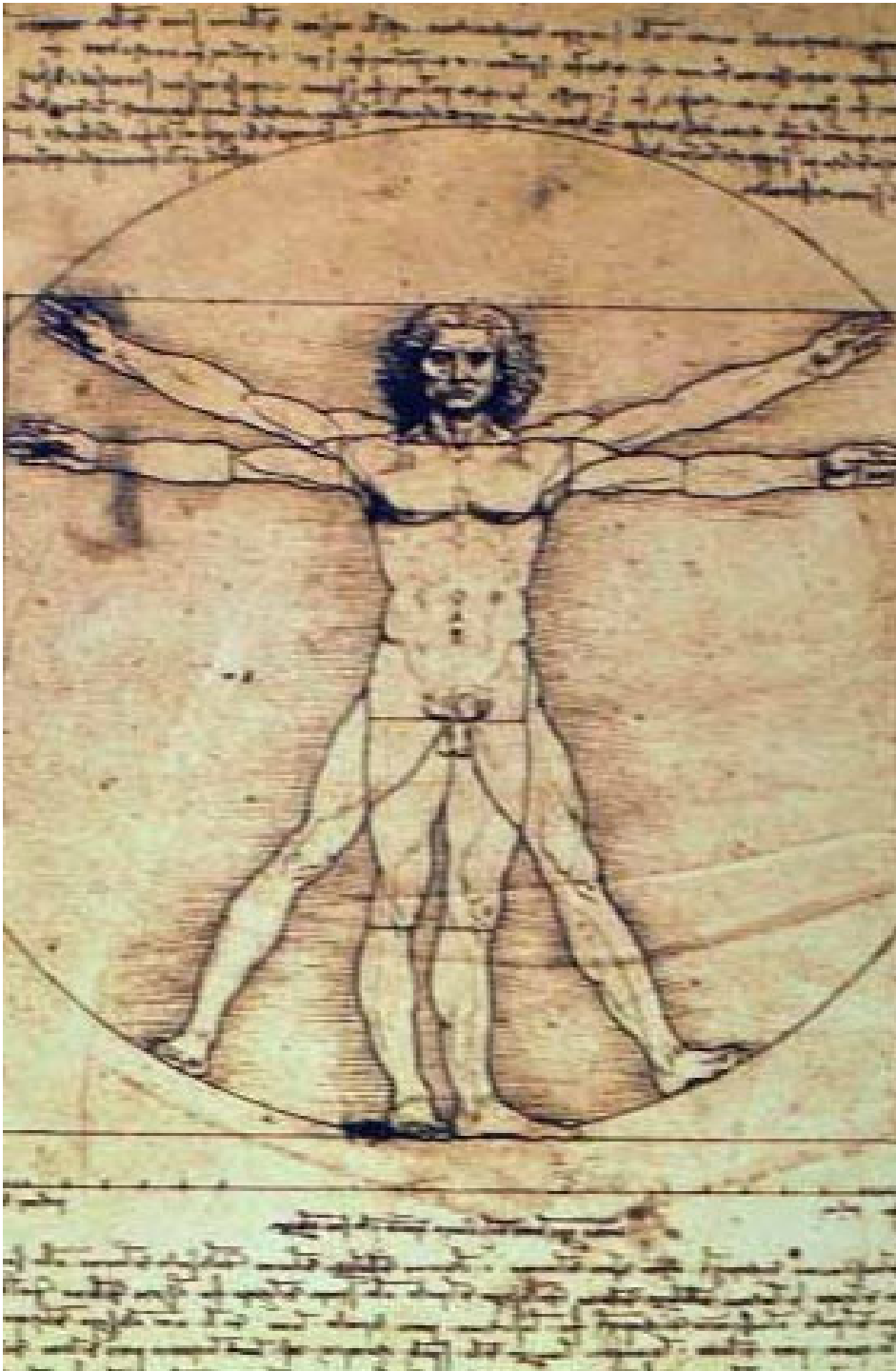




Interactive System インタラクティブ システム特論 (7)

Hiroyuki Kajimoto
kajimoto@uec.ac.jp
Twitter kajimoto



Schedule

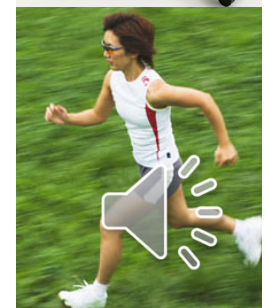
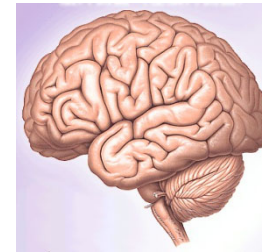
講義番号/No.	講義日/Date	内容/Contents	pdf	video	レポート締切日/Report Deadline
1	4/11	人間計測手法／Measuring Human	[pdf] 2024年版	video	4/18
-	4/18	補足（オンライン・オンデマンド）/Supplemental (online, on demand)			
2	4/25	視覚／Human Vision System	[pdf] 2024年版	video	5/02
3	5/02	視覚センシング／Visual Sensing	[pdf] 2024年版	video	5/09
4	5/09	視覚ディスプレイ／Visual Display	[pdf] 2024年版	video	5/16
5	5/16	聴覚、聴覚インタフェース／Auditory Interface	[pdf] 2024年版	video	5/23
6	5/23	触覚、触覚インタフェース／Tactile Interface	[pdf] 2024年版	video	5/30
7	5/30	触覚、触覚インタフェース 2／Tactile Interface2	[pdf] 2024年版	video	6/06
-	6/06	春ターム試験日のため休講/Class cancelled			
8	6/13	力覚、力覚インタフェース／Haptic Interface	[pdf] 2024年版	video	6/20
9	6/20	移動感覚インタフェース／Locomotion Interface	[pdf] 2023年版	video	6/27
-	6/27	プレゼンビデオ準備/Presentation video upload	[pdf]	-	7/04
-	-	プレゼンビデオ評価（1）/Watch group 1 video	-	-	7/11
-	-	プレゼンビデオ評価（2）/Watch group 2 video	-	-	7/18
-	-	プレゼンビデオ評価（3）/Watch group 3 video	-	-	7/25

Google Classroomのアナウンスに注意してください。



Outline of the lecture

1. 人間計測手法／Measuring Human
2. 視覚／Human Vision System
3. 視覚センシング／Visual Sensing
4. 視覚ディスプレイ／Visual Display
5. 聴覚、聴覚インタフェース／Auditory Interface
6. 触覚、触覚インタフェース／Tactile Interface
7. 触覚、触覚インタフェース2／Tactile Interface
8. 力覚、力覚インタフェース／Haptic Interface
9. 移動感覚インタフェース／Locomotion Interface



触覚ディスプレイの応用分野の方向性

Elements of application for tactile display

- **Touch Panel & Mobile**
 - 市場が巨大。差別化要素としての触覚
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 - 身体全体への触覚提示により、触覚にも臨場感を生じる
- **Tactile AR**
 - 触覚を現実世界で使うことでAR化する



Touch-Panelの課題:文房具(入力装置)として未熟



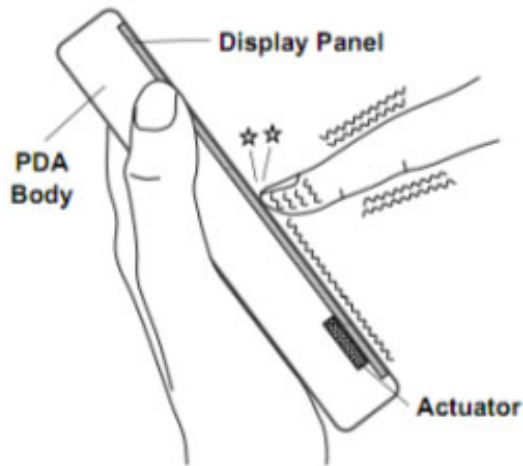
ユーザの意図を汲み取るセンシング&認識の問題と、
ユーザにフィードバックする情報提示の問題

インタラクション研究としては、前者のセンシングとジェスチャ認識に関するものが非常に多いですが、この授業では後者の触覚提示側の事例を取り上げます。

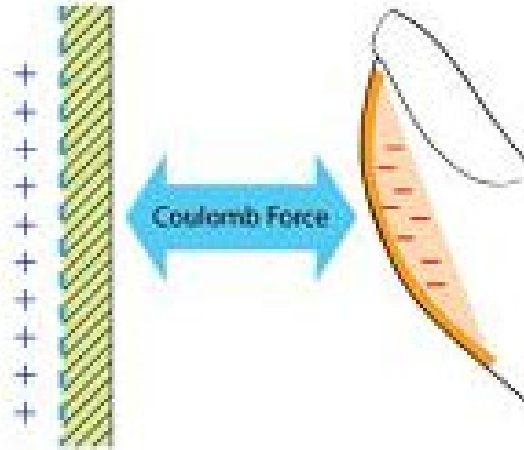
While interaction research on touch-panel mainly focuses on sensing and gesture recognitions, we show tactile display examples.



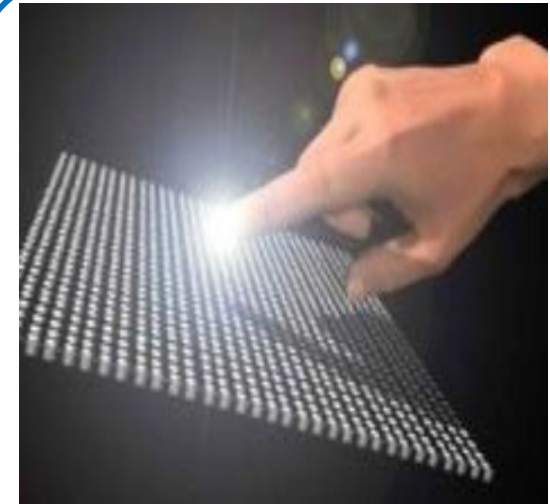
タッチパネルに触覚を付与する Make touch panel tangible.



Active Click
(Fukumoto, CHI2001)



TeslaTouch
(Bau, UIST2010)



Skeletouch
(Kajimoto, 2012)

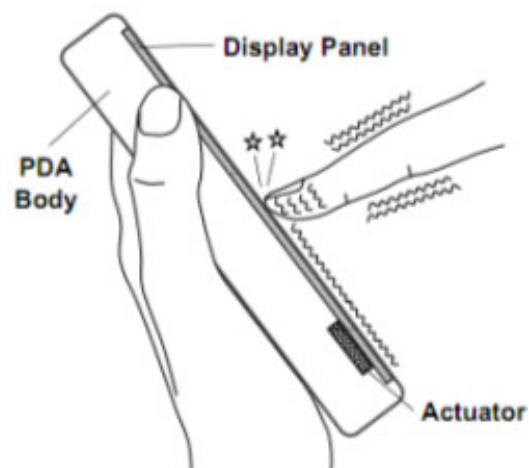
「透明」という制約のため、可能な手法は限定

Transparency is required not to obstruct visual display

- ✓ 全面振動
- ✓ 摩擦制御
- ✓ 神経駆動



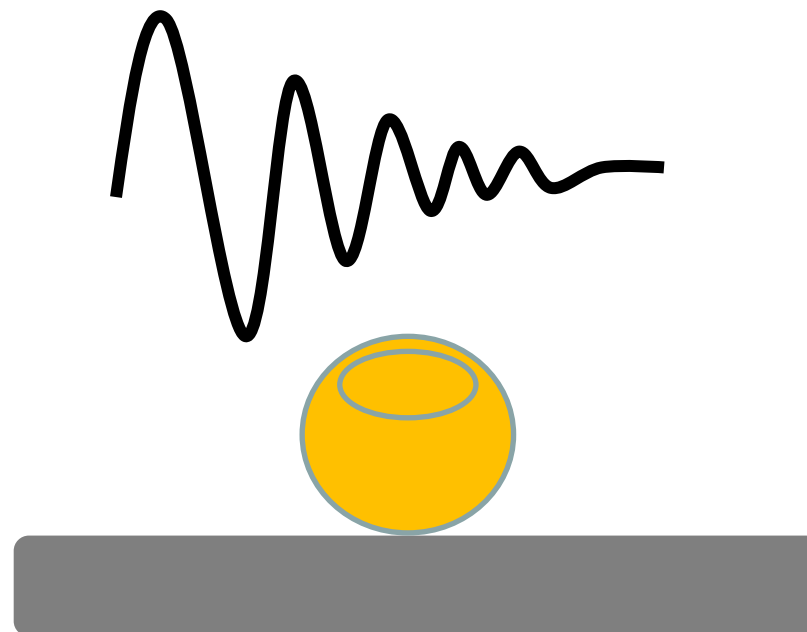
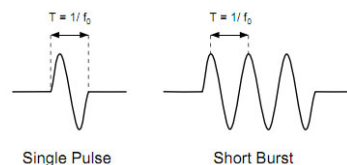
全面振動 Whole plate vibration



Active Click
(Fukumoto, CHI2001)



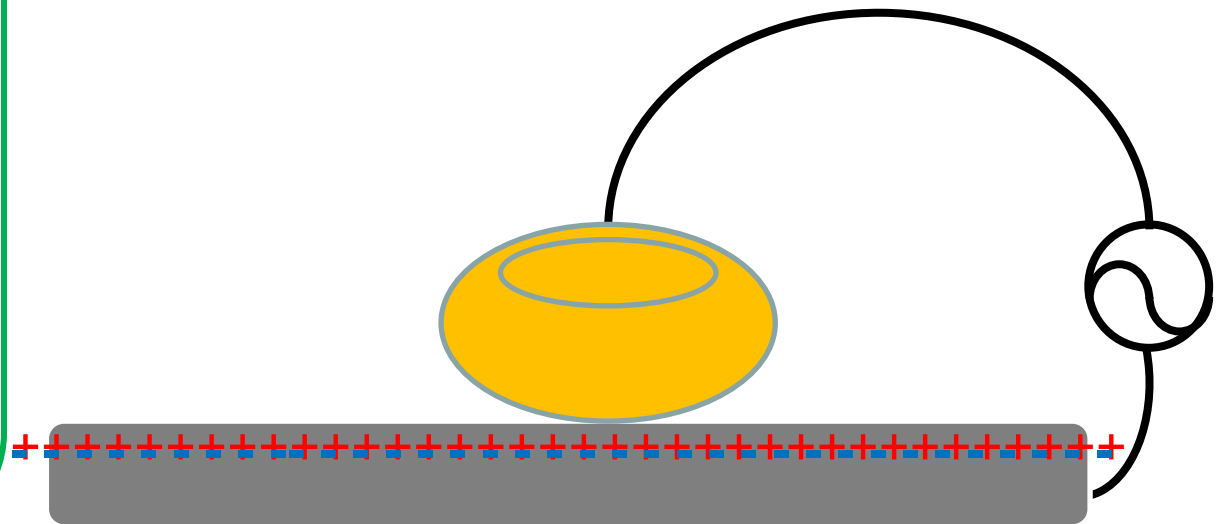
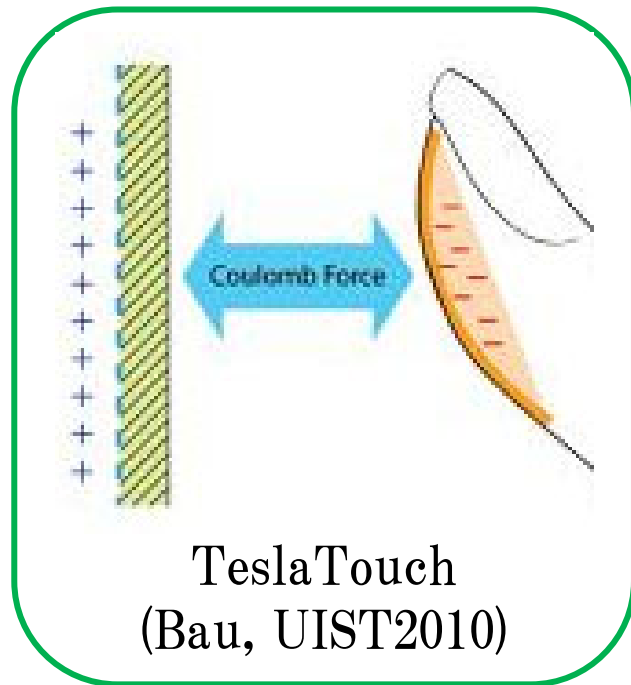
図 1: アクチュエータの設置状況
PDA の筐体に貼り付けている。



