreover, we show two different techniques to encode information through skin-dragging motion with accuracy up to 94%. We finally showcase a set of applications that, by combining sequences of tactile stimuli, achieve higher expressiveness than prior methods.

AUTHOR KEYWORDS

Haptics; wearable; ring; eyes-free; skin-drag.

ACM Classification Keywords

H.5.2. [Information interfaces and presentation]: User Interfaces – Haptic I/O

INTRODUCTION

Smart rings are becoming more popular, receiving both commercial endorsement and attention from researchers [29]. Like other wearable devices, they benefit from the social acceptability of traditional jewelry [22], but also from direct contact with the finger skin. These properties make them particularly suitable for always-available input interactions [1, 5, 18, 24, 35], and rich but subtle notifications [21, 28]. It is therefore unsurprising that researchers have explored a variety of notification modalities for smart rings and similar finger augmentation devices, including: light [16]; small displays [30]; sound [28]; and, in particular, tactile feedback. Several types of tactile feedback have been considered, including: vibration patterns [3, 12, 21]; pressure and shear [36]; force [15, 19, 26]; and, poke and thermal [28].

CHI 2017, May 06-11, 2017, Denver, CO, USA

DOI: http://dx.doi.org/10.1145/3025453.3025703

Figure 1. *tactoRing* contains a small movable skin-drag tactor that can rotate around the finger. Motion is indicated by the black arrow, and the dragging surface area in red.

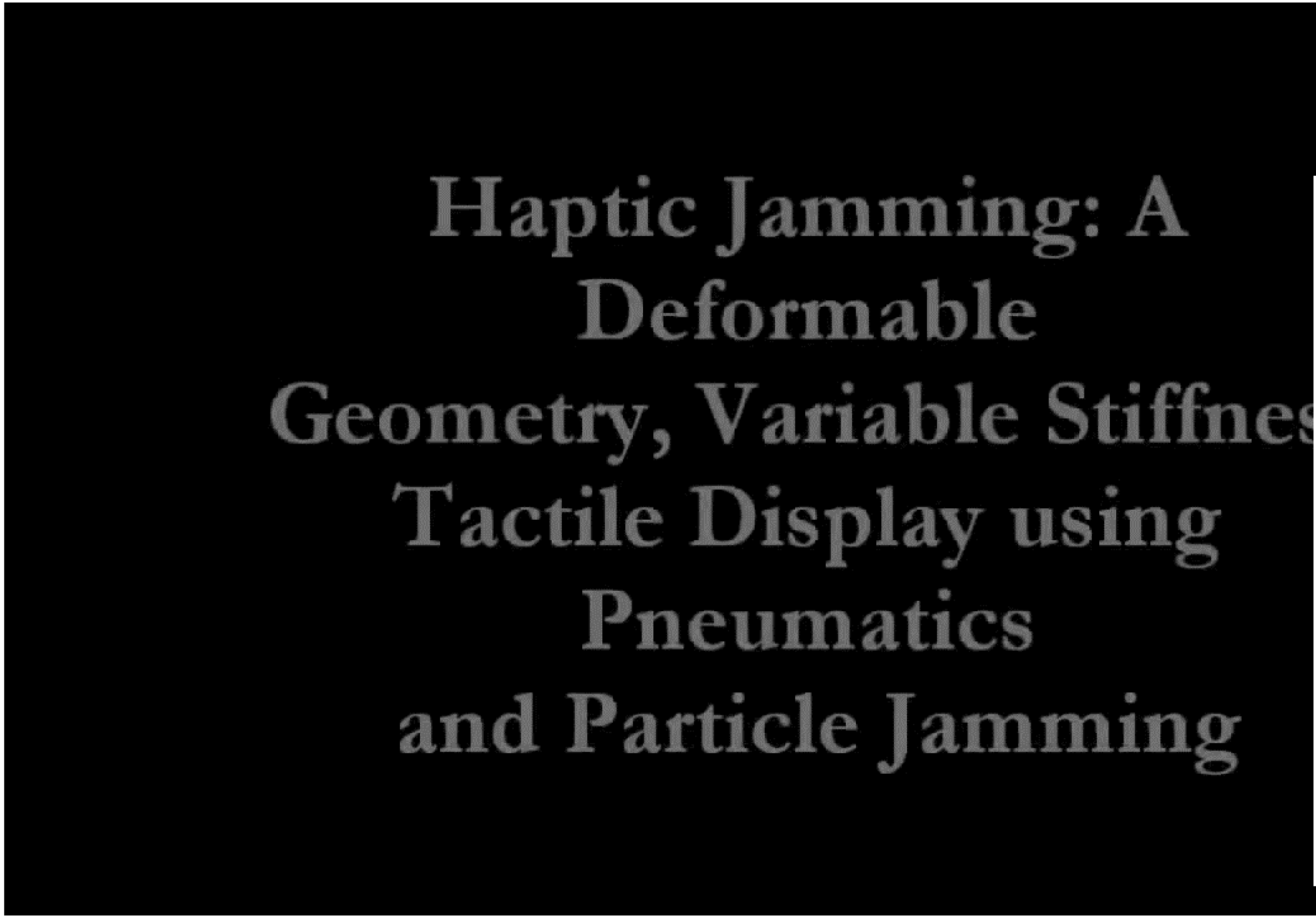
However, while tactile notifications have the benefit of not requiring constant attention from users, and support eyes-free interactions, the expressiveness and the amount of information that can be clearly communicated to users through the haptic channel using currently available finger wearable devices is quite limited. In fact, most of these devices operate by exciting only a small set of tactile skin receptors [13, 36]. They fail to exploit the spatial resolution of the finger skin, which is capable of disambiguating points as close as 2-5mm [14, 33].

In this paper we present *tactoRing*, a novel haptic ring that excites the user's skin by dragging a small movable tactor (i.e., a small tactile actuator, such as a pin) around the finger. By simultaneously stimulating the Merkel cells on the epidermis (SA1) through pressure, and the Meissner corpuscles (RA1) and the Ruffini's endings (SA2) in the dermis through stretching the skin and low frequency vibrations (e.g., rubbing) [14], we are able to achieve higher discrete spatial resolution on the finger and convey richer and more expressive messages to users than traditional methods.

This paper describes the *tactoRing* prototype in detail, and demonstrates its accuracy with a series of user studies. Specifically, we investigated the capability of users to perceive the movable tactor and discern its dragging motion to different locations around the finger. To overcome low spatial resolution, we present two different interaction techniques based on skin dragging (*DoublePoint* and *VirtualPoint*) and demonstrate, with a study, that they are suitable for accurate identification of eight unique targets around the finger. Finally, we instantiate concrete examples of usage for the presented techniques in four applications, and indicate possible future research directions.

CHI 17
Je et.al.

Practical jamming



Haptic Jamming: A Deformable Geometry, Variable Stiffnes Tactile Display using Pneumatics and Particle Jamming

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

Andrew A. Stanley[1]* astan@stanford.edu
James C. Gwilliam[1,2]* jim.gwilliam@jhu.edu
Allison M. Okamura[1] aokamura@stanford.edu

[1]Department of Mechanical Engineering, Stanford University
[2]Department of Biomedical Engineering, Johns Hopkins University

ABSTRACT

Many controllable tactile displays present the user with either variable mechanical properties or adjustable surface geometries, but controlling both simultaneously is challenging due to electromechanical complexity and the size/weight constraints of haptic applications. This paper discusses the design, manufacturing, control, and preliminary evaluation of a novel haptic display that achieves both variable stiffness and deformable geometry via air pressure and a technique called particle jamming. The surface of the device consists of a flat, deformable layer of hollow silicone cells filled with coffee grounds. It selectively solidifies in different regions when the air is vacuumed out of individual cells, jamming the coffee particles together. The silicone layer is clamped over a chamber with regulated air pressure. Different sequences of air pressure and vacuum level adjustment allow regions of the surface to display a small rigid lump, a large soft plane, and various other combinations of lump size and stiffness. Experimental data from individual cells show that surface stiffness increases with vacuum level and the elliptical shape of the cells become increasingly spherical with increased chamber pressure.

Index Terms: H.5.2 [Information Interfaces and Presentation]: User Interfaces—Haptic I/O;

1 INTRODUCTION

An ideal tactile display would be capable of controlling and transmitting multiple tactile quantities simultaneously, such as geometry, compliance, texture, and temperature. However, most tactile displays are limited in the scope of tactile sensations they can evoke, in large part because of the electromechanical complexities associated with developing devices that meet the physical constraints of many haptic applications. Researchers have developed displays optimized to display changes in surface geometry or shape (e.g., [5] [9] [11] [21]), although these displays do not allow for independent control of surface compliance. Others have developed displays that focus on controlling compliance and surface properties (e.g., [13] [22]), but do not actively control surface shape or geometry. Recently, air-jet-based tactile devices have been used to create simple displays that can control perceived geometry and surface properties simultaneously and independently [8] [10].

Distributed tactile displays that enable “encountered-type” interactions are particularly attractive because they allow users to freely explore a surface or object. Several existing tactile displays convey haptic information about virtual or remote geometries and stiffnesses without requiring the user to wear or hold onto a device. The concept of “digital clay” [18] was proposed for 3D computer input/output interfaces; several potential methods have been conceptualized for creating a controllably deformable surface, including an array of fluid-driven actuators [24]. Other approaches include tactile arrays of electrorheological [22] and magnetorheological [13] fluids, which transform material properties under application of an electric or magnetic field, respectively. The “T-PaD” (and its subsequent family of surface haptics devices) creates variable friction on a surface through ultrasonic vibrations [23]. Another surface haptics approach uses small electrostatic forces to vary surface friction [2]. Other implementations, including shape memory alloy arrays [21] and other types of pin arrays are summarized in [5].

Figure 1: Haptic Jamming array prototype with four hexagonal cells.

This paper introduces a novel tactile display approach in the encountered-type and surface haptics design space. Haptic Jamming is capable of independent control of geometry and mechanical properties simultaneously using air pressure and a technique known as particle jamming. A four-cell prototype, shown in Fig. 1, uses different input sequences of air pressure beneath the cells and vacuum level adjustment within the jamming cells to allow regions of the surface to display a small rigid lump, a large soft plane, or various other combinations of lump size and stiffness.

In this paper, we review prior work in particle jamming robotics and interfaces, explain our manufacturing approach, experimentally evaluate the device’s output, and provide the design of a multi-cell display. The current design is appropriate as an output device only, although it can be integrated with other components to allow user input as well. The Haptic Jamming approach has many potential applications; it was originally designed to be a component of an encountered-type combined cutaneous/kinesthetic display for medical training.

2 BACKGROUND

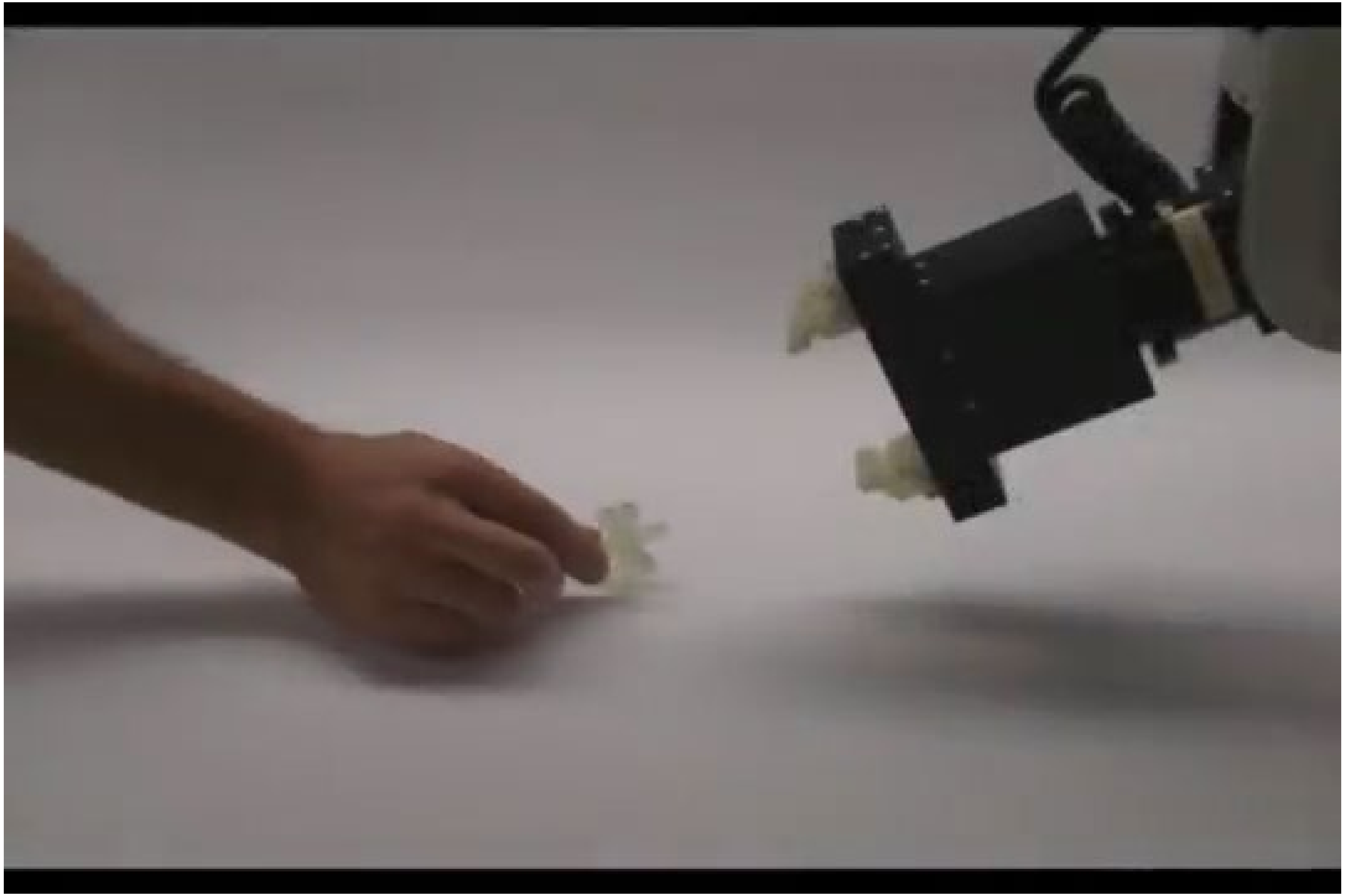
Particle jamming provides a method to quickly adjust the physical properties of an object. In most jamming designs, the object con-

---

*These authors contributed equally to this work.

IEEE World Haptics Conference 2013
14-18 April, Daejeon, Korea
978-1-4799-0088-6/13/$31.00 ©2013 IEEE

IEEE Haptics 13
Stanley et.al.



Brown, Eric, Nicholas Rodenberg, John Amend, Annan Mozeika, Erik Steltz, Mitchell R. Zakin, Hod Lipson, and Heinrich M. Jaeger. "Universal robotic gripper based on the jamming of granular material." *Proceedings of the National Academy of Sciences* 107, no. 44 (2010): 18809-18814.

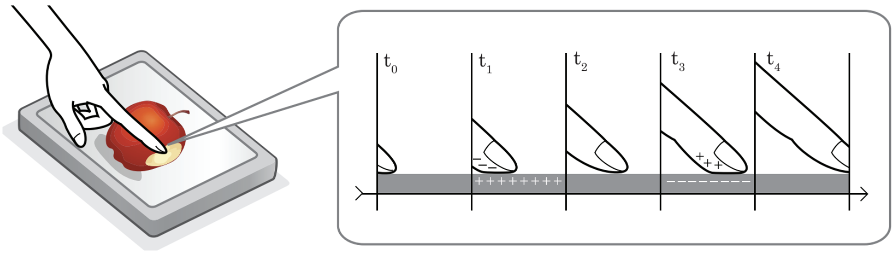
Variable friction surfaces

Ultrasonic vibration could reduce the coefficient of friction of sandpaper; the same principle is here applied to glass.

Northwestern TPad

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.