	空間解像度	能動性
全面振動	Low (finger size)	Active



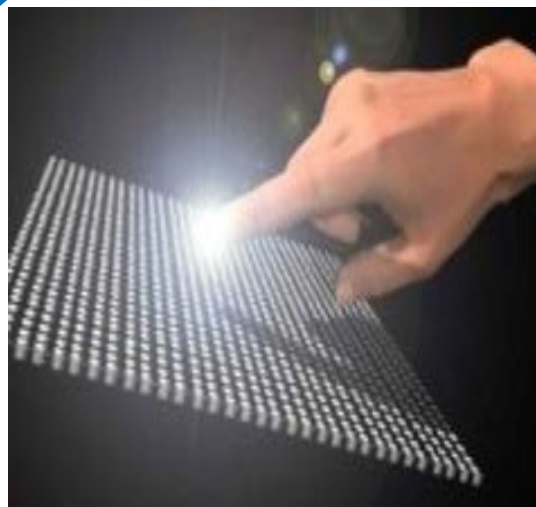
摩擦係数の制御 Friction modulation



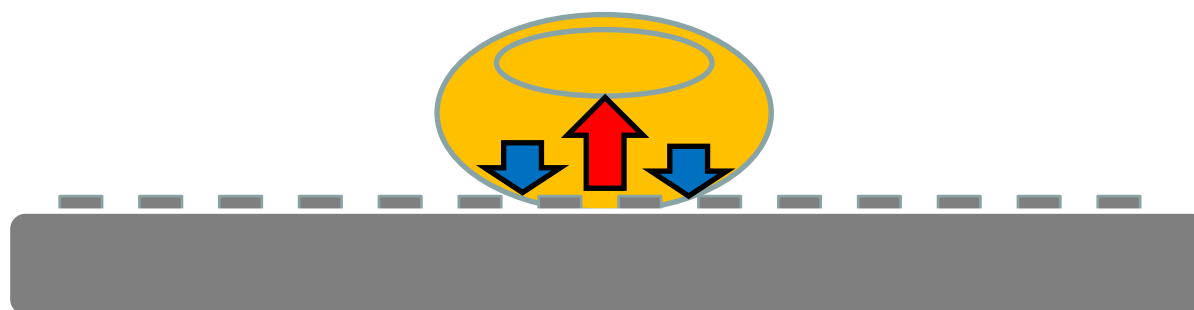
	空間解像度	能動性
全面振動	Low (finger size)	Active
摩擦制御	Potentially High	Passive



電気刺激による直接駆動 Direct electrical stimulation



Skeletouch
(Kajimoto, 2012)



	空間解像度	能動性
全面振動	Low (finger size)	Active
摩擦制御	Potentially High	Passive
神経駆動	High	Active



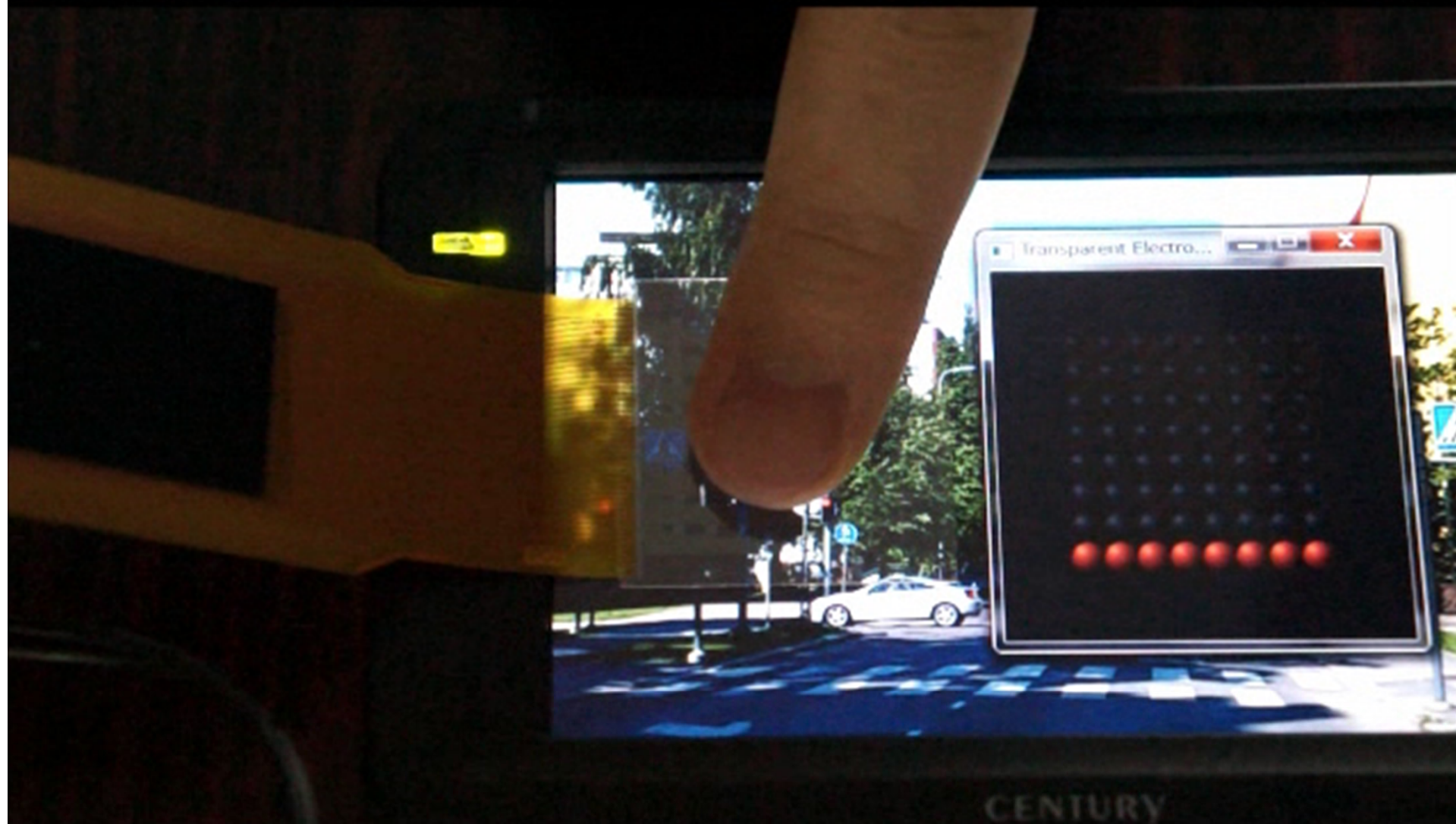
透明電極(2012. Mar)



64 transparent electrodes are made of ITO
(Indium, Tin, Oxide)

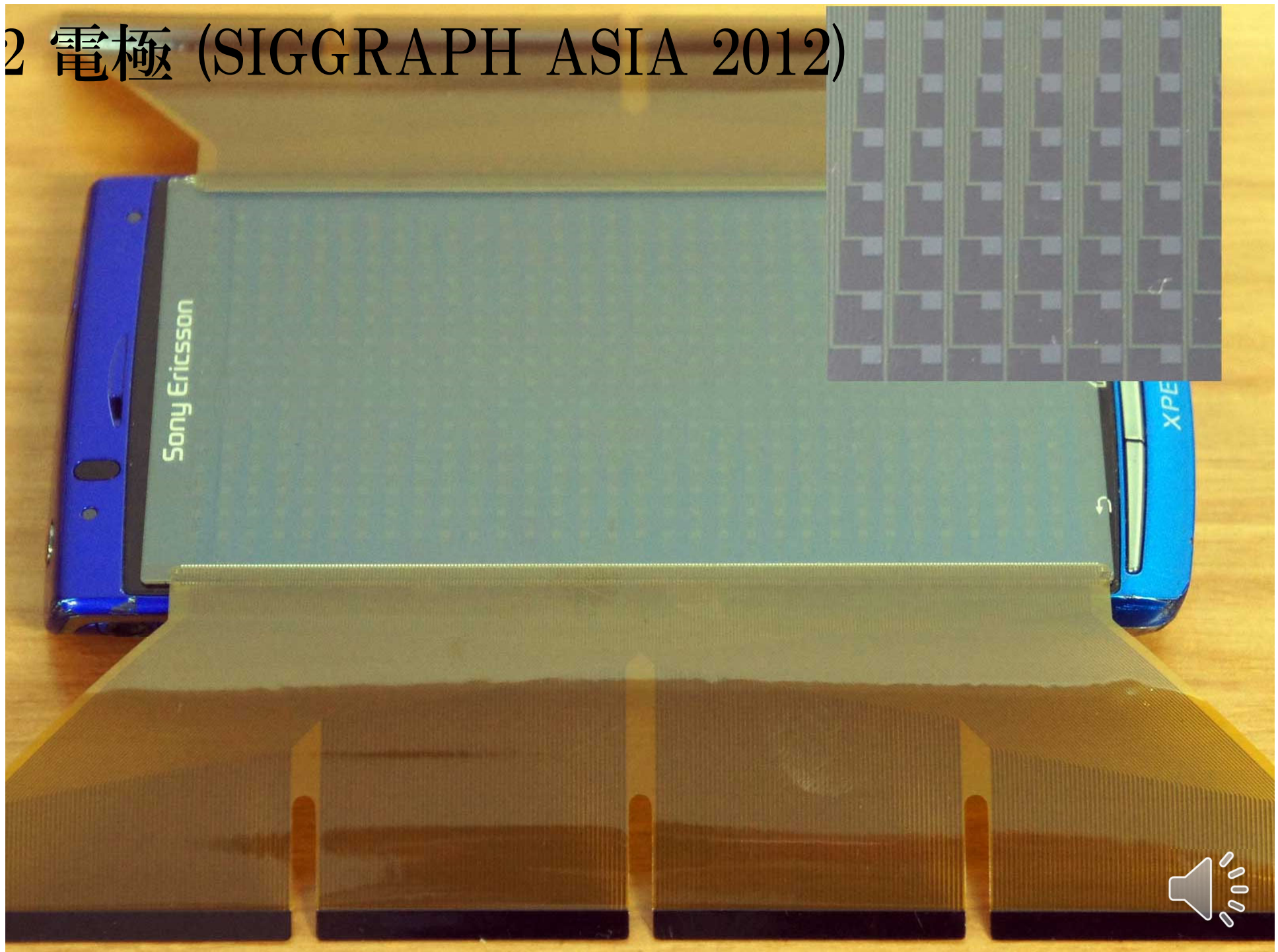


刺激と計測



はじめからタッチパネルの機能を備えている

2 電極 (SIGGRAPH ASIA 2012)



透明という制約を外す Avoid limitation from transparency

(CHI2016) Haptic Edge Display for Mobile Tactile Interaction

Sungjune Jang, Lawrence H Kim, Kesler Tanner, Hiroshi Ishii, Sean Follmer



<https://www.youtube.com/watch?v=R1InHeWsSMU>

モバイルデバイスの側面に1次元触覚提示を行う. 画面の自然な拡張として機能.



透明という制約を外す Avoid limitation from transparency

(CHI2016) Tactile Presentation to the Back of a Smartphone with Simultaneous Screen Operation. Sugarragchaa Khurelbaatar, Yuriko Nakai, Ryuta Okazaki, Vibol Yem, Hiroyuki Kajimoto.



https://www.youtube.com/watch?v=7Dv-9po_vcg

- モバイルデバイスの背面に触覚提示を行う。電気刺激を用いる。
- Presenting tactile patterns at the back of the smartphone



(UIST2019) Tactlets: Adding Tactile Feedback to 3D Objects Using Custom Printed Controls

Tactlets

Adding Tactile Feedback to 3D Objects Using Custom Printed Controls

Daniel Groeger¹, Martin Feick¹,
Anusha Withana² and Jürgen Steimle¹

ACM UIST '19

¹ Saarland University, Saarland Informatics Campus

² School of Computer Science, The University of Sydney



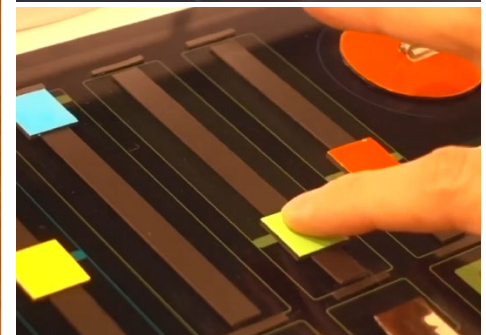
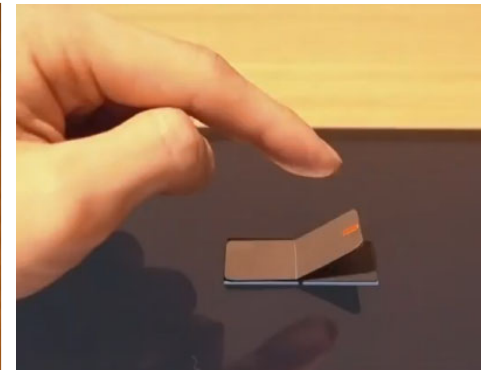
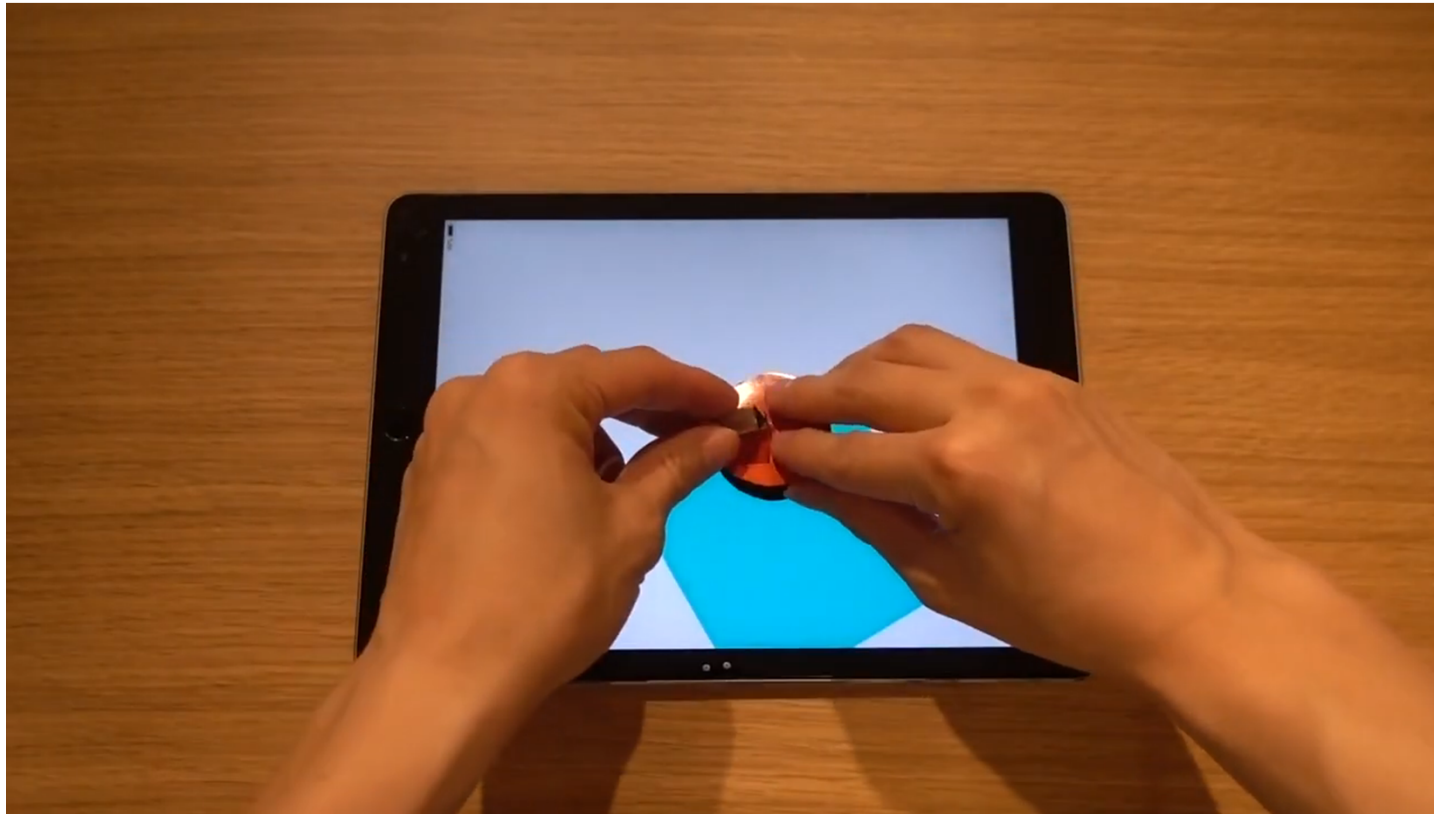
Saarland Informatics Campus **SIC**



- モバイルデバイスの側面に電気刺激

アクチュエータによる制約という前提を見直す

(CHI2019) Magnetact: Magnetic-sheet-based Haptic Interfaces for Touch Devices,
Kentaro Yasu



<https://www.youtube.com/watch?v=4V45hoqSMjk>

- 磁石シートを使ったパッシブな触覚提示。予めシートにパターンを着磁しておくことで、スライダ、回転ボリューム、スイッチ等幅広い触感を提示可能。
- Passive type haptic interface using magnetic sheet. Tactile pattern is “printed” on the sheet using magnet.