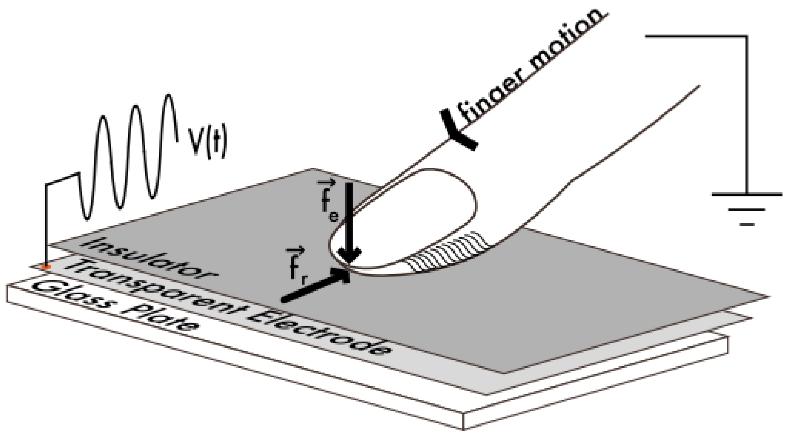
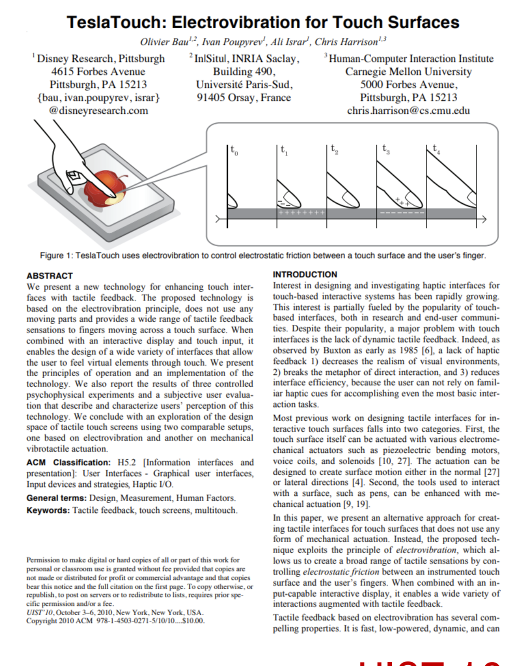


Figure 2: TeslaTouch operating principle.



TeslaTouch: Electrovibration for Touch Surfaces

Olivier Bau[1,2], Ivan Poupyrev[1], Ali Israr[1], Chris Harrison[1,3]

[1] Disney Research, Pittsburgh
4615 Forbes Avenue
Pittsburgh, PA 15213
{bau, ivan.poupyrev, israr}
@disneyresearch.com

[2] In|Situ|, INRIA Saclay,
Building 490,
Université Paris-Sud,
91405 Orsay, France

[3] Human-Computer Interaction Institute
Carnegie Mellon University
5000 Forbes Avenue,
Pittsburgh, PA 15213
chris.harrison@cs.cmu.edu

Figure 1: TeslaTouch uses electrovibration to control electrostatic friction between a touch surface and the user’s finger.

ABSTRACT

We present a new technology for enhancing touch interfaces with tactile feedback. The proposed technology is based on the electrovibration principle, does not use any moving parts and provides a wide range of tactile feedback sensations to fingers moving across a touch surface. When combined with an interactive display and touch input, it enables the design of a wide variety of interfaces that allow the user to feel virtual elements through touch. We present the principles of operation and an implementation of the technology. We also report the results of three controlled psychophysical experiments and a subjective user evaluation that describe and characterize users’ perception of this technology. We conclude with an exploration of the design space of tactile touch screens using two comparable setups, one based on electrovibration and another on mechanical vibrotactile actuation.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces, Input devices and strategies, Haptic I/O.

General terms: Design, Measurement, Human Factors.

Keywords: Tactile feedback, touch screens, multitouch.

UIST'10, October 3–6, 2010, New York, New York, USA.

INTRODUCTION

Interest in designing and investigating haptic interfaces for touch-based interactive systems has been rapidly growing. This interest is partially fueled by the popularity of touch-based interfaces, both in research and end-user communities. Despite their popularity, a major problem with touch interfaces is the lack of dynamic tactile feedback. Indeed, as observed by Buxton as early as 1985 [6], a lack of haptic feedback 1) decreases the realism of visual environments, 2) breaks the metaphor of direct interaction, and 3) reduces interface efficiency, because the user can not rely on familiar haptic cues for accomplishing even the most basic interaction tasks.

Most previous work on designing tactile interfaces for interactive touch surfaces falls into two categories. First, the touch surface itself can be actuated with various electromechanical actuators such as piezoelectric bending motors, voice coils, and solenoids [10, 27]. The actuation can be designed to create surface motion either in the normal [27] or lateral directions [4]. Second, the tools used to interact with a surface, such as pens, can be enhanced with mechanical actuation [9, 19].

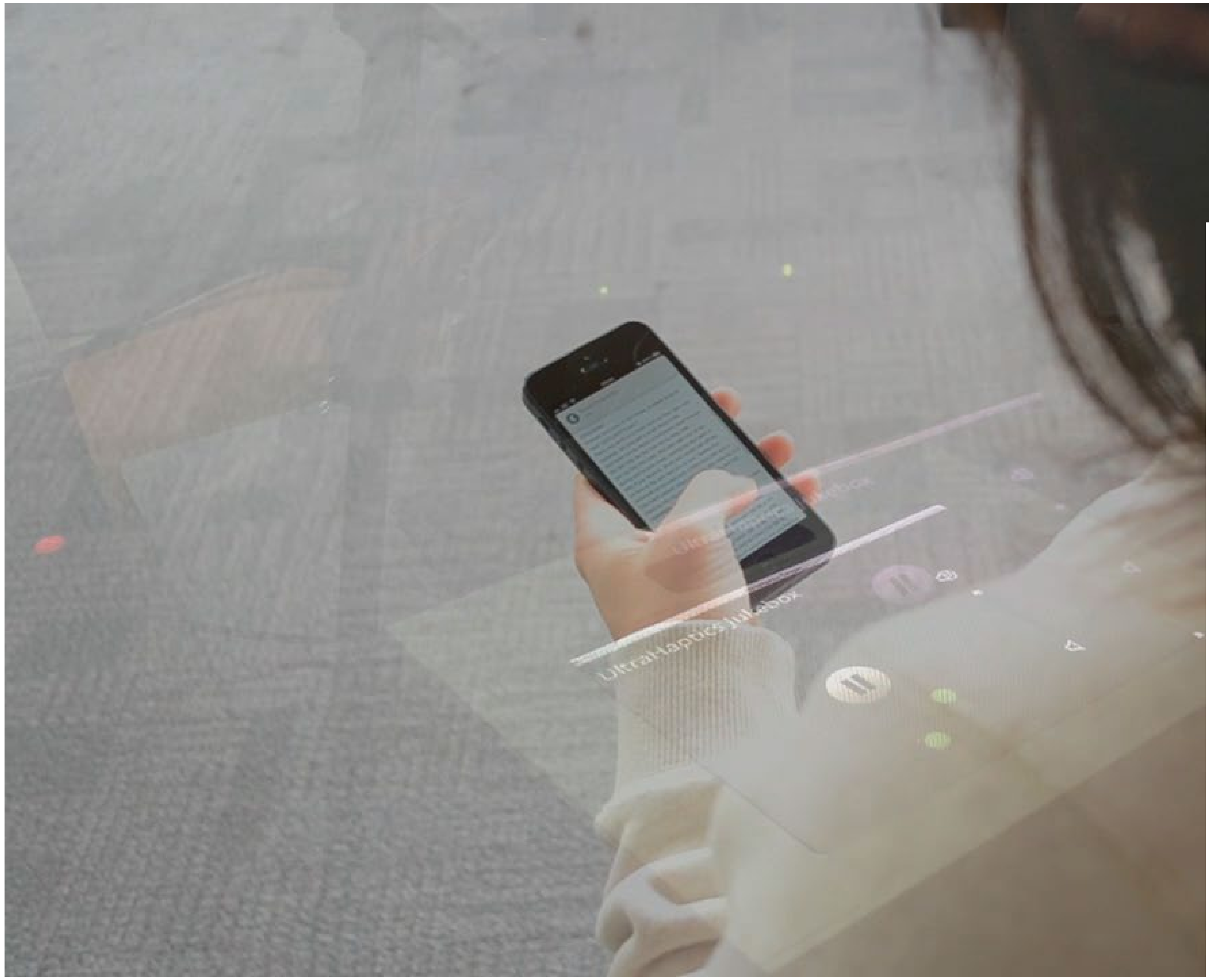
In this paper, we present an alternative approach for creating tactile interfaces for touch surfaces that does not use any form of mechanical actuation. Instead, the proposed technique exploits the principle of *electrovibration*, which allows us to create a broad range of tactile sensations by controlling *electrostatic friction* between an instrumented touch surface and the user’s fingers. When combined with an input-capable interactive display, it enables a wide variety of interactions augmented with tactile feedback.