アクチュエータによる制約という前提を見直す

[Haptics Symposium 2020] StickyTouch: A Tactile Display with Changeable Adhesive Distribution
by Yoshitaka Ishihara, Yuichi Itoh, Ryo Shirai, Kazuyuki Fujita, Kazuki Takashima, and Takao Onoye



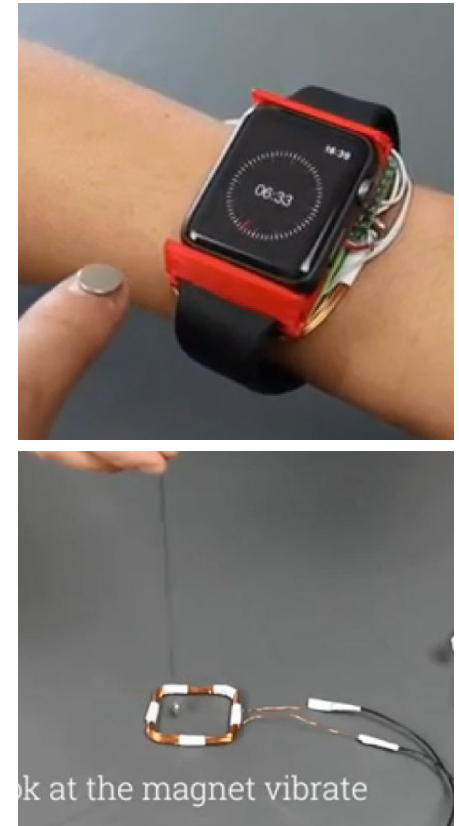
<https://www.youtube.com/watch?v=PzQbHAJUNnY>

- 温度変化によって粘着性が大きく変化するシートを使い、タッチディスプレイを作成。



アクチュエータによる制約という前提を見直す

(CHI2019) Magnetips: Combining Fingertip Tracking and Haptic Feedback for Around-Device Interaction.
Jess McIntosh, Paul Strohmeier, Jarrod Knibbe, Sebastian Boring, Kasper Hornbæk



<https://www.youtube.com/watch?v=-IBZ2xzx2jU>

非接触触覚の一つの形。「磁石だけは載せる」ことを許容することで、

- 地磁気コンパスによる触覚インタフェース
- 振動提示

の両方を可能とする。

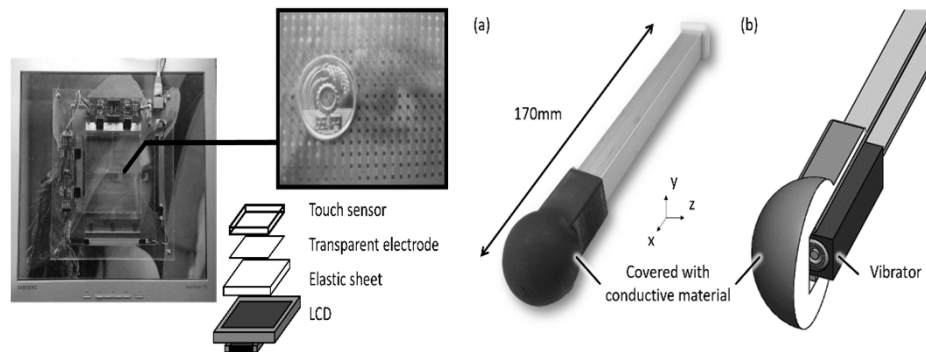


タッチパネルの時間遅延 Latency of touchpanel

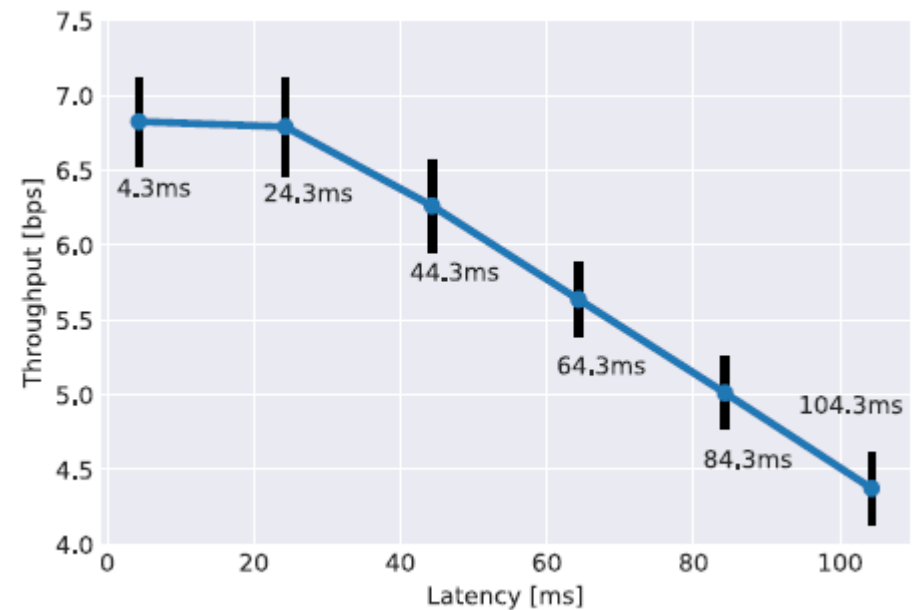
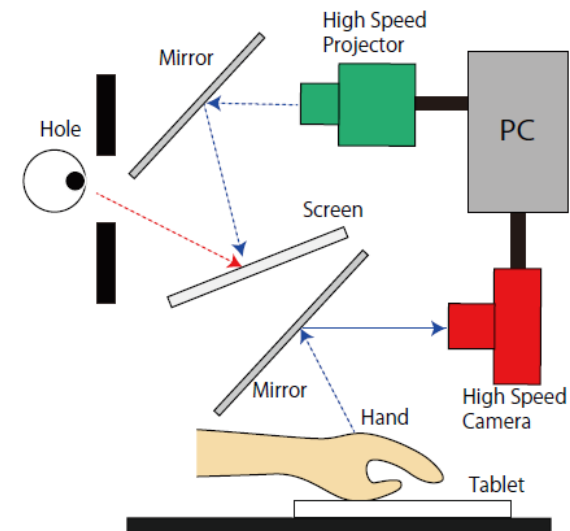


Microsoft Research Applied Sciences Group: High Performance Touch (2012)

<https://www.youtube.com/watch?v=vOvQCPLkPt4>

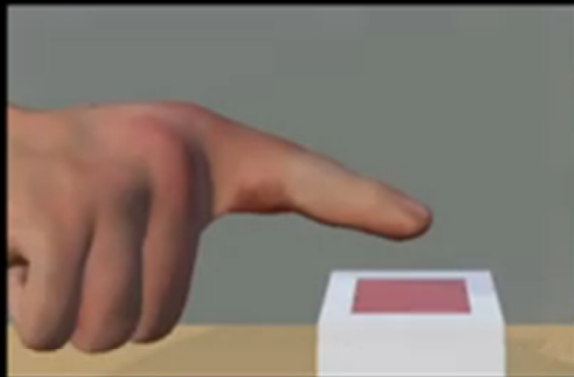


T. Hachisu, H. Kajimoto: Vibration Feedback Latency Affects Material Perception during Rod Tapping Interactions. IEEE Trans. on Haptics, Vol.10, No.2, pp.288-295, 2017
叩き動作では5ms程度の遅延で知覚に影響が生じ始める



門脇他：身体感覚と視覚情報にずれが生じる没入環境における低遅延な映像のユーザーへの影響、日本VR学会論文集(2019)
高速プロジェクタ+高速カメラによる低遅延システムでフックの法則の実験等で評価。24.3msまではほぼ平坦

Using tangible object is challenging in VR
as error is inherent to tracking systems



Virtual
Gap



Real
Contact



Virtual
Interpenetration

<https://www.youtube.com/watch?v=aopB5rFlacc>

- 物体表面の静電容量センシングでタッチ近傍の距離を正確に把握し、触覚的な触った瞬間と視覚的な触った瞬間を一致させる。光学的計測と融合。
- VRの中で触覚は実物を使う、という場面において有用。



触覚ディスプレイの応用分野の方向性

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Emotion (情動)



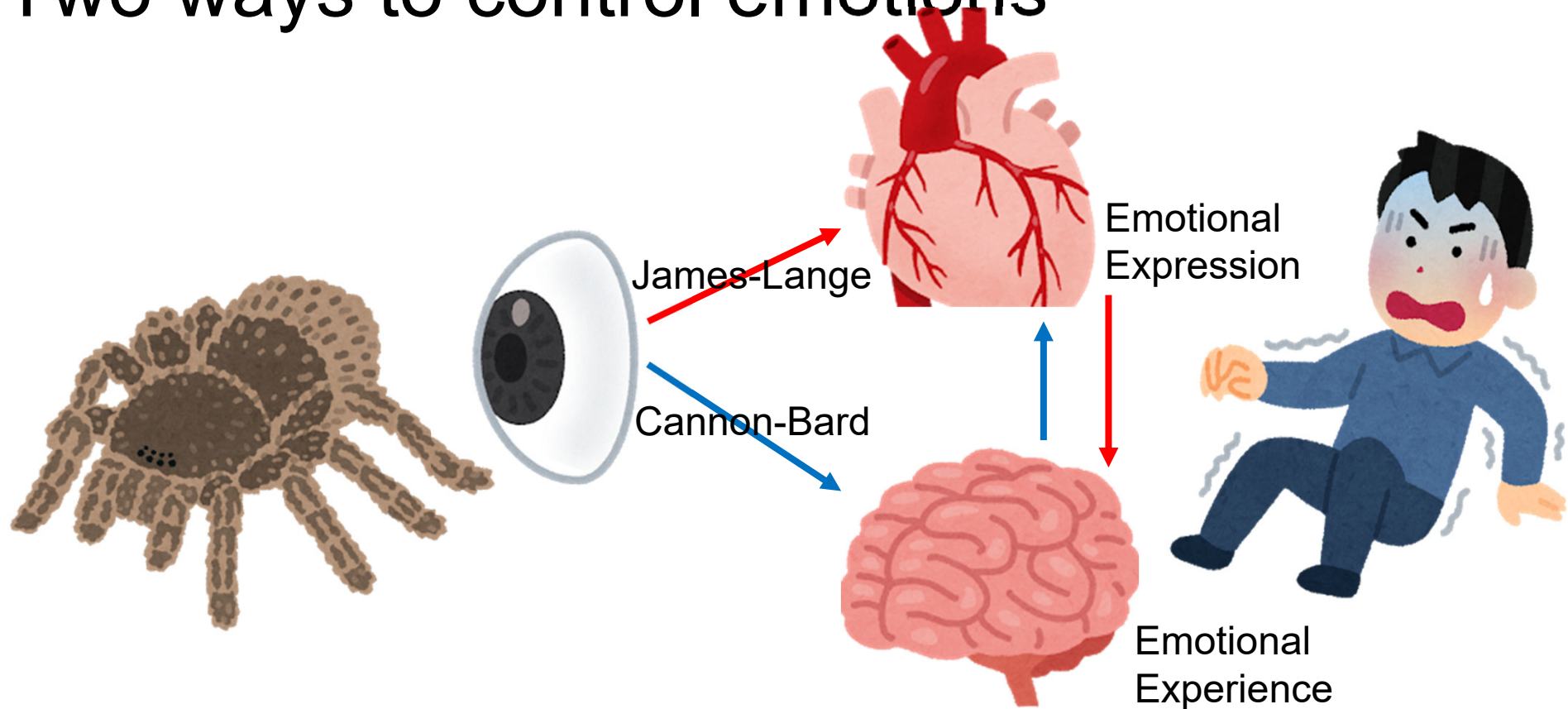
Lemmens, P. Cromptvoets, F. Brokken, D. van den Eerenbeemd, J. de Vries, G.-J. ,
“A body-conforming tactile jacket to enrich movie viewing,” Haptics Symposium 2009.

映画鑑賞時に、シーンにあった情動を誘起する振動パターンを提示



心を相手にする:二つの考え

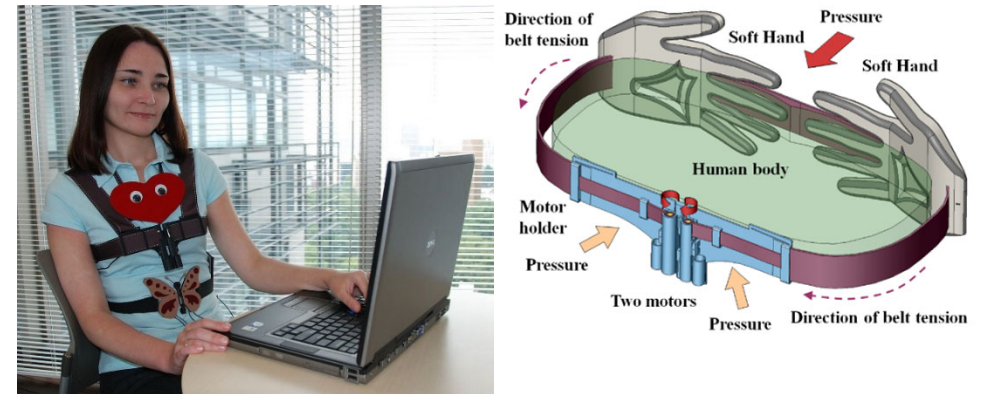
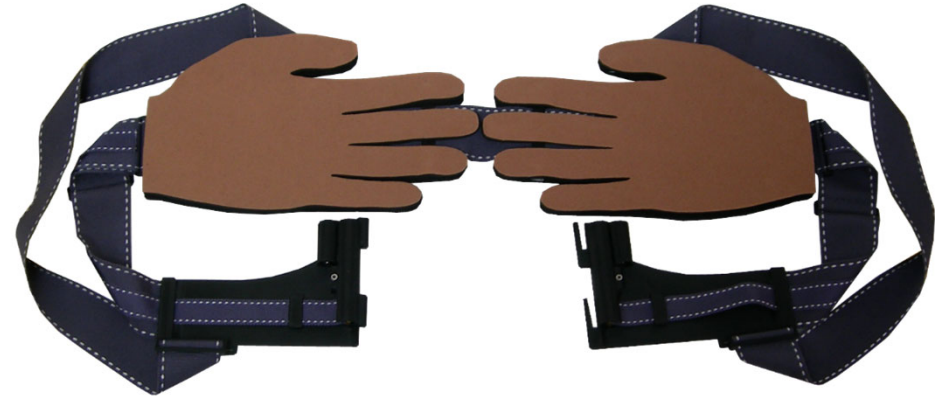
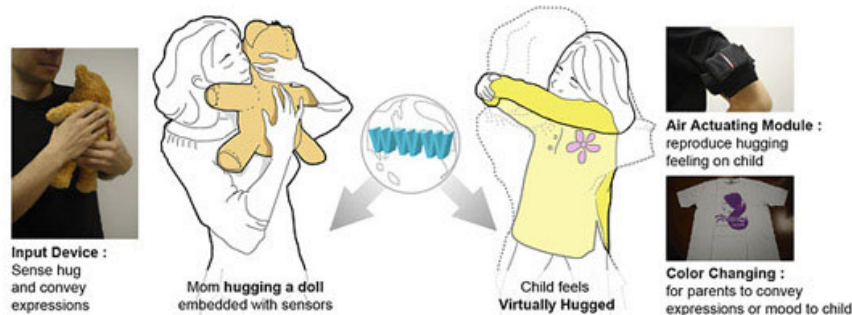
Two ways to control emotions



- コンテンツのリアリティ・臨場感を向上させ、それによって情動を増幅。
- 情動によって生じる自己の「生理反応」を提示し、それによって情動を誘導。
- Contents is “experienced” and it induces emotional state.
- Stimuli directly elicit emotional state, and it is recognized as emotional experience.



Affection(愛情、愛着)



Teh, James & Cheok, Adrian & Choi, Yongsoon & Fernando, Charith & Peiris, Roshan & Fernando, Owen. (2009). Huggy pajama: a parent and child hugging communication system.

D. Tsetserukou, A. Neviarouskaya, H. Prendinger, N. Kawakami, M. Ishizuka, S. Tachi, "Enhancing Mediated Interpersonal Communication through Affective Haptics" INTETAIN'09



Hair as an Emotional Display



Hairs are affected not only by surrounding environment (wind and temperature), but also by our own mind. When we drive hairs synchronizing with emotional contents (ex. scary voice), **our emotional reaction is increased.**



Tactile presentation to ears



K.Aou, A.Ishii, M.Furukawa, S.Fukushima, H.Kajimoto: The Enhancement of Hearing using a Combination of Sound and Skin Sensation to the Pinna, UIST2010

<http://shogofukushima.com/?p=6>



Tactile presentation to ears

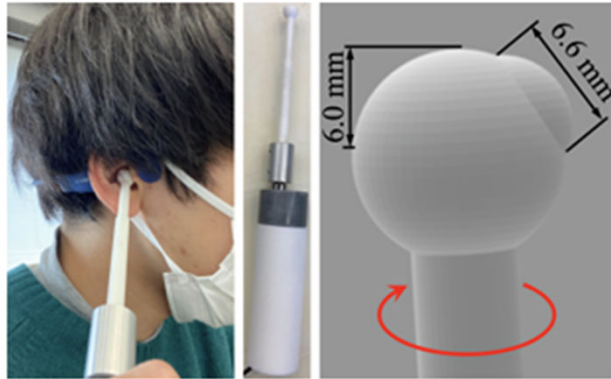


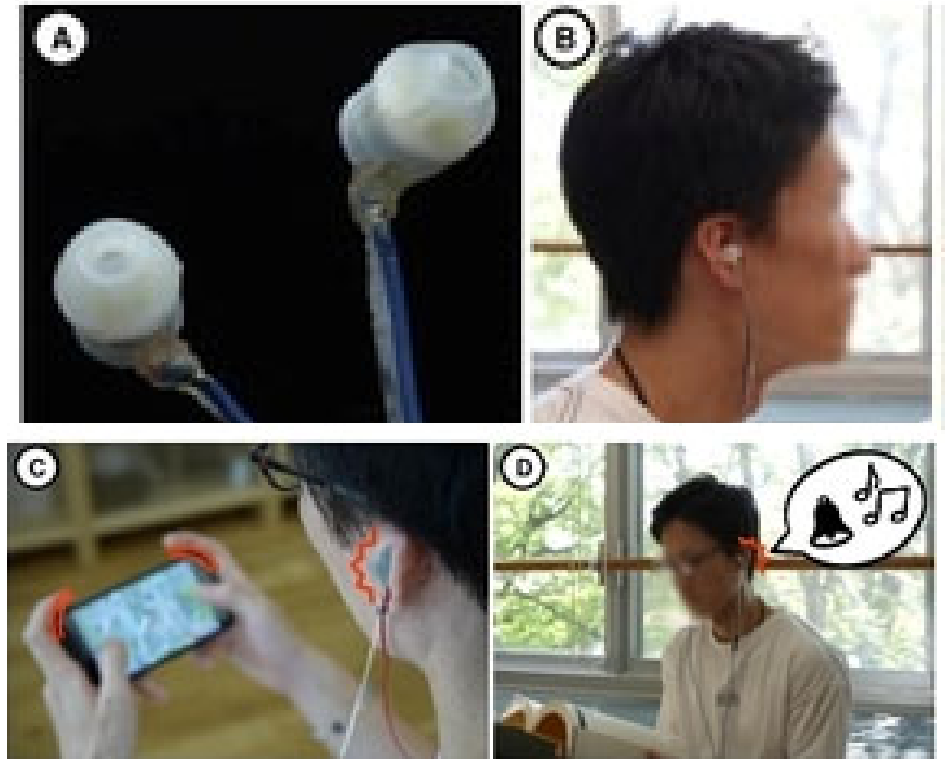
図 1: 左) 実験の様子. 中央) 刺激子全体. 右) 刺激子の先端および回転方向

耳の穴の中に刺激を加えるとポジティブ感情がよりよく出る。

Positive emotions are better produced when stimulation is applied in the ear canal.

後藤、岡本、VRSJ2023、1D1-10

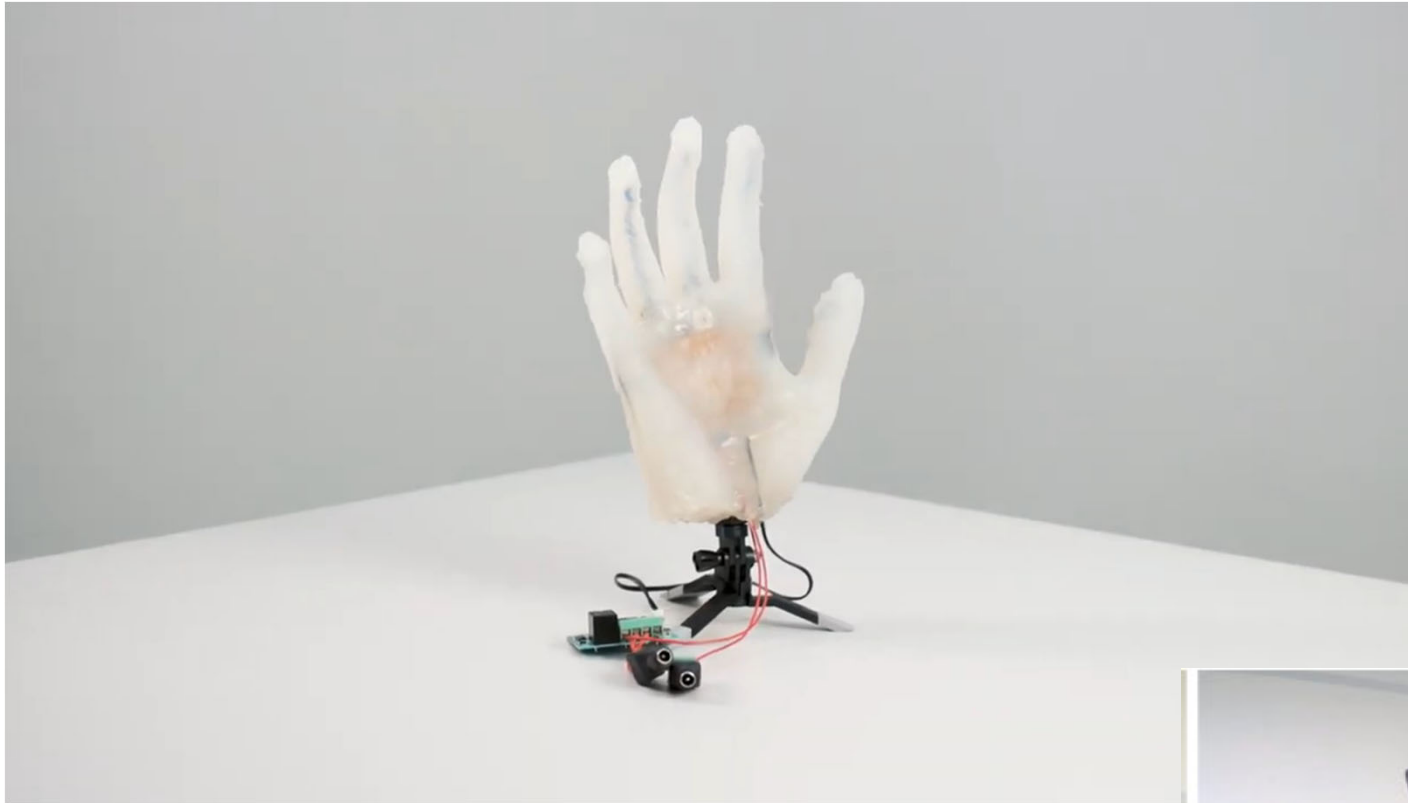
耳孔摩擦刺激による聴覚コンテンツの感情変化



[CHI2025] FlexEar-Tips: Shape-Adjustable Ear Tips Using Pressure Control

<https://dl.acm.org/doi/10.1145/3706598.3714177>

(CHI2020) A Human Touch: Social Touch Increases the Perceived Human-likeness of Agents in Virtual Reality, Matthias Hoppe;Beat Rossmys;Daniel Peter Neumann;Stephan Streuber;Albrecht Schmidt;Tonja-Katrin Machulla



- <https://www.youtube.com/watch?v=kE-6nDyVtKs>
- 人らしい手を実際に触れさせることでSocial Engageを強める。



(CHI2020) Designing and Evaluating Calmer, a Device for Simulating Maternal Skin-to-Skin Holding for Premature Infants, Sabrina Hauser;Melinda J. Suto;Liisa Holsti;Manon Ranger;Karon E. MacLean



Designing and Evaluating Calmer, a Device for Simulating Maternal Skin-to-Skin Holding for Premature Infants

Sabrina Hauser¹, Melinda Suto², Liisa Holsti², Manon Ranger³, Karon E. MacLean⁴

¹Umeå Institute of Design, Umeå University, Umeå, Sweden, sabrina.hauser@umu.se;

²Dept. of Occupational Science & Occup. Therapy, University of British Columbia, Vancouver, Canada, {msuto, liisa.holsti}@ubc.ca;

³School of Nursing, University of British Columbia, Vancouver, Canada, manon.ranger@ubc.ca;

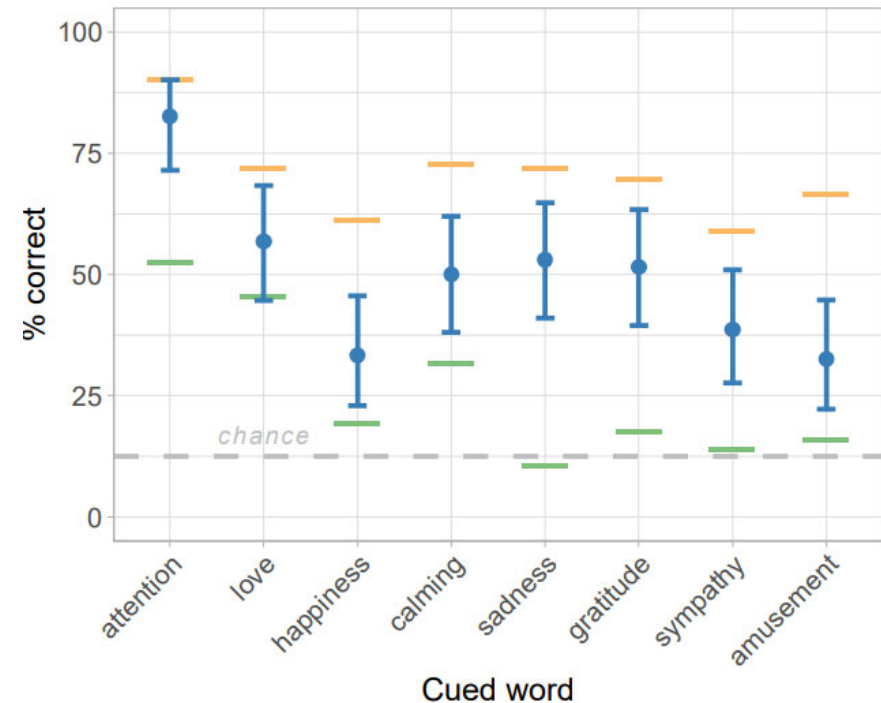
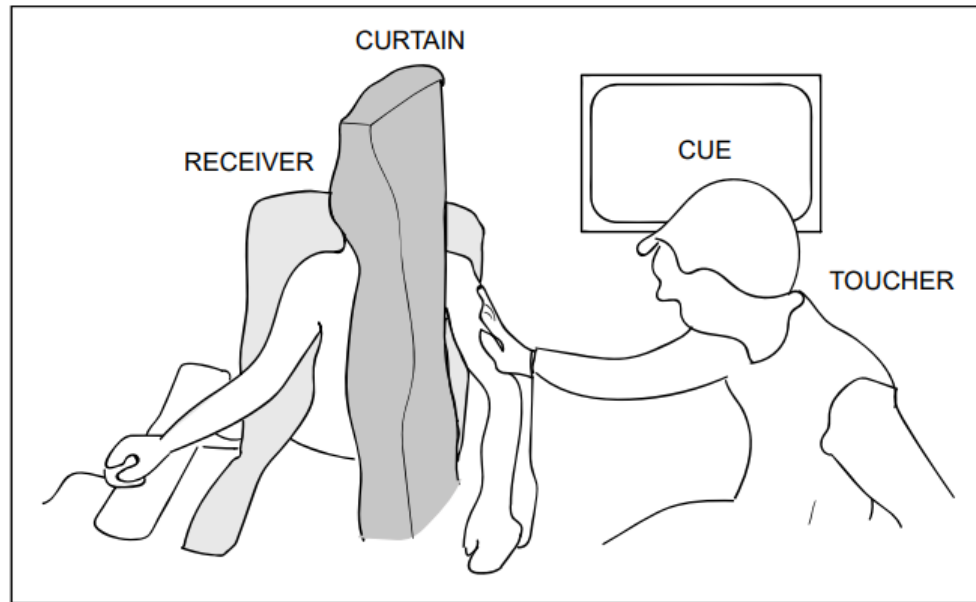
⁴Department of Computer Science, University of British Columbia, Vancouver, Canada, maclean@cs.ubc.ca

<https://www.youtube.com/watch?v=x35P24MDIiA>

- 未成熟児の保育器内環境を提案。母親の呼吸と心拍を記録して提示



(WorldHaptics2019) Affective Touch Communication in Close Adult Relationships
Sarah McIntyre, Athanasia Mounbou, Rebecca Boehme, Peder Mortvedt Isager,
Frances W. Y. Lau, Ali Israr, Ellen A. Lumpkin, Freddy Abnoui, Hakan Olausson



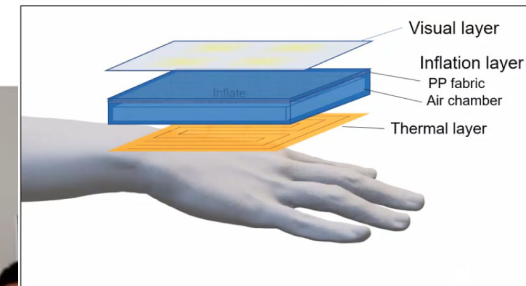
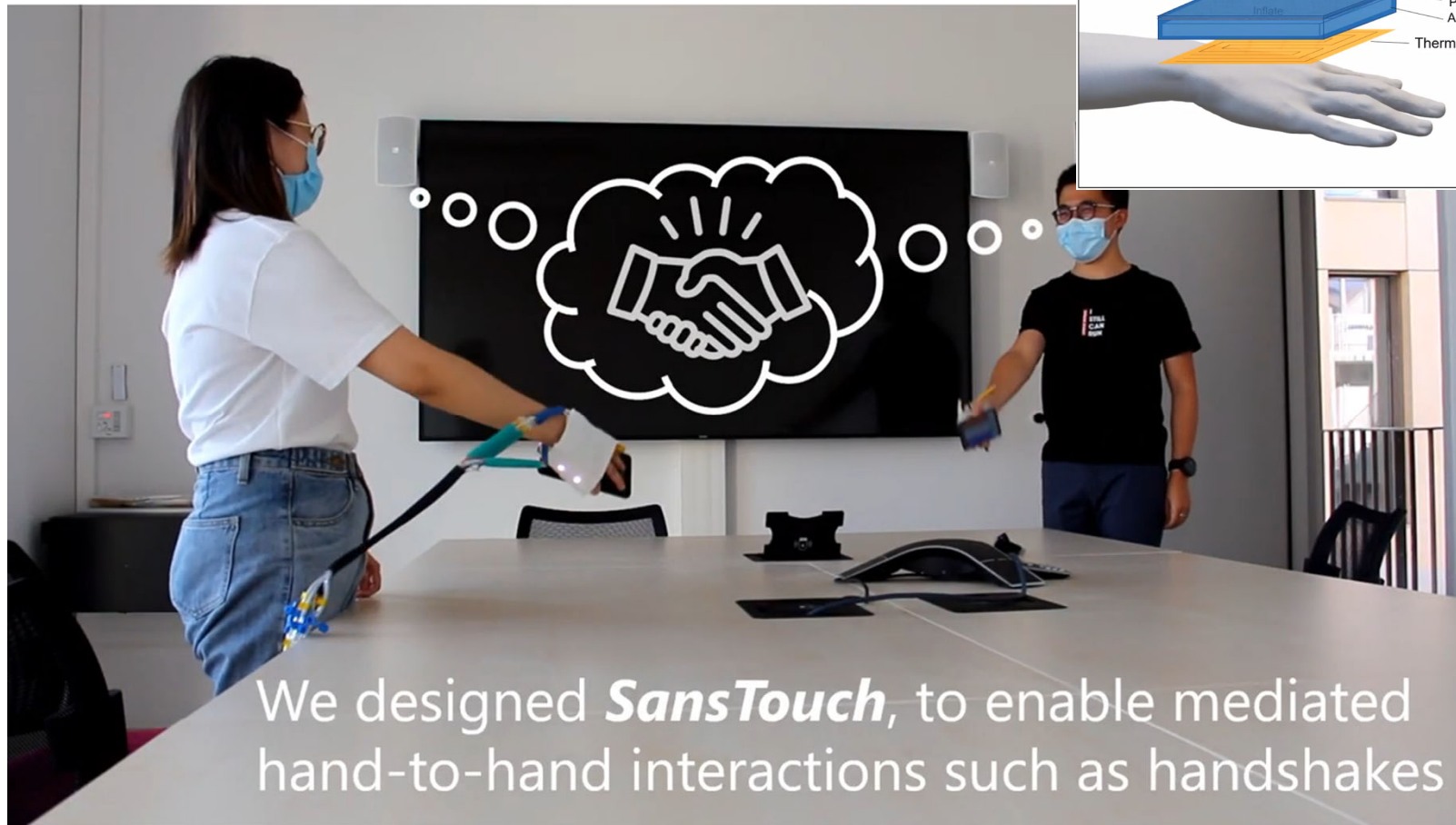
そもそも触覚でどの程度「伝えたい感情」が伝わるかの検証。

ToucherとReceiverは知り合いのペア。

Attention, love, happiness, calming, sadness, gratitude, sympathy, amusement
のいずれもチャンスレベルよりも高く伝わる。知り合いの程度は影響しなかった。

(CHI2021) Touch without Touching: Overcoming Social Distancing in Semi-Intimate Relationships with SansTouch

Zhuoming Zhang, Jessalyn Alvina, Robin Héron, Stéphane Safin, Françoise Detienne, Eric Lecolinet