Tactile feedback based on electrovibration has several compelling properties. It is fast, low-powered, dynamic, and can

UIST 10
Bau et.al.

Mid-air haptics

Ultrasonic haptics



UltraHaptics: Multi-Point Mid-Air Haptic Feedback for Touch Surfaces

Tom Carter[1], **Sue Ann Seah**[1], **Benjamin Long**[1], **Bruce Drinkwater**[2], **Sriram Subramanian**[1]
Department of Computer Science[1] and Department of Mechanical Engineering[2]
University of Bristol, UK
{t.carter, s.a.seah, b.long, sriram.subramanian, b.drinkwater}@bristol.ac.uk

Figure 1: The UltraHaptics system. Left: the hardware. Centre: a simulation of two focal points, with colour representing phase and brightness representing amplitude. Right: receiving two independent points of feedback while performing a pinch gesture.

ABSTRACT

We introduce *UltraHaptics*, a system designed to provide multi-point haptic feedback above an interactive surface. *UltraHaptics* employs focused ultrasound to project discrete points of haptic feedback through the display and directly on to users' unadorned hands. We investigate the desirable properties of an acoustically transparent display and demonstrate that the system is capable of creating multiple localised points of feedback in mid-air. Through psychophysical experiments we show that feedback points with different tactile properties can be identified at smaller separations. We also show that users are able to distinguish between different vibration frequencies of non-contact points with training. Finally, we explore a number of exciting new interaction possibilities that *UltraHaptics* provides.

Author Keywords

Haptic feedback; touch screens; interactive tabletops.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation: User Interfaces

UIST'13, October 8–11, 2013, St. Andrews, United Kingdom.

http://dx.doi.org/10.1145/2501988.2502018

INTRODUCTION

Multi-touch surfaces have become common in public settings, with large displays appearing in hotel lobbies, shopping malls and other high foot traffic areas. These systems are able to dynamically change their interface allowing multiple users to interact at the same time and with very little instruction. This ability to 'walk-up and use' removes barriers to interaction and encourages spontaneous use. However, in return for this flexibility we have sacrificed the tactile feedback afforded by physical controls.

Most previous research has focused on recreating this feedback on interactive surfaces. This can be achieved through vibration [2, 4] or by physically changing the shape of the surface [19, 20, 15].

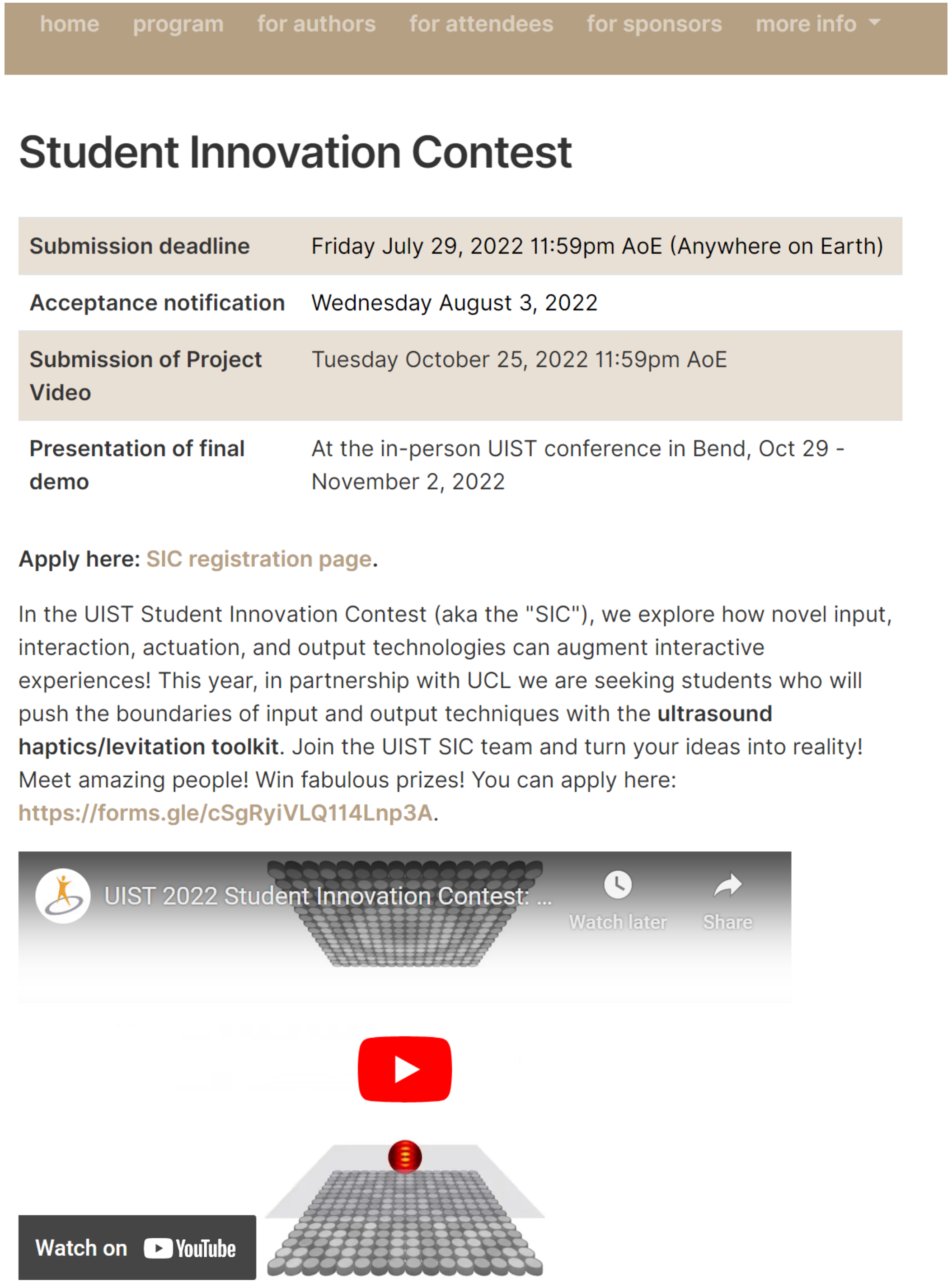
There are situations when receiving haptic feedback before touching the surface would be beneficial. These include when vision of the display is restricted, such as while driving, and when the user doesn't want to touch the device, such as when their hands are dirty. Providing feedback above the surface would also allow for an additional information channel alongside the visual. Previous methods capable of providing this feedback have involved a device worn upon the user's body [33, 30, 32].

In this paper, we introduce *UltraHaptics*, a system that provides haptic feedback above interactive surfaces and requires no contact with either tools, attachments or the surface itself. Instead, haptic sensations are projected through a screen and directly onto the user's hands. It employs the principle of

UIST 13
Cater et.al.

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.

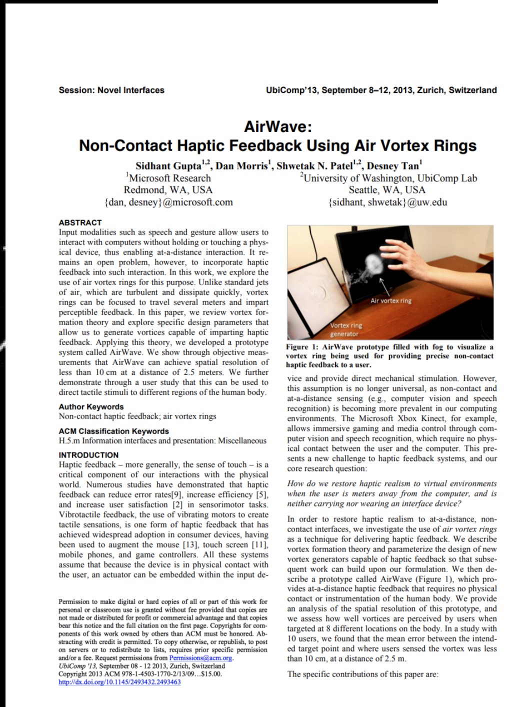
In the UIST Student Innovation Contest (aka the "SIC"), we explore how novel input, interaction, actuation, and output technologies can augment interactive experiences! This year, in partnership with UCL we are seeking students who will push the boundaries of input and output techniques with the **ultrasound 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

Non-Contact Haptic Feedback



Session: Novel Interfaces UbiComp'13, September 8–12, 2013, Zurich, Switzerland

AirWave:
Non-Contact Haptic Feedback Using Air Vortex Rings

Sidhant Gupta[1,2], Dan Morris[1], Shwetak N. Patel[1,2], Desney Tan[1]
[1]Microsoft Research
Redmond, WA, USA
{dan, desney}@microsoft.com
[2]University of Washington, UbiComp Lab
Seattle, WA, USA
{sidhant, shwetak}@uw.edu

ABSTRACT

Input modalities such as speech and gesture allow users to interact with computers without holding or touching a physical device, thus enabling at-a-distance interaction. It remains an open problem, however, to incorporate haptic feedback into such interaction. In this work, we explore the use of air vortex rings for this purpose. Unlike standard jets of air, which are turbulent and dissipate quickly, vortex rings can be focused to travel several meters and impart perceptible feedback. In this paper, we review vortex formation theory and explore specific design parameters that allow us to generate vortices capable of imparting haptic feedback. Applying this theory, we developed a prototype system called AirWave. We show through objective measurements that AirWave can achieve spatial resolution of less than 10 cm at a distance of 2.5 meters. We further demonstrate through a user study that this can be used to direct tactile stimuli to different regions of the human body.

Author Keywords

Non-contact haptic feedback; air vortex rings

ACM Classification Keywords

H.5.m Information interfaces and presentation: Miscellaneous

INTRODUCTION

Haptic feedback – more generally, the sense of touch – is a critical component of our interactions with the physical world. Numerous studies have demonstrated that haptic feedback can reduce error rates[9], increase efficiency [5], and increase user satisfaction [2] in sensorimotor tasks. Vibrotactile feedback, the use of vibrating motors to create tactile sensations, is one form of haptic feedback that has achieved widespread adoption in consumer devices, having been used to augment the mouse [13], touch screen [11], mobile phones, and game controllers. All these systems assume that because the device is in physical contact with the user, an actuator can be embedded within the input device and provide direct mechanical stimulation. However, this assumption is no longer universal, as non-contact and at-a-distance sensing (e.g., computer vision and speech recognition) is becoming more prevalent in our computing environments. The Microsoft Xbox Kinect, for example, allows immersive gaming and media control through computer vision and speech recognition, which require no physical contact between the user and the computer. This presents a new challenge to haptic feedback systems, and our core research question:

How do we restore haptic realism to virtual environments when the user is meters away from the computer, and is neither carrying nor wearing an interface device?

In order to restore haptic realism to at-a-distance, non-contact interfaces, we investigate the use of *air vortex rings* as a technique for delivering haptic feedback. We describe vortex formation theory and parameterize the design of new vortex generators capable of haptic feedback so that subsequent work can build upon our formulation. We then describe a prototype called AirWave (Figure 1), which provides at-a-distance haptic feedback that requires no physical contact or instrumentation of the human body. We provide an analysis of the spatial resolution of this prototype, and we assess how well vortices are perceived by users when targeted at 8 different locations on the body. In a study with 10 users, we found that the mean error between the intended target point and where users sensed the vortex was less than 10 cm, at a distance of 2.5 m.

The specific contributions of this paper are:

Figure 1: AirWave prototype filled with fog to visualize a vortex ring being used for providing precise non-contact haptic feedback to a user.

UbiComp '13, September 08 - 12 2013, Zurich, Switzerland

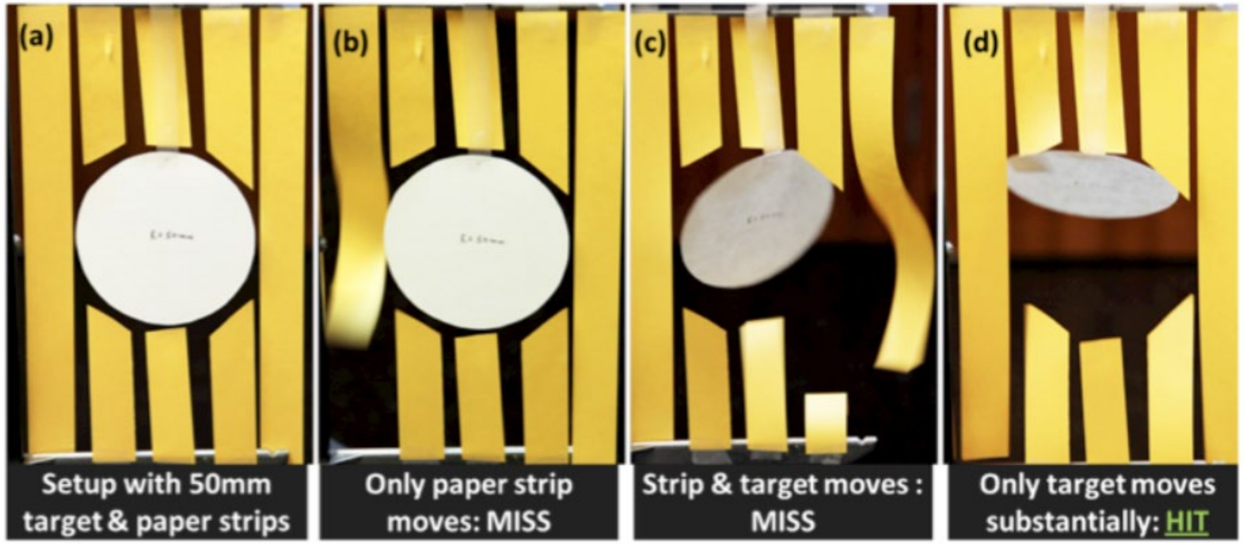
http://dx.doi.org/10.1145/2493432.2493463

UbiComp 13
Gupta et.al.

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.