<https://www.youtube.com/watch?v=FzzbzD-zGuU>

- ちょっと離れたところで遠隔握手。空気袋＋熱



触覚ディスプレイの応用分野の方向性

Elements of application for tactile display

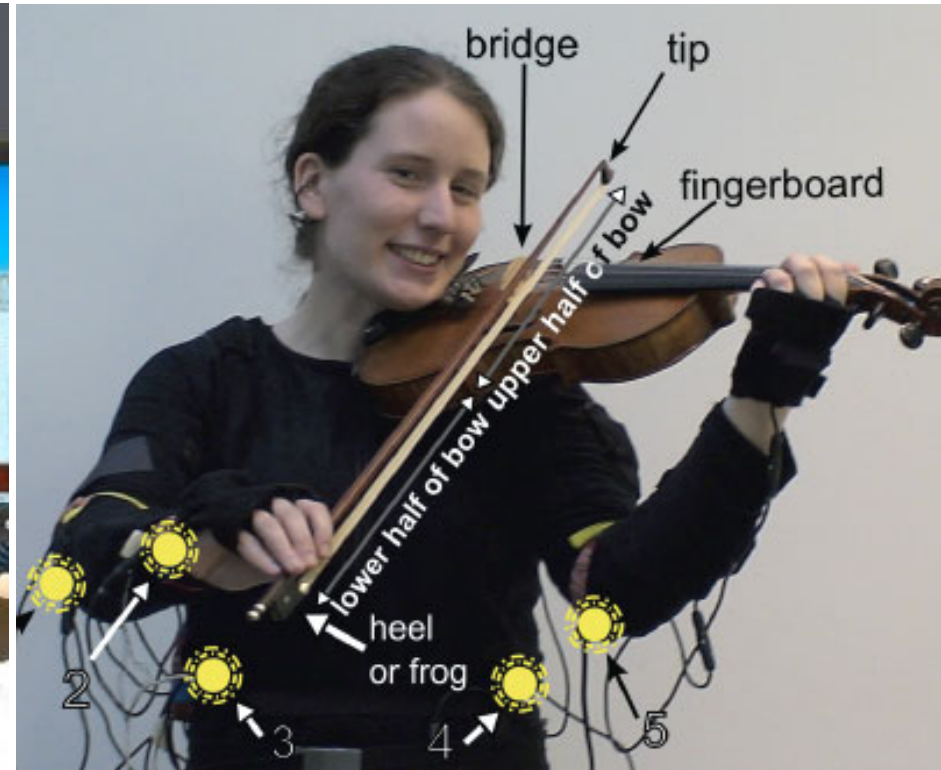
- **Touch Panel & Mobile**
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 - 触覚を現実世界で使うことでAR化する



Haptic Navigation: Conventional Approach



J. B. F. van Erp, EuroHaptics 2006

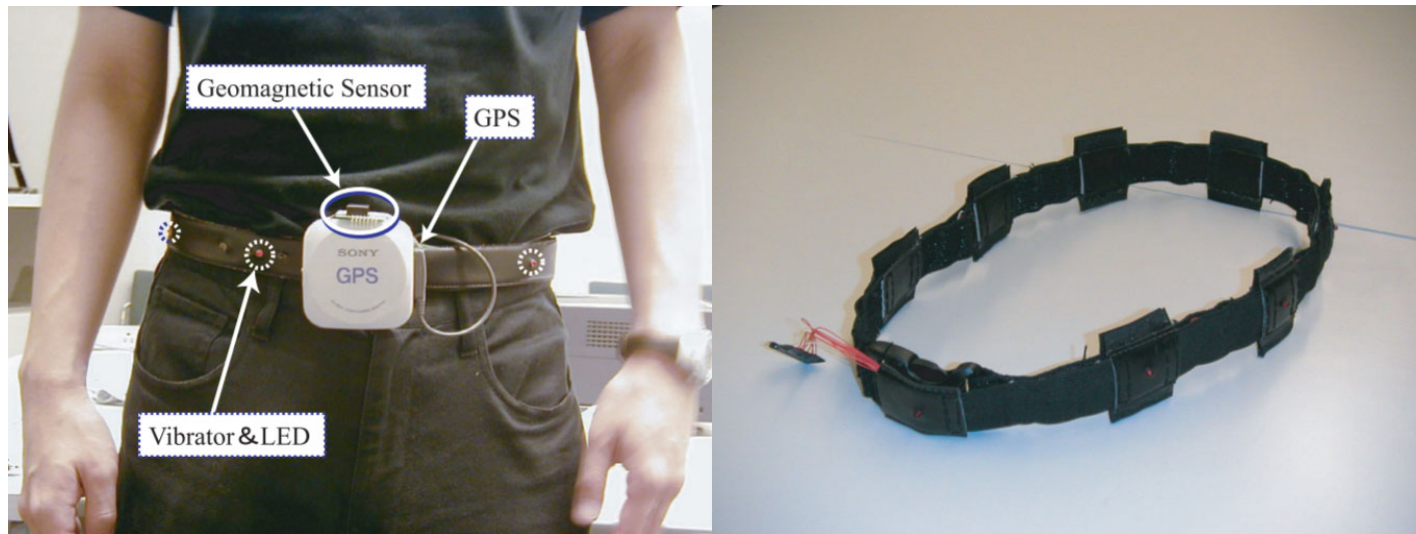


van der Linden et al., CHI 2011

Teach where to move, when to move, how to move,
and what is wrong.

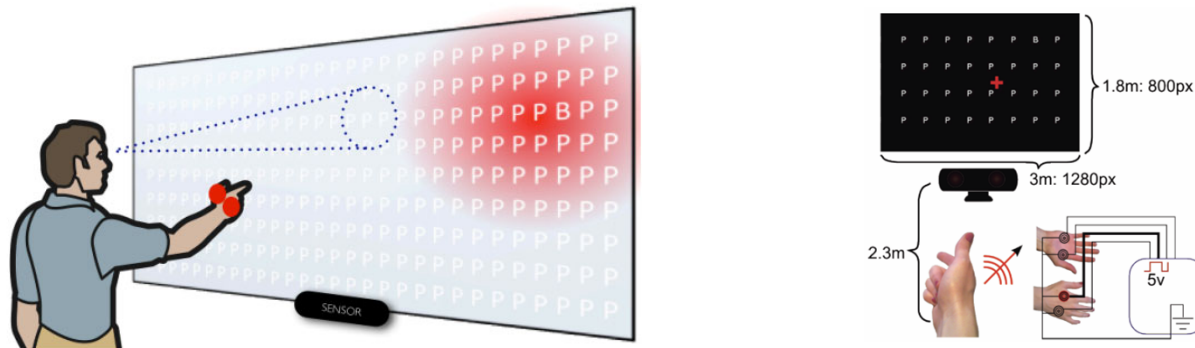


(Ubicomp2004)ActiveBelt: Belt-type Wearable Tactile Display for Directional Navigation, Koji Tsukada and Michiaki Yasumura



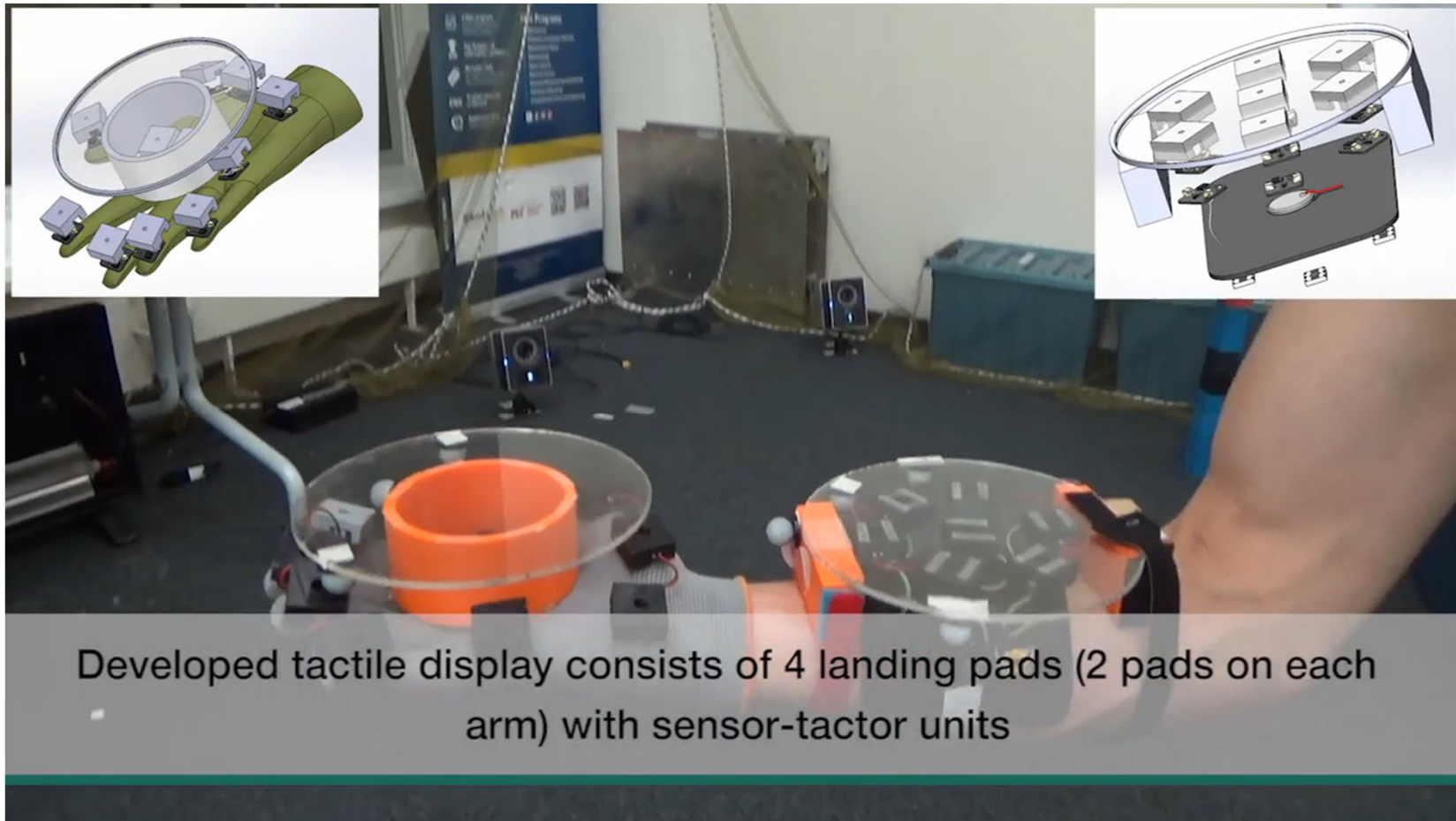
- GPSとの連動により目的地へ振動ナビゲーション

(UIST2012) Dynamic Tactile Guidance for Visual Search Tasks, Ville Lehtinen, Antti Oulasvirta, Antti Salovaara, Petteri Nurmi



- 現在の手と頭の位置をセンシング、目標位置との関係から振動によってガイド

SwarmCloak



https://www.youtube.com/watch?v=2a4XrG_u3RE

プロジェクション触覚でドローンを手腕上に着陸させる。人が最後の微調整をする際に触覚。
Landing drones on palms using projection.

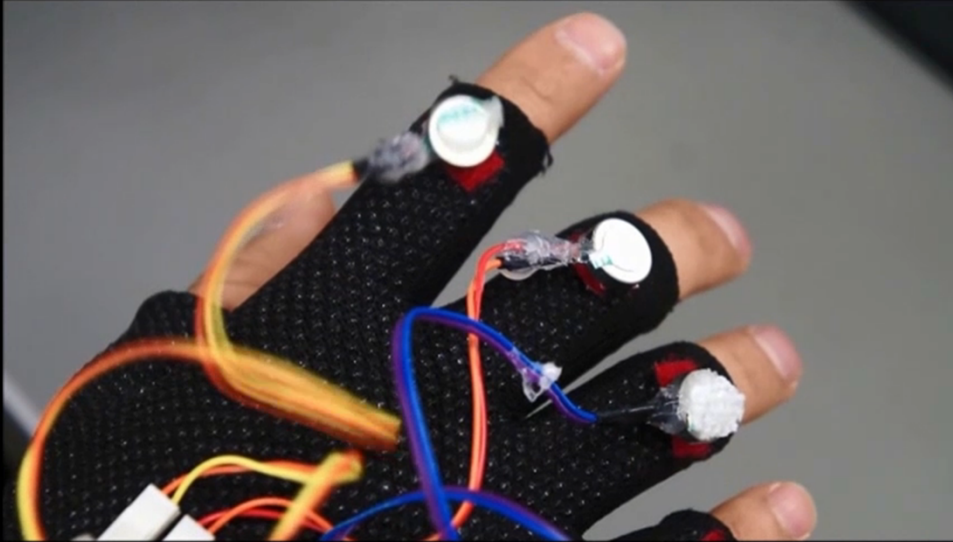
Evgeny Tsykunov et al.: SwarmCloak: Landing of Two Micro-Quadrotors on Human Hands Using Wearable Tactile Interface Driven by Light Intensity, Haptics Symposium 2020

Evgeny Tsykunov et al.: SwarmCloak: Landing of a Swarm of Nano-Quadrotors on Human Arms, Siggraph Asia 2019



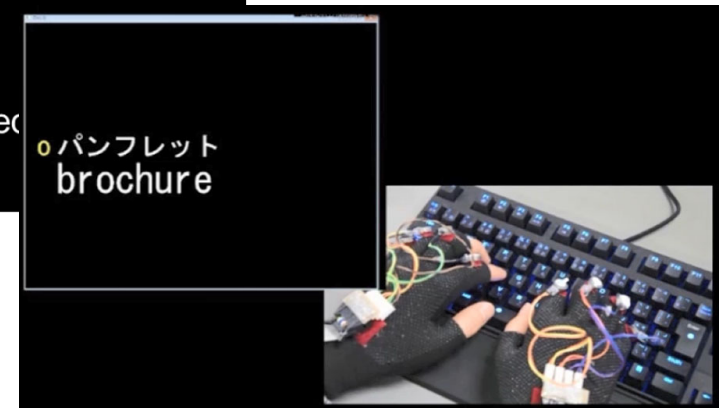
Insufficient cue is better for learning?

System



We designed a glove-type tactile device with eight vibrators situated at the root of each finger, excluding the thumbs

<https://www.youtube.com/watch?v=sbroRznBHIY>



- キーボード用のボキャブラリ学習。各指への振動は不十分な手がかかりだがそれによって学習が可能。
- Vibration to finger is used for vocabulary learning, which is insufficient but good for learning.

D. Ogawa, S. Ikeno, R. Okazaki, T. Hachisu, H. Kajimoto : Tactile Cue Presentation for Vocabulary Learning with Keyboard, UIST 2014, October 5-8, 2014

Passive Learning?



<https://www.youtube.com/watch?v=uEdr6iY6F-w>

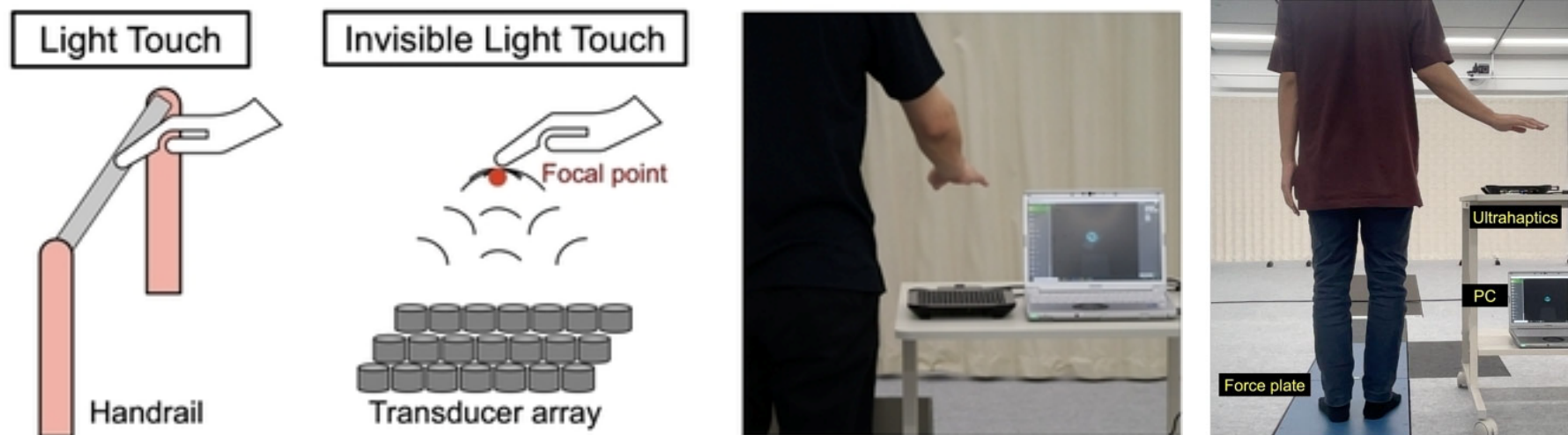
- 各指への振動パターン提示⇒受動的であるにも関わらず指の使い方を覚える
- 触覚提示による運動パタンの学習事例？

Huang, K., Starner, T., Do, E., Weinberg, G., Kohlsdorf, D., Ahlrichs, C. and Leibrandt, R. Mobile Music Touch - Mobile Tactile Stimulation for Passive Learning. *CHI 2010*.



[CHI2025] Invisible Light Touch: Standing Balance Improvement by Mid-Air Haptic Feedback

<https://dl.acm.org/doi/10.1145/3706598.3713396>



- 立っているときの立位バランスを取るために、「ちょっとした触覚刺激」があると良いことが知られている (Light touch effect)
- 空中超音波をつかってやってみた。空中超音波をつかってやってみた。刺激の有無と、刺激の時空間変化がある場合で比較。刺激があると効果があるが、刺激の変化があると効果が無くなる
- It is known that a “slight tactile stimulus” can help maintain postural balance while standing—a phenomenon referred to as the *light touch effect*. They investigated this effect using mid-air ultrasound stimulation.

触覚ディスプレイの応用分野の方向性

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 - 市場が巨大。差別化要素としての触覚
- **Emotion, Affection**
 - 触覚は驚きから愛情まで、幅広い情動へ働きかけることが出来る
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- **Reality, Multimodal**
 - 触覚が視聴覚に加わることで存在感、現実感を上げることが出来る
- **The Whole Body**
 - 身体全体への触覚提示により、触覚にも臨場感を生じる
- **Tactile AR**
 - 触覚を現実世界で使うことでAR化する



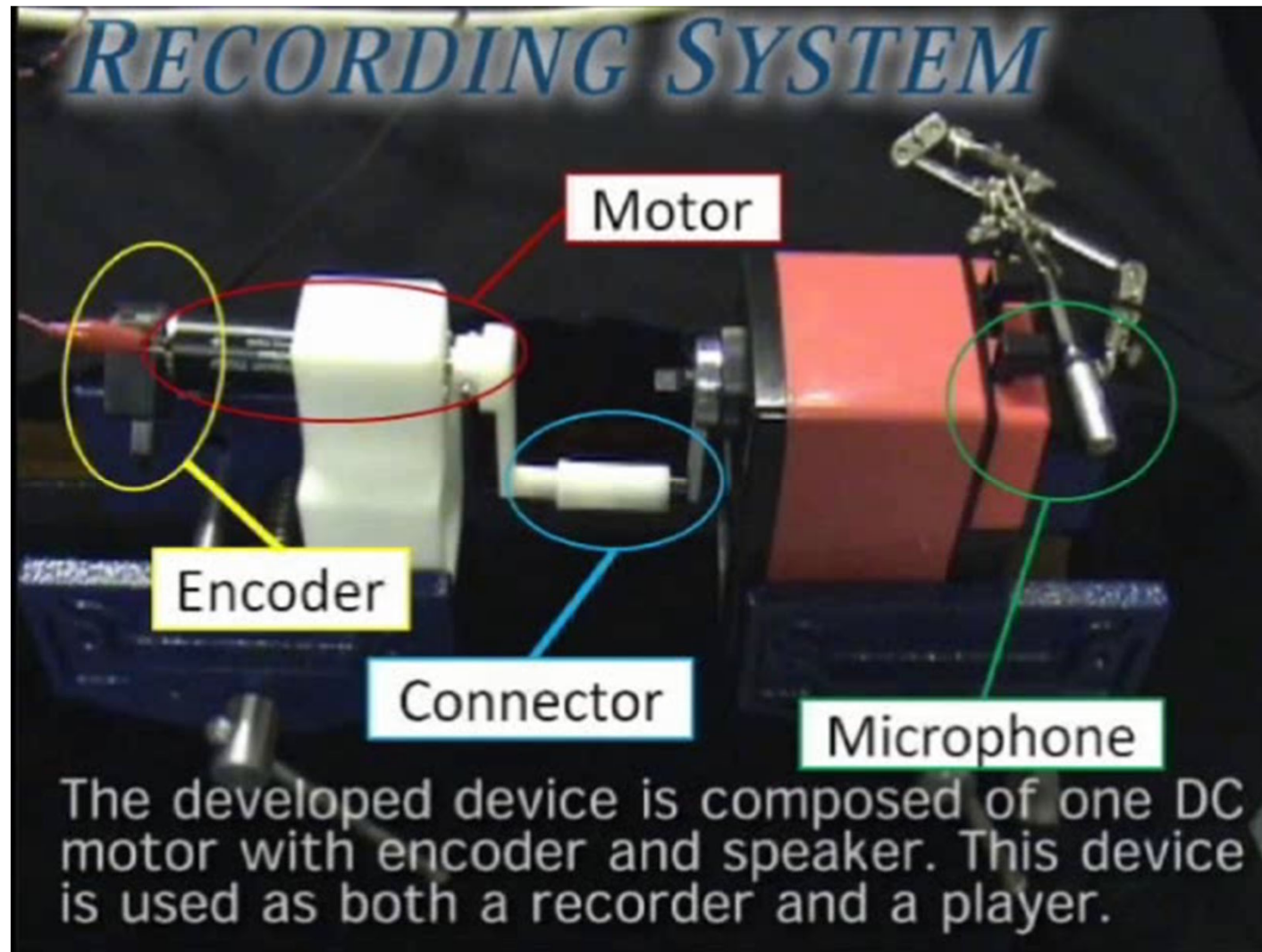
スパイスとしての触覚



(株)バンダイ ∞プチプチ



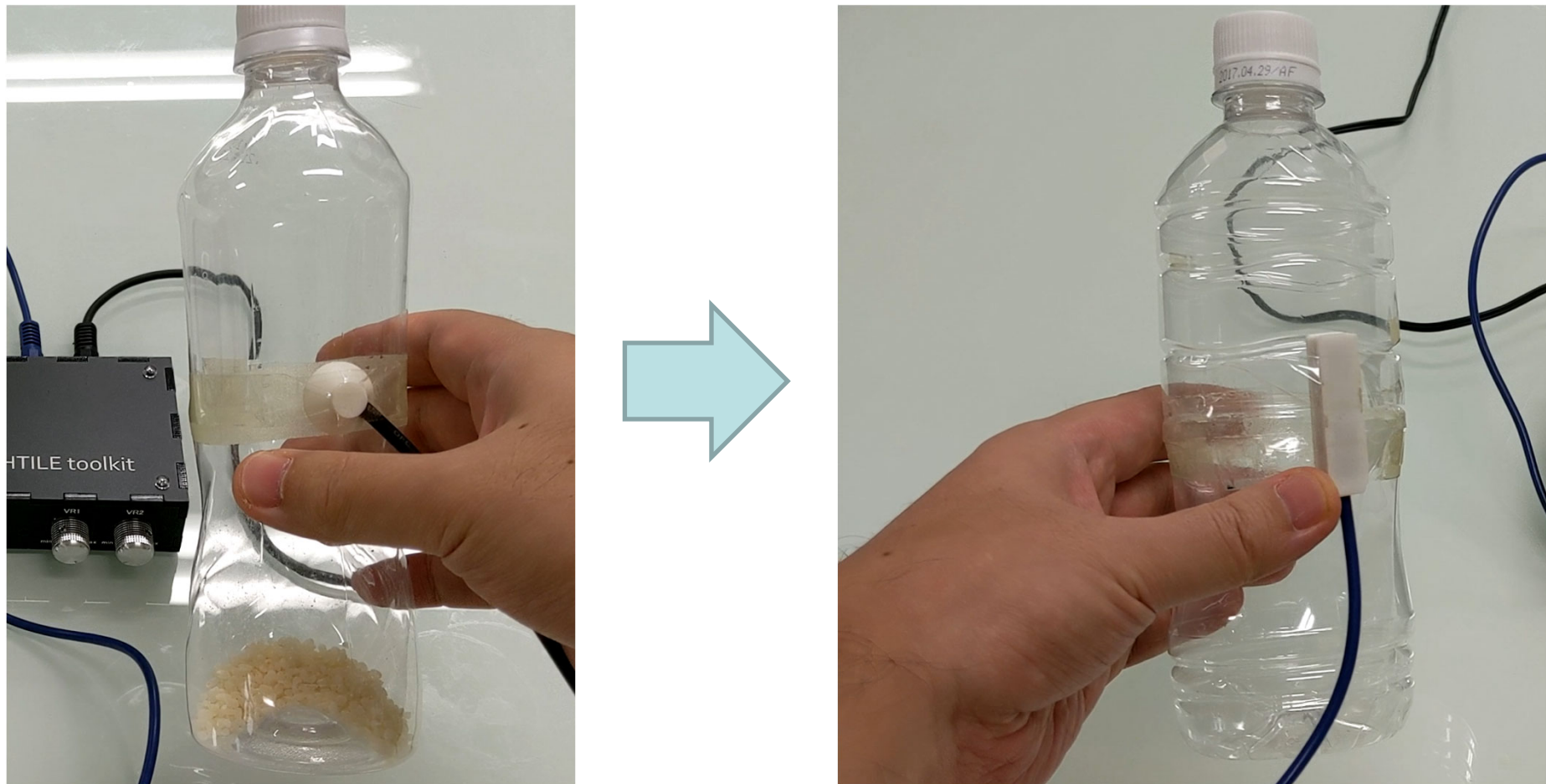
Eternal Sharpener



Y. Kojima, Y. Hashimoto, H. Kajimoto: Eternal Sharpener - A Rotational Haptic Display that Records and Replays the Sensation of Sharpening a Pencil, IEEE RO-MAN2009.



Techtile Toolkit (<http://www.techtile.org/>)

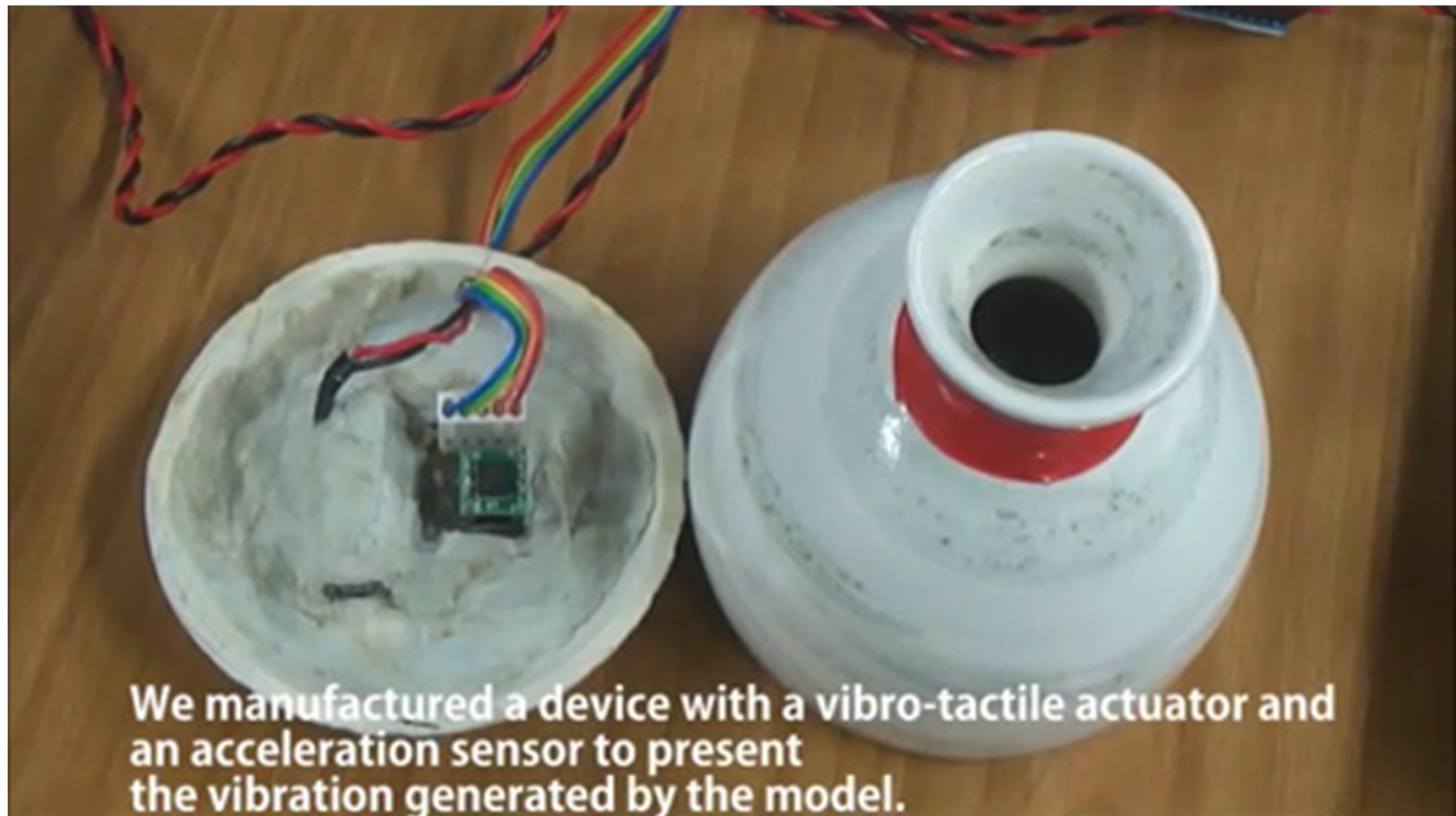


- 単純な振動の記録と再生を、音領域も含めた幅広いレンジで行なうことで、明瞭な触覚的価値を示した。
- Minamizawa, K., Kakehi, Y., Nakatani, M., Mihara, S., & Tachi, S. (2012). TECHTILE toolkit: A prototyping tool for designing haptic media. : *ACM SIGGRAPH 2012 Emerging Technologies, SIGGRAPH'12* (ACM SIGGRAPH 2012 Emerging Technologies, SIGGRAPH'12). <https://doi.org/10.1145/2343456.2343478>

<https://www.youtube.com/watch?v=eoztAbSlpfU>



とくとく感 / pouring bottle feeling



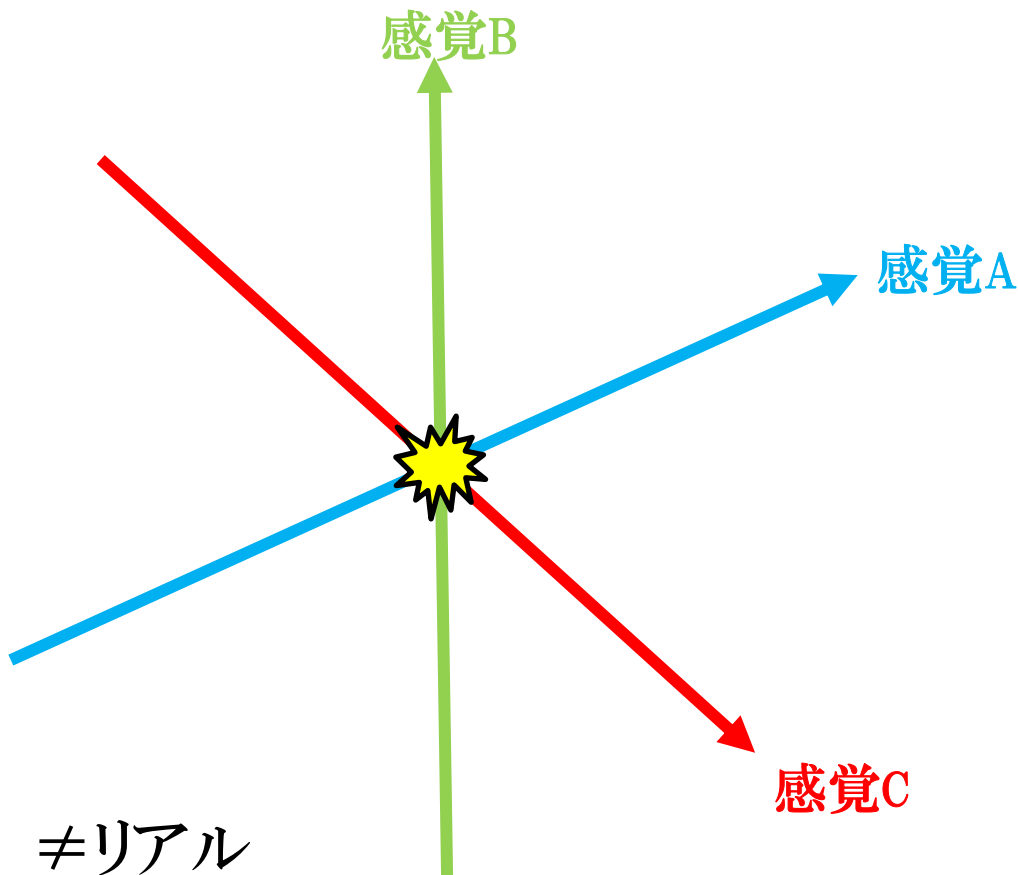
<https://www.youtube.com/watch?v=ACJBxextDdE>

- ボトルから注ぐ音と振動を記録・再生

- S. Ikeno, R. Okazaki, T. Hachisu, H. Kajimoto: Creating an Impression of Virtual Liquid by Modeling Japanese Sake Bottle Vibrations, IEEE 3DUI 2015, March 23-24, 2015



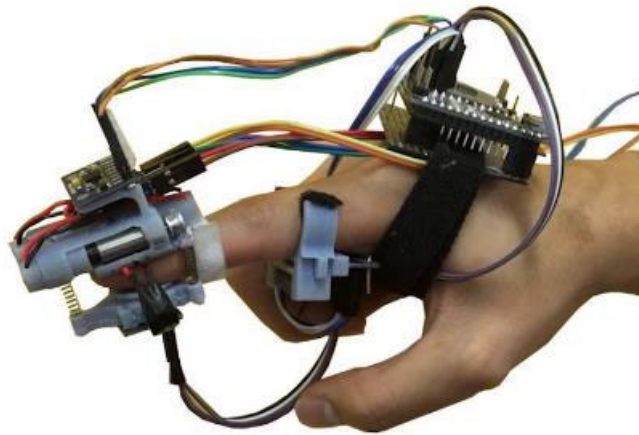
存在感・現実感 Feeling of existence



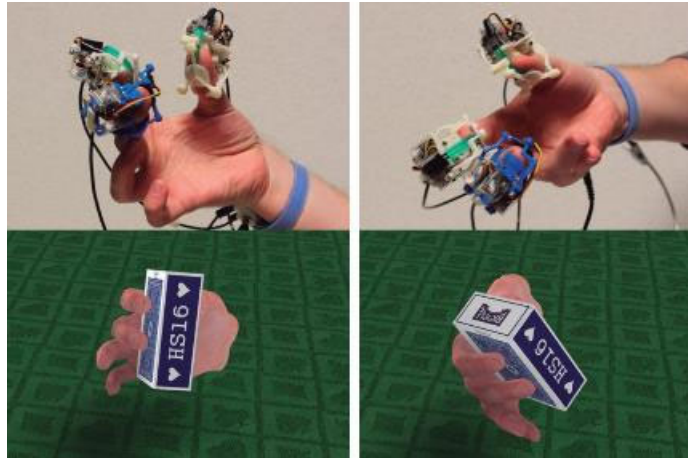
複数の感覚が同一の事物から生じていることが納得された時に初めてリアリティとなる. クロスモーダル(複数感覚統合)による一種の感覚. 触覚は単純にチャンネルを増やすためだけでも価値がある.
Feeling of existence does not come from resolution of the sensation, but rather, it comes from cross-modal cues.