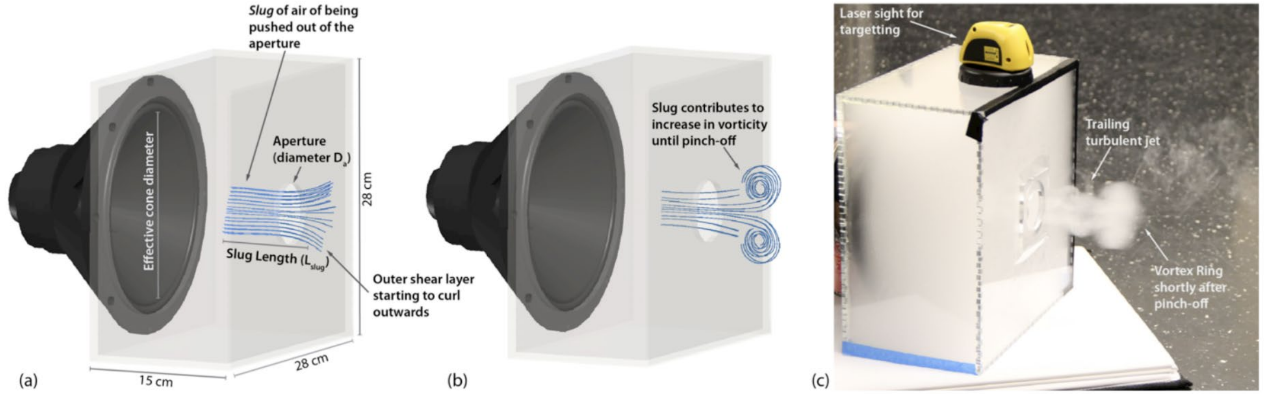
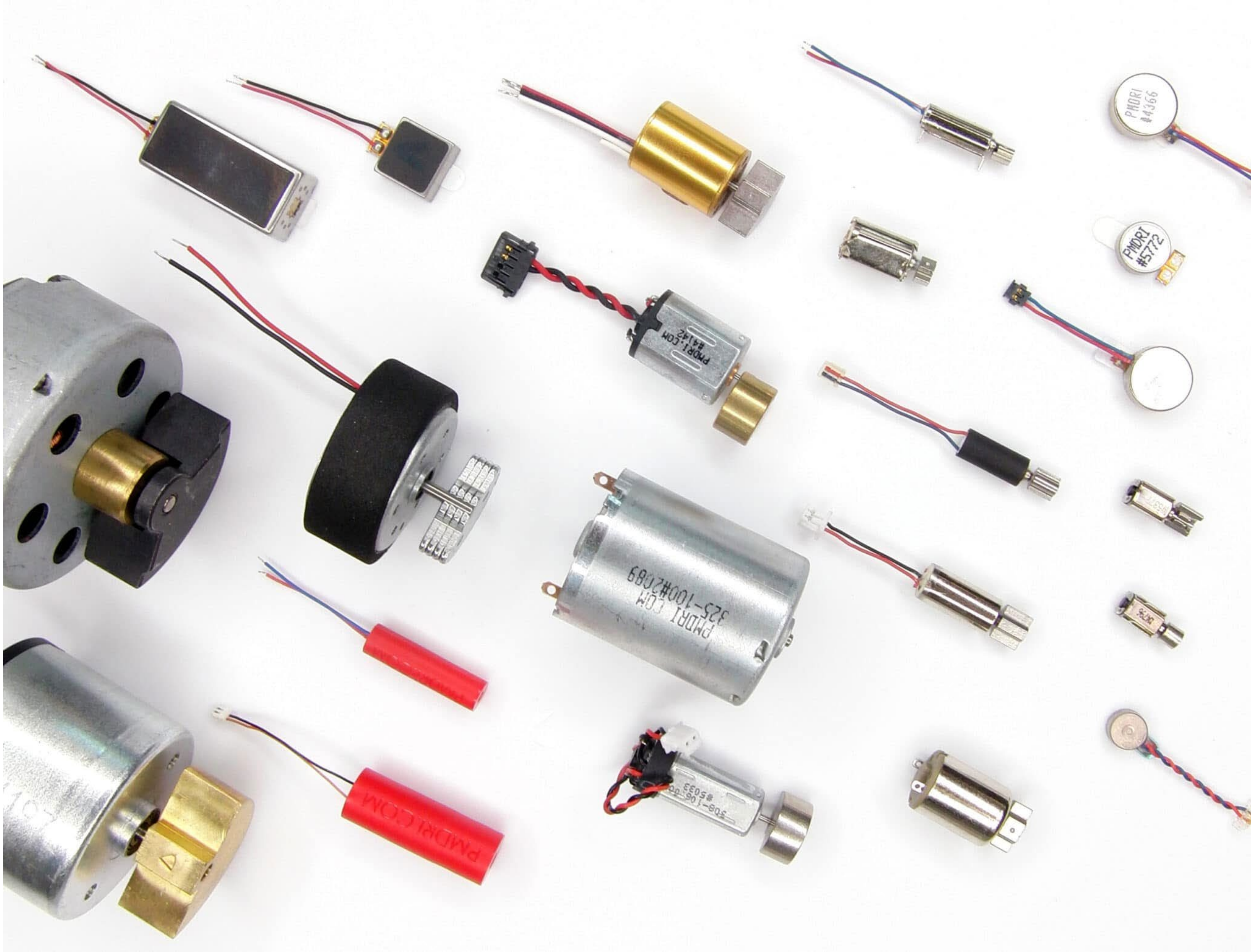


Figure 3: Vortex generator prototype and vortex ring formation process. (a) As the slug of air is pushed out of the aperture, the boundary layer starts to curl outwards as it exits, then (b) vorticity increases until pinch-off, causing the vortex to detach. (c) AirWave prototype filled with fog to visualize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

Vibration feedback



eccentric rotating
mass motors
(ERM)