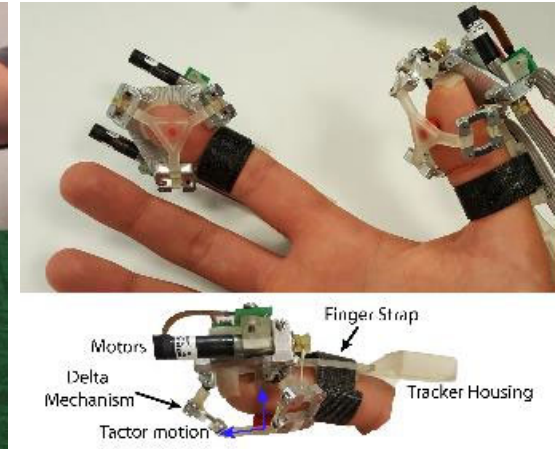
VR・遠隔での作業支援



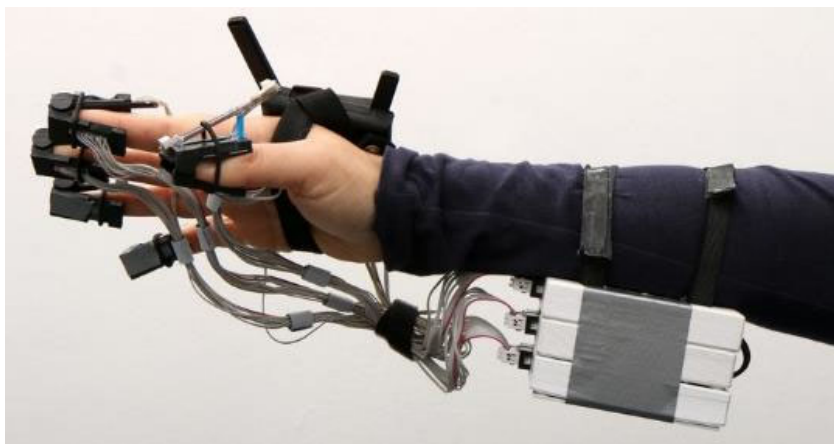
Kim et al., URAI2016



Wearable Haptics project by SIRS Lab



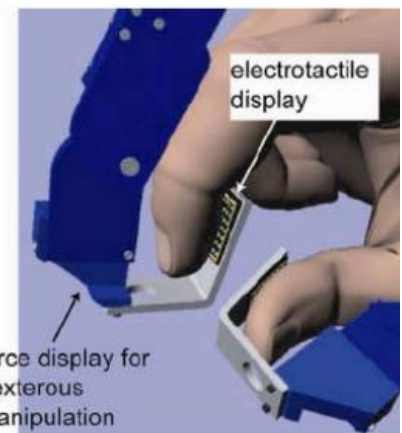
Schorr et al., IEEE ToH, 2017



Sagardia et al., IEEE Aerospace Conference, 2015



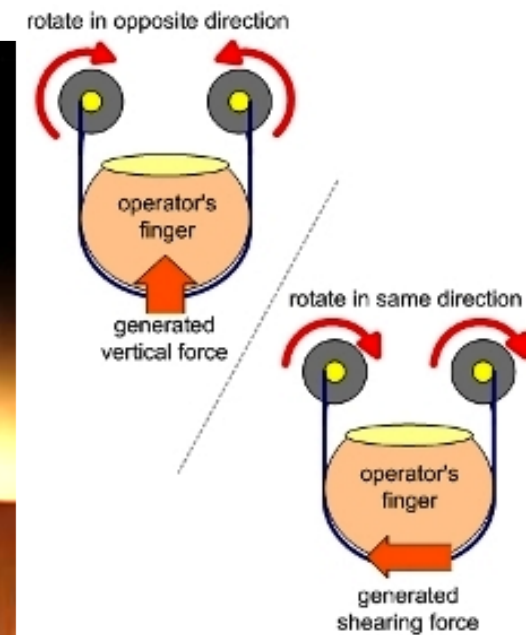
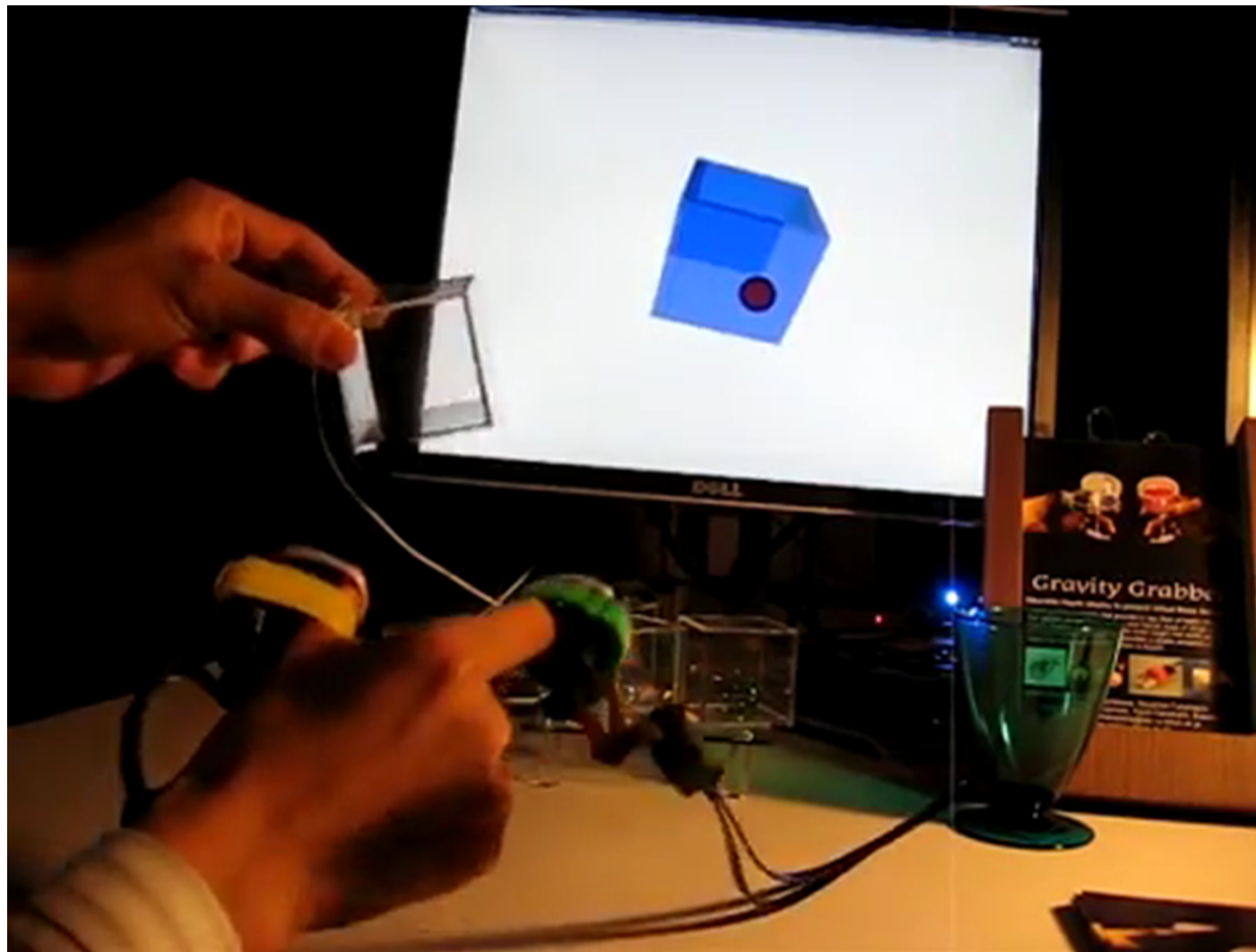
Sato et al., Siggraph2007



Vibration / Pressure / Force vector / Distributed tactile



Gravity Grabber

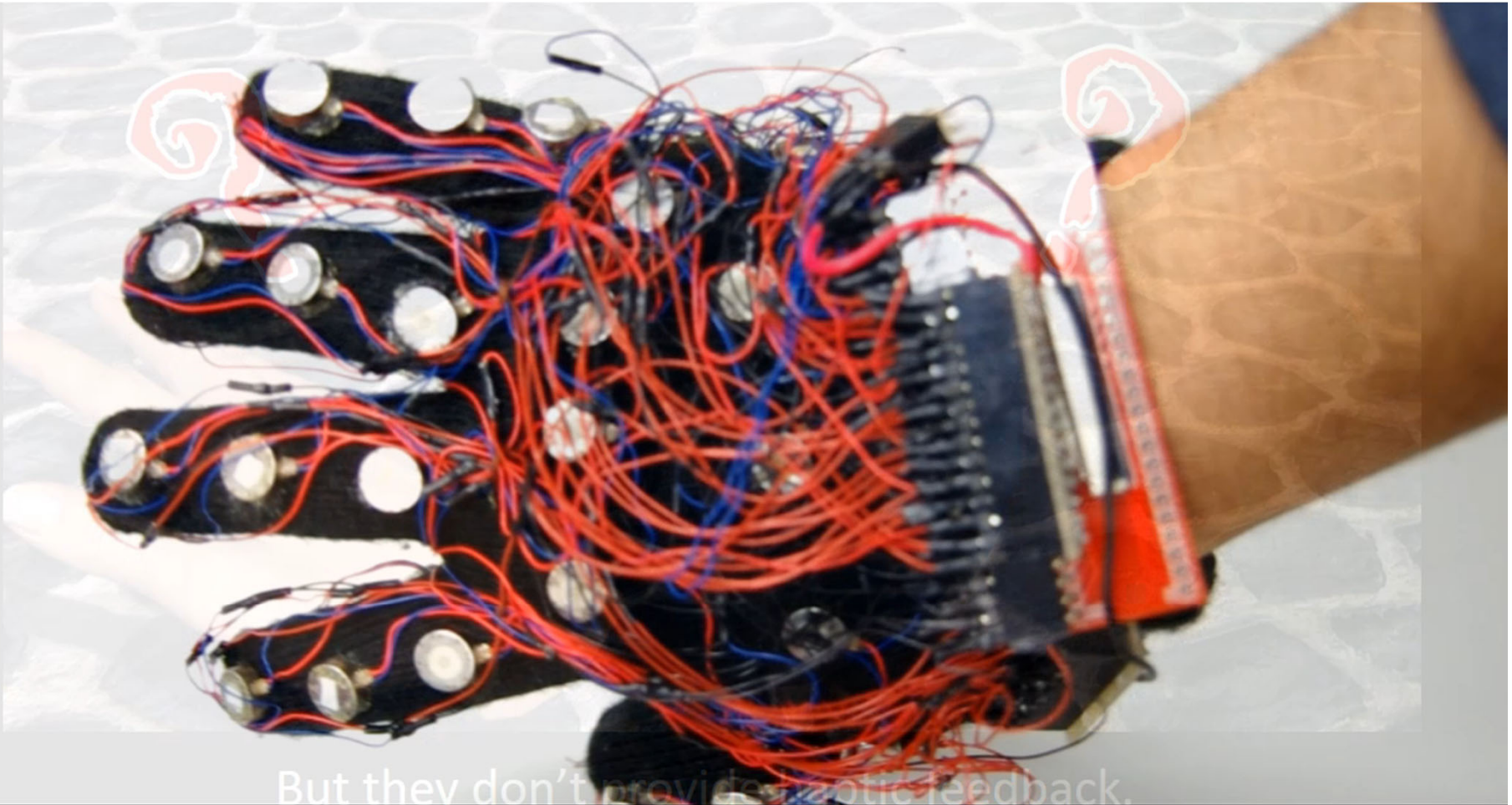


<https://www.youtube.com/watch?v=oEGBXu-N51w>

Kouta Minamizawa, Hiroyuki Kajimoto, Naoki Kawakami, Susumu Tachi: "Wearable Haptic Display to Present Gravity Sensation - Preliminary Observations and Device Design", WorldHaptics 2007



The whole hand vibration



But they don't provide haptic feedback.
Affordable and easy to use for everyone.

We have developed haptic glove with 52 LRA vibrators.

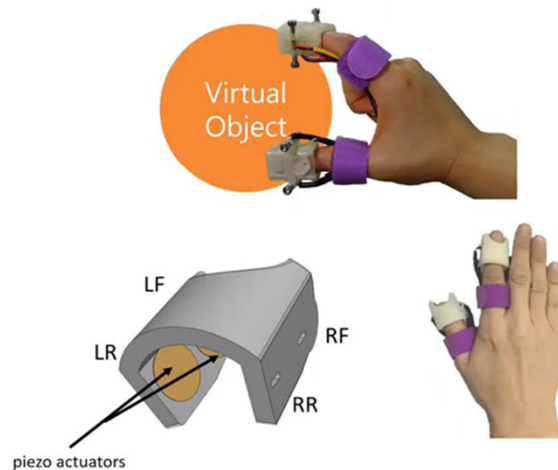
Kenta Tanabe, Seiya Takei, Hiroyuki Kajimoto: The Whole Hand Haptic Glove Using Numerous Linear Resonant Actuators, IEEE World Haptics Conference 2015



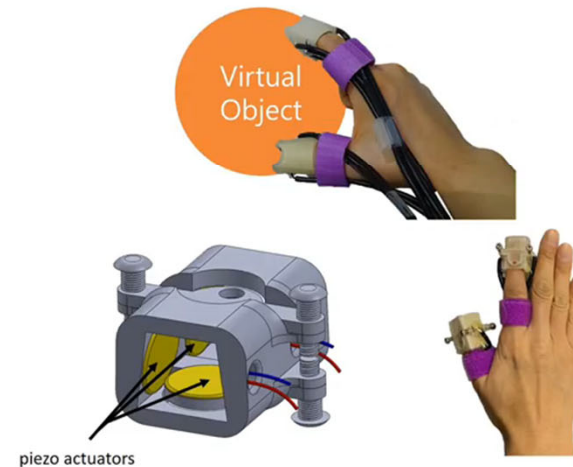
Methods

❖ Hardware

Type A vibrotactile fingertip interface



Type B vibrotactile fingertip interface



There are two types of vibrotactile fingertip interface in our study,

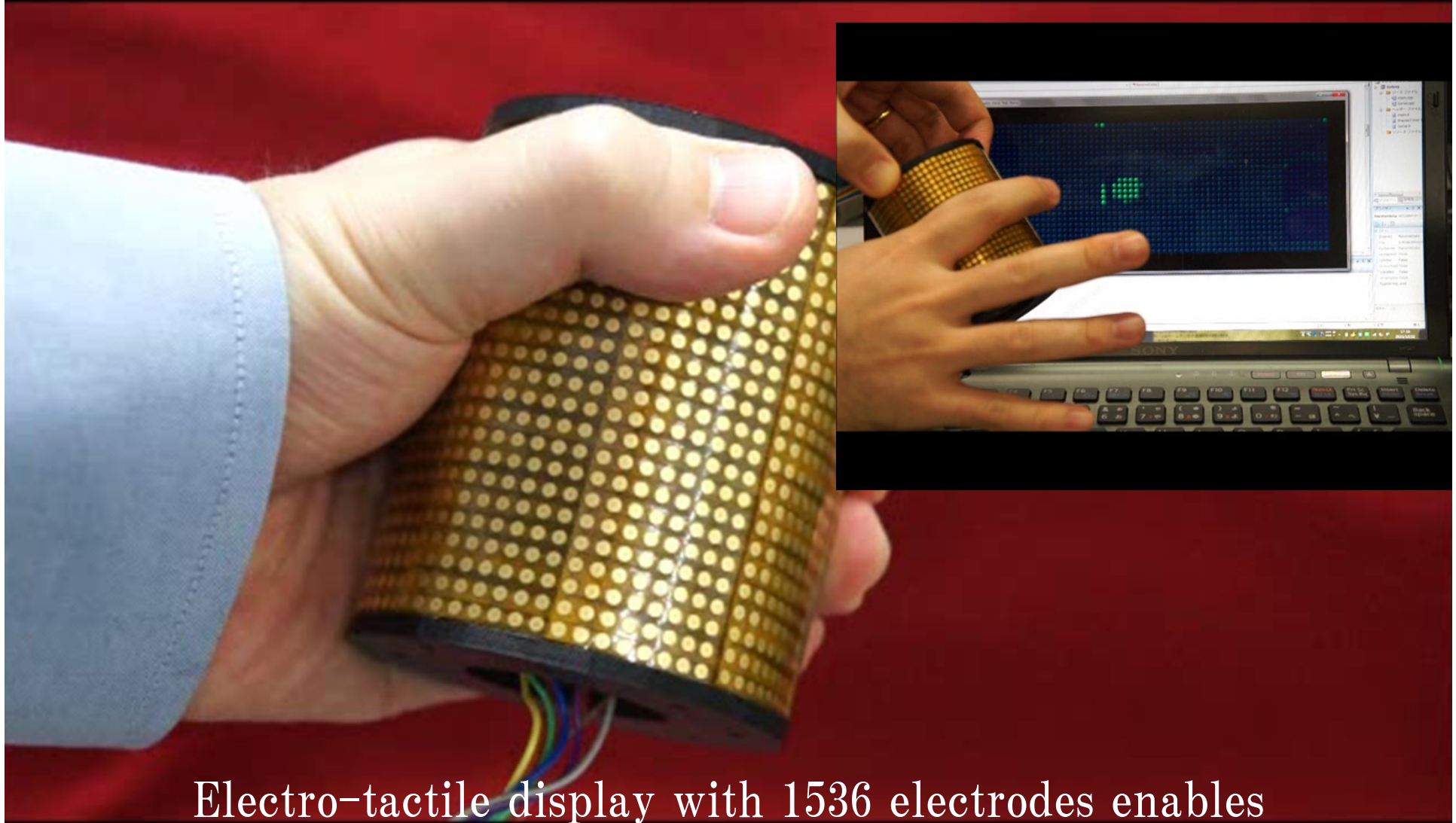
5

<https://www.youtube.com/watch?v=sNP4D-7uc4o>

- 多指でのVRインタラクション。振動提示を指の腹だけでなく側面に与え、指がバーチャル物体に入り込んだときのめり込み量を表現する。
- VR interaction with multiple fingers. The vibration presentation is given not only to the belly of the finger, but also to the side of the finger to express the amount of immersion when the finger enters the virtual object.