Shaftless vibration motors

10 mm, ~0.8 g

www.precisionmicrodrives.com

Three pole DC motor
with eccentric coil

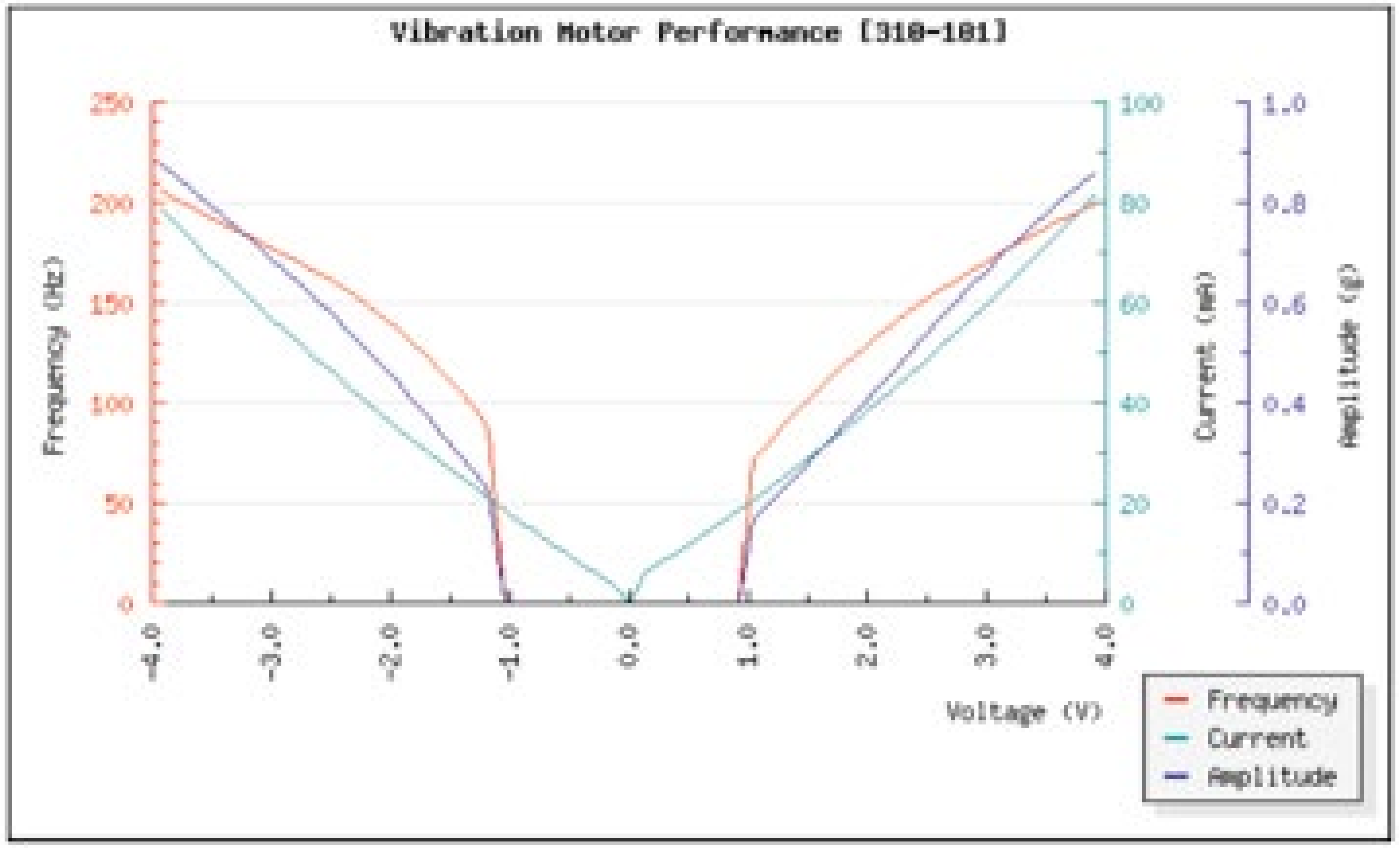
8 mm, ~0.4 g

12 mm, ~0.9 g

12 mm, ~0.6 g

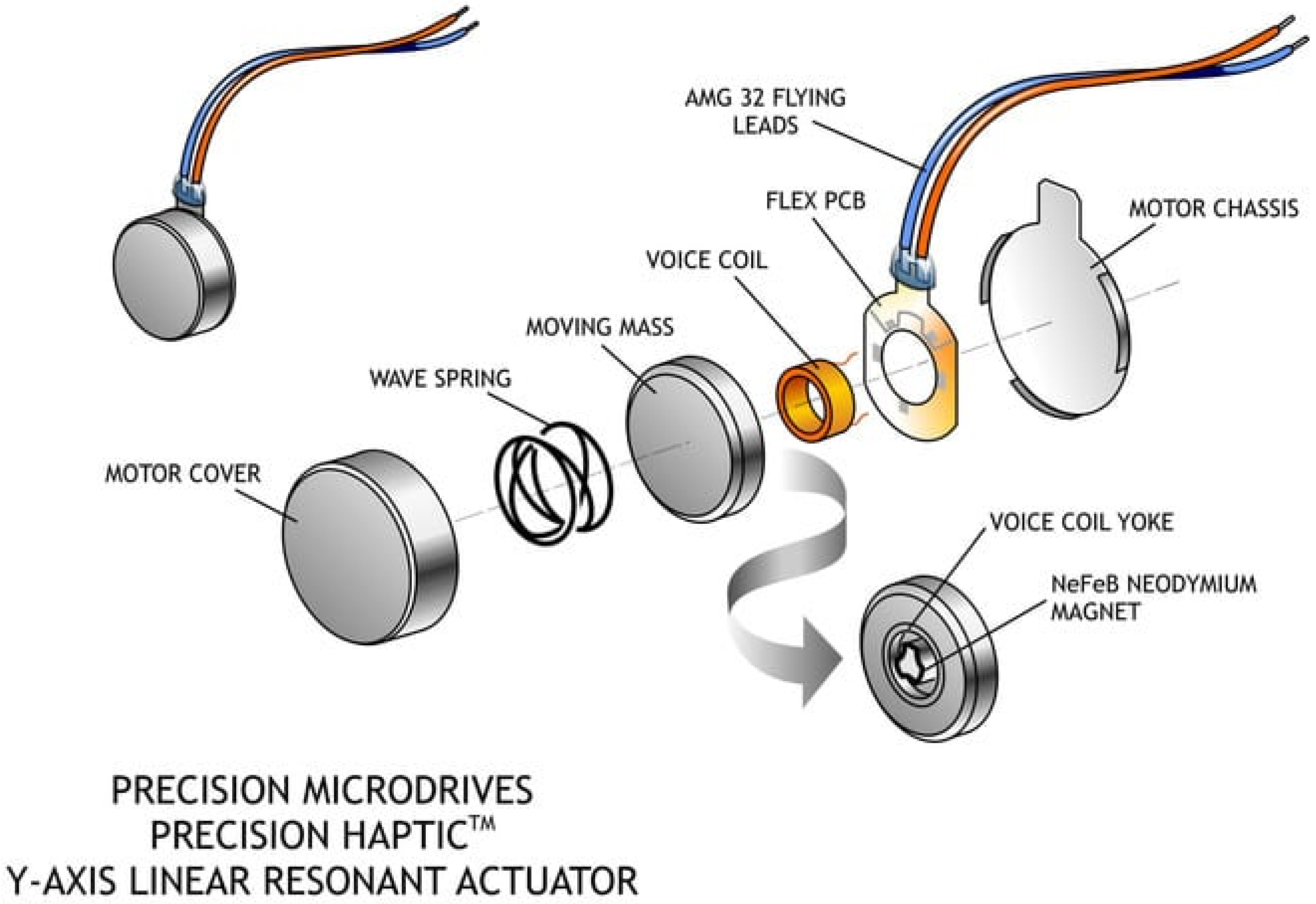
K. J. Kuchenbecker

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

THE UNIVERSITY OF
CHICAGO

MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere

Alex Mazursky
University of Chicago
alexmazursky@uchicago.edu

Shan-Yuan Teng
University of Chicago
tengshanyuan@uchicago.edu

Romain Nith
University of Chicago
rnith@uchicago.edu

Pedro Lopes
University of Chicago
pedrolopes@uchicago.edu

Figure 1: (a) We propose a new type of haptic actuator, which we call MagnetIO, that is comprised of two parts: *any number* of soft interactive patches that can be applied anywhere and *one* battery-powered voice-coil worn on the user's fingernail. (b) When the fingernail-worn device contacts *any* of the interactive patches it detects its magnetic signature and (c) makes the patch *vibrate*. (d) To allow these otherwise passive patches to vibrate, we make them from silicone with regions doped with neodymium powder, resulting in soft and stretchable magnets. (e) This novel decoupling of traditional vibration motors allows users to add interactive patches to their surroundings by attaching them to walls, objects or even other devices or appliances without instrumenting the object with electronics.

ABSTRACT

We propose a new type of haptic actuator, which we call MagnetIO, that is comprised of two parts: one battery-powered voice-coil worn on the user's fingernail and any number of interactive soft patches that can be attached onto any surface (everyday objects, user's body, appliances, etc.). When the user's finger wearing our voice-coil contacts any of the interactive patches it detects its magnetic signature via magnetometer and vibrates the patch, adding haptic feedback to otherwise input-only interactions. To allow these passive patches to vibrate, we make them from silicone with regions doped with polarized neodymium powder, resulting in soft and stretchable magnets. This stretchable form-factor allows them to be wrapped to the user's body or everyday objects of various shapes. We demonstrate how these add haptic output to many situations, such as adding haptic buttons to the walls of one's home. In our technical evaluation, we demonstrate that our interactive patches can be excited across a wide range of frequencies (0-500 Hz) and can be tuned to resonate at specific frequencies based on the patch's geometry. Furthermore, we demonstrate that MagnetIO's vibration intensity is as powerful as a typical linear resonant actuator (LRA); yet, unlike these rigid actuators, our passive patches operate as springs with multiple modes of vibration, which enables a wider band around its resonant frequency than an equivalent LRA.

CCS CONCEPTS

• **Human computer interaction (HCI)**; • **Interaction devices**; • **Haptic devices**;

KEYWORDS

soft magnets, ubiquitous haptics, fabrication

ACM Reference Format:
Alex Mazursky, Shan-Yuan Teng, Romain Nith, and Pedro Lopes. 2021. MagnetIO: Passive yet Interactive Soft Haptic Patches Anywhere. In *CHI Conference on Human Factors in Computing Systems (CHI '21), May 08–13, 2021, Yokohama, Japan.* ACM, New York, NY, USA, 15 pages. https://doi.org/10.1145/3411764.3445543

1 INTRODUCTION

Today's interactive devices increasingly instrument every kind of surface, effectively adding interactive functionality even to passive everyday objects such as walls, tables, and rapidly prototyped objects [14, 28, 64, 75, 76], as well as to the user's body [35, 36, 61]. To enable sensing these interactions, researchers engineered conformable/stretchable sensing devices so that these can comfortably

---

CHI '21, May 08–13, 2021, Yokohama, Japan

ACM ISBN 978-1-4503-8096-6/21/05...$15.00
https://doi.org/10.1145/3411764.3445543

CHI 21
Mazursky et.al.

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

Session: Novel Interfaces UbiComp'13, September 8–12, 2013, Zurich, Switzerland

AirWave:
Non-Contact Haptic Feedback Using Air Vortex Rings

Sidhant Gupta[1,2], **Dan Morris**[1], **Shwetak N. Patel**[1,2], **Desney Tan**[1]
[1]Microsoft Research
Redmond, WA, USA
{dan, desney}@microsoft.com
[2]University of Washington, UbiComp Lab
Seattle, WA, USA
{sidhant, shwetak}@uw.edu

ABSTRACT

Input modalities such as speech and gesture allow users to interact with computers without holding or touching a physical device, thus enabling at-a-distance interaction. It remains an open problem, however, to incorporate haptic feedback into such interaction. In this work, we explore the use of air vortex rings for this purpose. Unlike standard jets of air, which are turbulent and dissipate quickly, vortex rings can be focused to travel several meters and impart perceptible feedback. In this paper, we review vortex formation theory and explore specific design parameters that allow us to generate vortices capable of imparting haptic feedback. Applying this theory, we developed a prototype system called AirWave. We show through objective measurements that AirWave can achieve spatial resolution of less than 10 cm at a distance of 2.5 meters. We further demonstrate through a user study that this can be used to direct tactile stimuli to different regions of the human body.

Author Keywords

Non-contact haptic feedback; air vortex rings

ACM Classification Keywords

H.5.m Information interfaces and presentation: Miscellaneous

INTRODUCTION

Haptic feedback – more generally, the sense of touch – is a critical component of our interactions with the physical world. Numerous studies have demonstrated that haptic feedback can reduce error rates[9], increase efficiency [5], and increase user satisfaction [2] in sensorimotor tasks. Vibrotactile feedback, the use of vibrating motors to create tactile sensations, is one form of haptic feedback that has achieved widespread adoption in consumer devices, having been used to augment the mouse [13], touch screen [11], mobile phones, and game controllers. All these systems assume that because the device is in physical contact with the user, an actuator can be embedded within the input device and provide direct mechanical stimulation. However, this assumption is no longer universal, as non-contact and at-a-distance sensing (e.g., computer vision and speech recognition) is becoming more prevalent in our computing environments. The Microsoft Xbox Kinect, for example, allows immersive gaming and media control through computer vision and speech recognition, which require no physical contact between the user and the computer. This presents a new challenge to haptic feedback systems, and our core research question:

How do we restore haptic realism to virtual environments when the user is meters away from the computer, and is neither carrying nor wearing an interface device?

In order to restore haptic realism to at-a-distance, non-contact interfaces, we investigate the use of *air vortex rings* as a technique for delivering haptic feedback. We describe vortex formation theory and parameterize the design of new vortex generators capable of haptic feedback so that subsequent work can build upon our formulation. We then describe a prototype called AirWave (Figure 1), which provides at-a-distance haptic feedback that requires no physical contact or instrumentation of the human body. We provide an analysis of the spatial resolution of this prototype, and we assess how well vortices are perceived by users when targeted at 8 different locations on the body. In a study with 10 users, we found that the mean error between the intended target point and where users sensed the vortex was less than 10 cm, at a distance of 2.5 m.

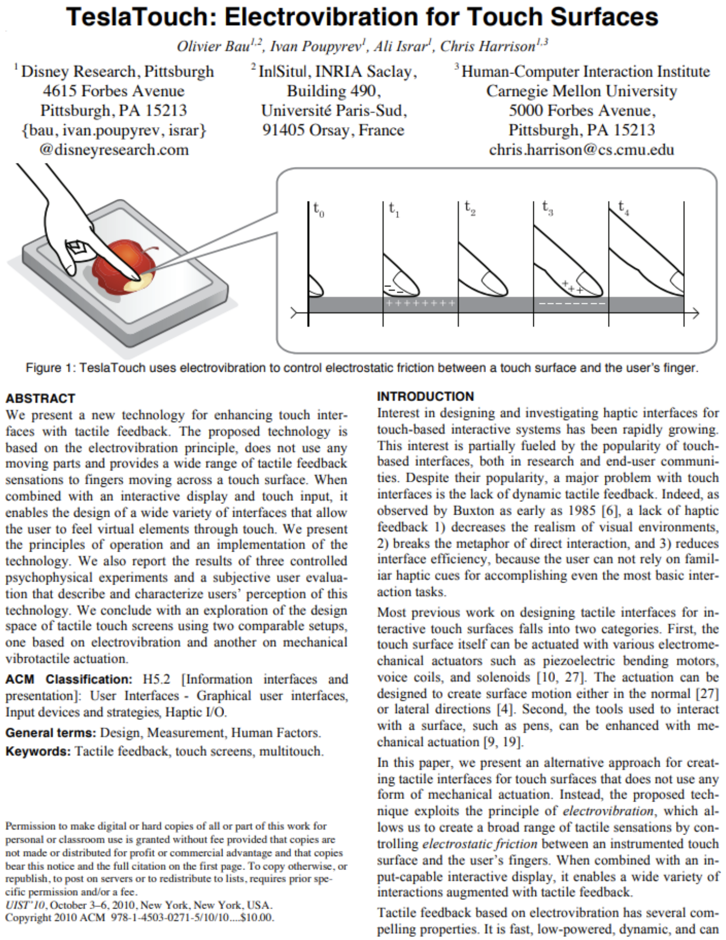
The specific contributions of this paper are:

Figure 1: AirWave prototype filled with fog to visualize a vortex ring being used for providing precise non-contact haptic feedback to a user.

UbiComp '13, September 08 - 12 2013, Zurich, Switzerland

http://dx.doi.org/10.1145/2493432.2493463

UbiComp 13
Gupta et.al.



TeslaTouch: Electrovibration for Touch Surfaces

Olivier Bau[1,2]*, Ivan Poupyrev*[1]*, Ali Israr*[1]*, Chris Harrison*[1,3]
[1] Disney Research, Pittsburgh
4615 Forbes Avenue
Pittsburgh, PA 15213
{bau, ivan.poupyrev, israr}
@disneyresearch.com
[2] In|Situ|, INRIA Saclay,
Building 490,
Université Paris-Sud,
91405 Orsay, France
[3] Human-Computer Interaction Institute
Carnegie Mellon University
5000 Forbes Avenue,
Pittsburgh, PA 15213
chris.harrison@cs.cmu.edu

Figure 1: TeslaTouch uses electrovibration to control electrostatic friction between a touch surface and the user's finger.

ABSTRACT

We present a new technology for enhancing touch interfaces with tactile feedback. The proposed technology is based on the electrovibration principle, does not use any moving parts and provides a wide range of tactile feedback sensations to fingers moving across a touch surface. When combined with an interactive display and touch input, it enables the design of a wide variety of interfaces that allow the user to feel virtual elements through touch. We present the principles of operation and an implementation of the technology. We also report the results of three controlled psychophysical experiments and a subjective user evaluation that describe and characterize users' perception of this technology. We conclude with an exploration of the design space of tactile touch screens using two comparable setups, one based on electrovibration and another on mechanical vibrotactile actuation.

ACM Classification: H5.2 [Information interfaces and presentation]: User Interfaces - Graphical user interfaces, Input devices and strategies, Haptic I/O.

General terms: Design, Measurement, Human Factors.

Keywords: Tactile feedback, touch screens, multitouch.

INTRODUCTION

Interest in designing and investigating haptic interfaces for touch-based interactive systems has been rapidly growing. This interest is partially fueled by the popularity of touch-based interfaces, both in research and end-user communities. Despite their popularity, a major problem with touch interfaces is the lack of dynamic tactile feedback. Indeed, as observed by Buxton as early as 1985 [6], a lack of haptic feedback 1) decreases the realism of visual environments, 2) breaks the metaphor of direct interaction, and 3) reduces interface efficiency, because the user can not rely on familiar haptic cues for accomplishing even the most basic interaction tasks.

Most previous work on designing tactile interfaces for interactive touch surfaces falls into two categories. First, the touch surface itself can be actuated with various electromechanical actuators such as piezoelectric bending motors, voice coils, and solenoids [10, 27]. The actuation can be designed to create surface motion either in the normal [27] or lateral directions [4]. Second, the tools used to interact with a surface, such as pens, can be enhanced with mechanical actuation [9, 19].

In this paper, we present an alternative approach for creating tactile interfaces for touch surfaces that does not use any form of mechanical actuation. Instead, the proposed technique exploits the principle of *electrovibration*, which allows us to create a broad range of tactile sensations by controlling *electrostatic friction* between an instrumented touch surface and the user's fingers. When combined with an input-capable interactive display, it enables a wide variety of interactions augmented with tactile feedback.

Tactile feedback based on electrovibration has several compelling properties. It is fast, low-powered, dynamic, and can

UIST'10, October 3–6, 2010, New York, New York, USA.

UIST 10
Bau et.al.