The whole palm

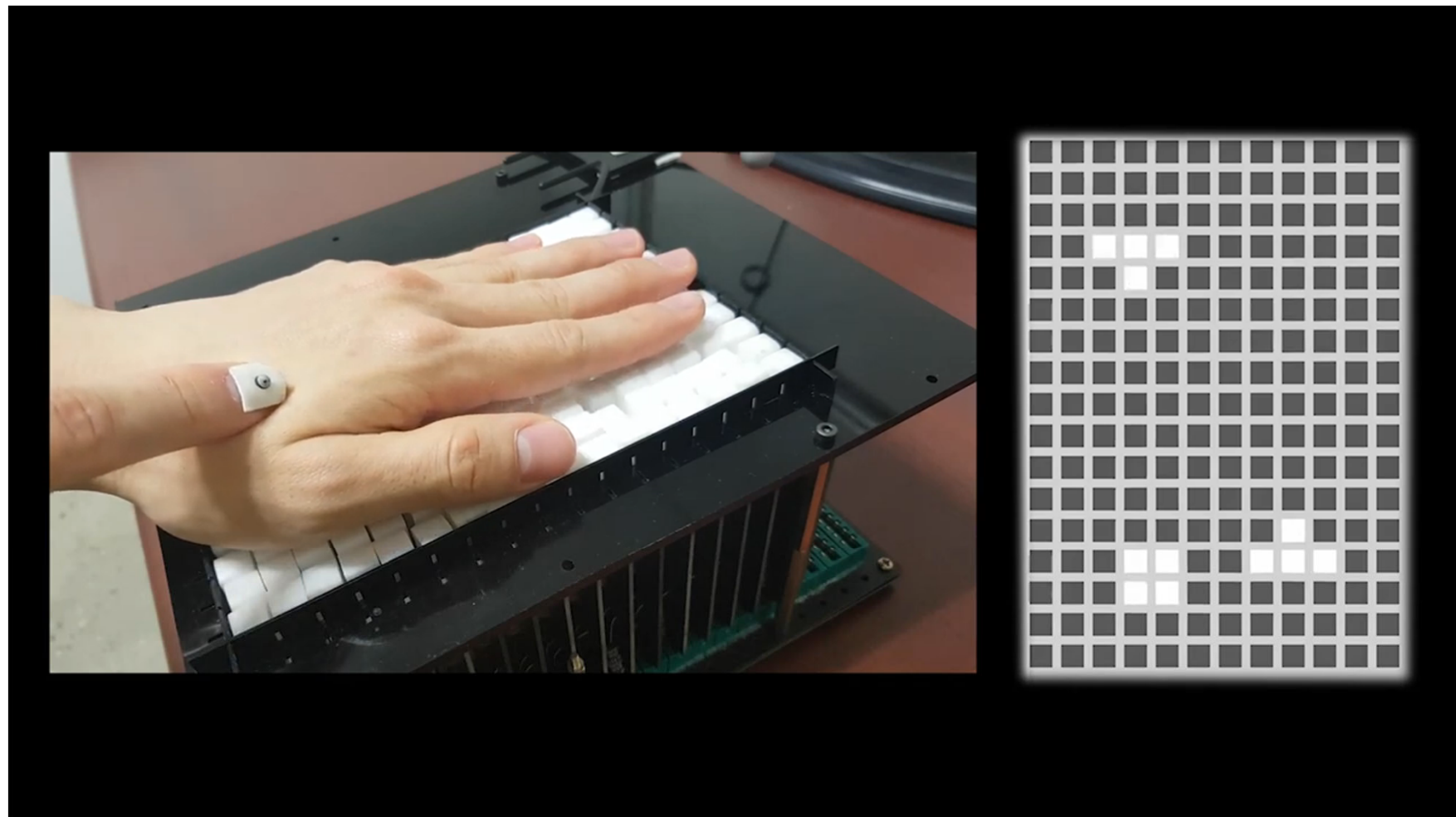


Electro-tactile display with 1536 electrodes enables
the whole palm interaction.



Kajimoto, "Design of Cylindrical Whole-hand Haptic Interface using Electrocutaneous Display," EuroHaptics2012.

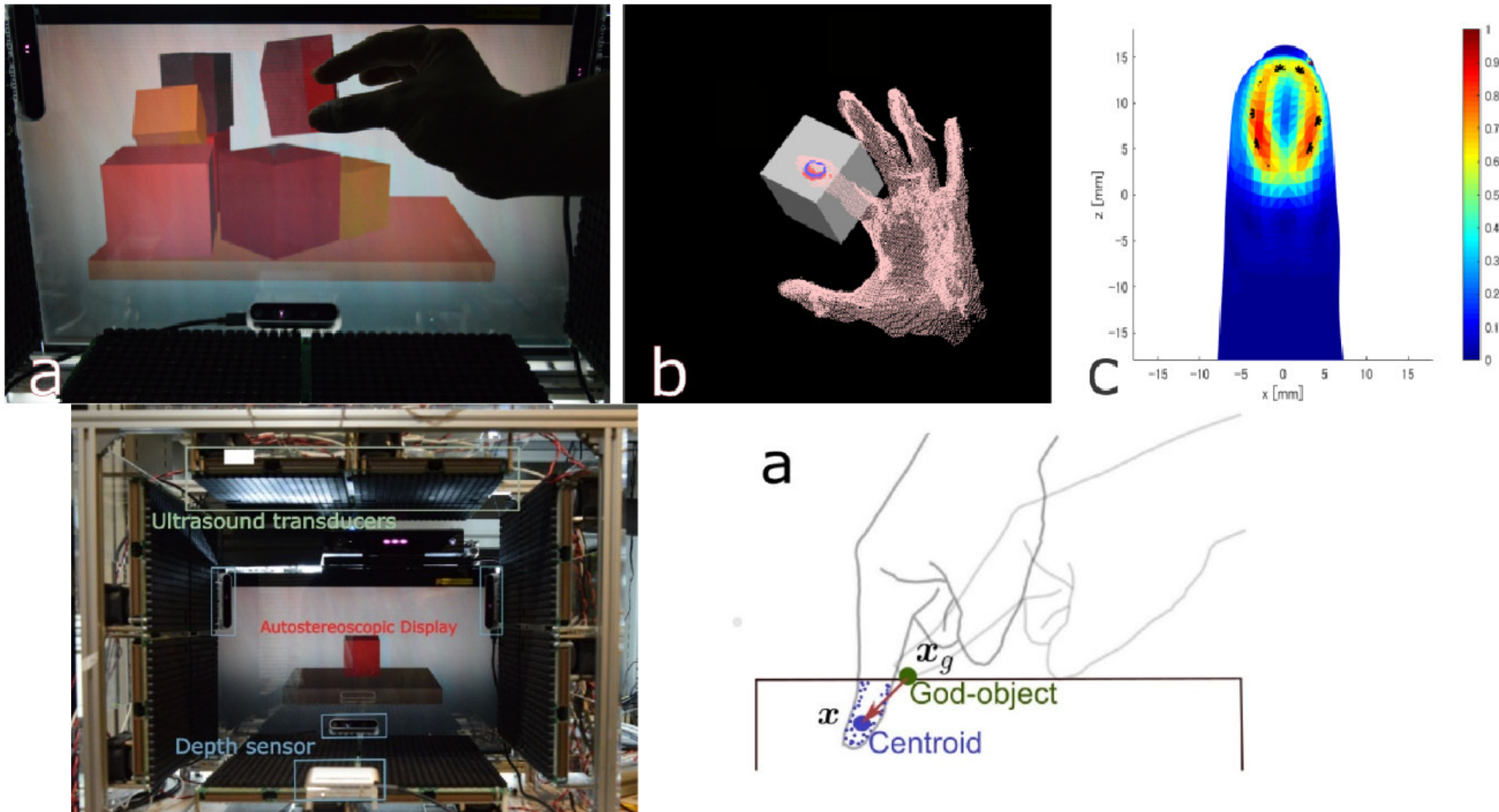
(CHI2021) ThroughHand: 2D Tactile Interaction to Simultaneously Recognize and Touch Multiple Objects
Jingun Jung, Sunmin Son, Sangyoon Lee, Yeonsu Kim, Geehyuk Lee



<https://www.youtube.com/watch?v=ohBngBO65N4>

- 視覚障害者用の2D画面インタラクション。非利き手の手のひら全体への触覚提示と、利き手での操作を両立。磁石を使うことで非利き手の上からなぞるという工夫。
- 2D screen interaction for the visually impaired. It combines tactile presentation to the entire palm of the non-dominant hand and manipulation with the dominant hand. By using a magnet, the user can trace over the non-dominant hand.

[CHI2019] Direct Finger Manipulation of 3D Object Image with Ultrasound Haptic Feedback. Atsushi Matsubayashi Yasutoshi Makino Hiroyuki Shinoda



- 超音波触覚. VR環境での把持感を指先への圧力分布で提示する.
- Ultrasonic tactile sensation: presenting the grasping sensation in VR environment by pressure distribution to the fingertip.



(UIST2022) TipTrap: A Co-located Direct Manipulation Technique for Acoustically Levitated Content

Eimontas Jankauskis, Sonia Elizondo, Roberto A Montano-Murillo, Asier Marzo, Diego Martinez Plasencia



<https://www.youtube.com/watch?v=pTS3wIFDfdw&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJCIfAn&index=82>

音響浮揚粒子を直接操作する技術を提案し、ユーザーの皮膚での超音波の反射を利用して指先近くに機能的な音響トラップを作成し、選択、操作、選択解除の基本的な段階を実現。

Directly manipulates acoustic levitation particles, creating a functional acoustic trap near the fingertip using ultrasonic reflections on the user's skin.

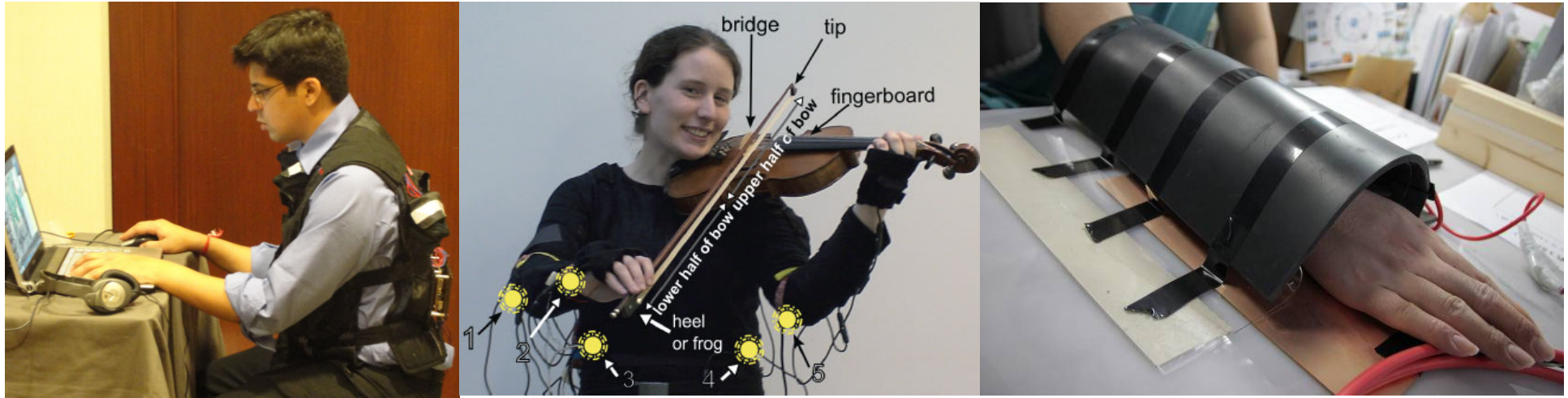
触覚ディスプレイの応用分野の方向性

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- **Touch Panel & Mobile**
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全身性 Whole body haptics



- 視覚：広視野化が「**臨場感・没入感**」という価値を生む。
- 触覚：全身提示によって同様の価値が生じる。

すでにここまでの応用事例の多くが「指先」では無い。

The whole-body haptics gives a sensation of presence and immersion, like large visual display does.



虫How(2007学生プロジェクト)



臨場感

≠リアル

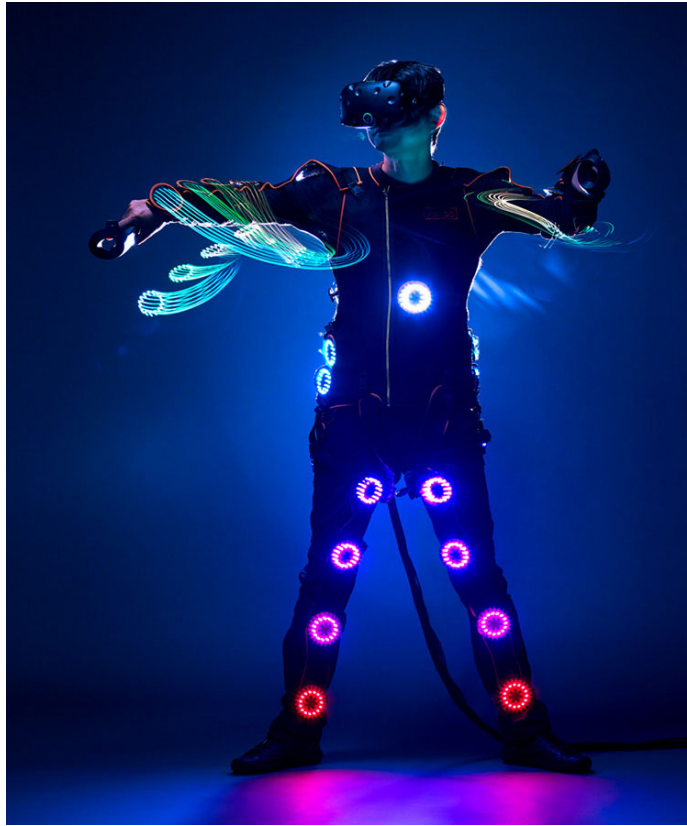
「その場」に「私」が「臨んでいる」感覚。

提示されているものと自分との相対関係が納得された
時に初めて臨場感となる。

つまり臨場感とは、鑑賞者自身の発見であり、触覚は非
常に適している。



全身への触覚提示 / The whole body haptics



Synesthesia Suit



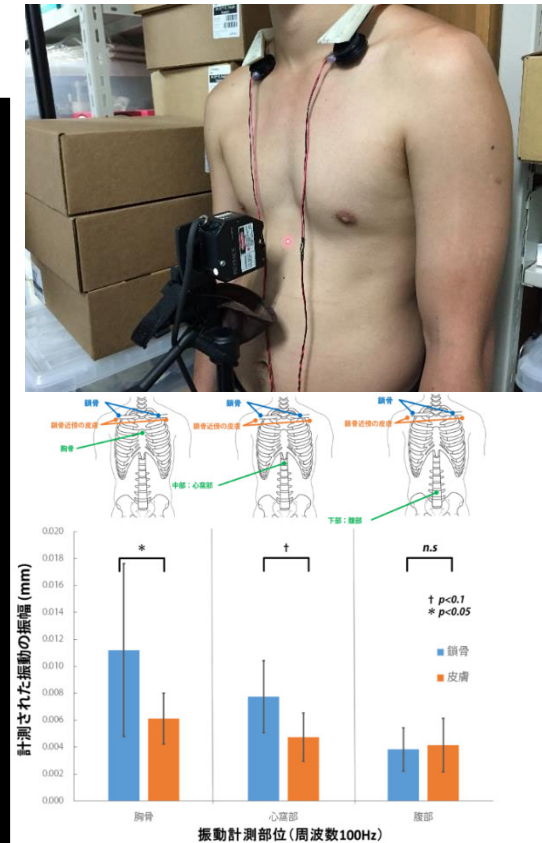
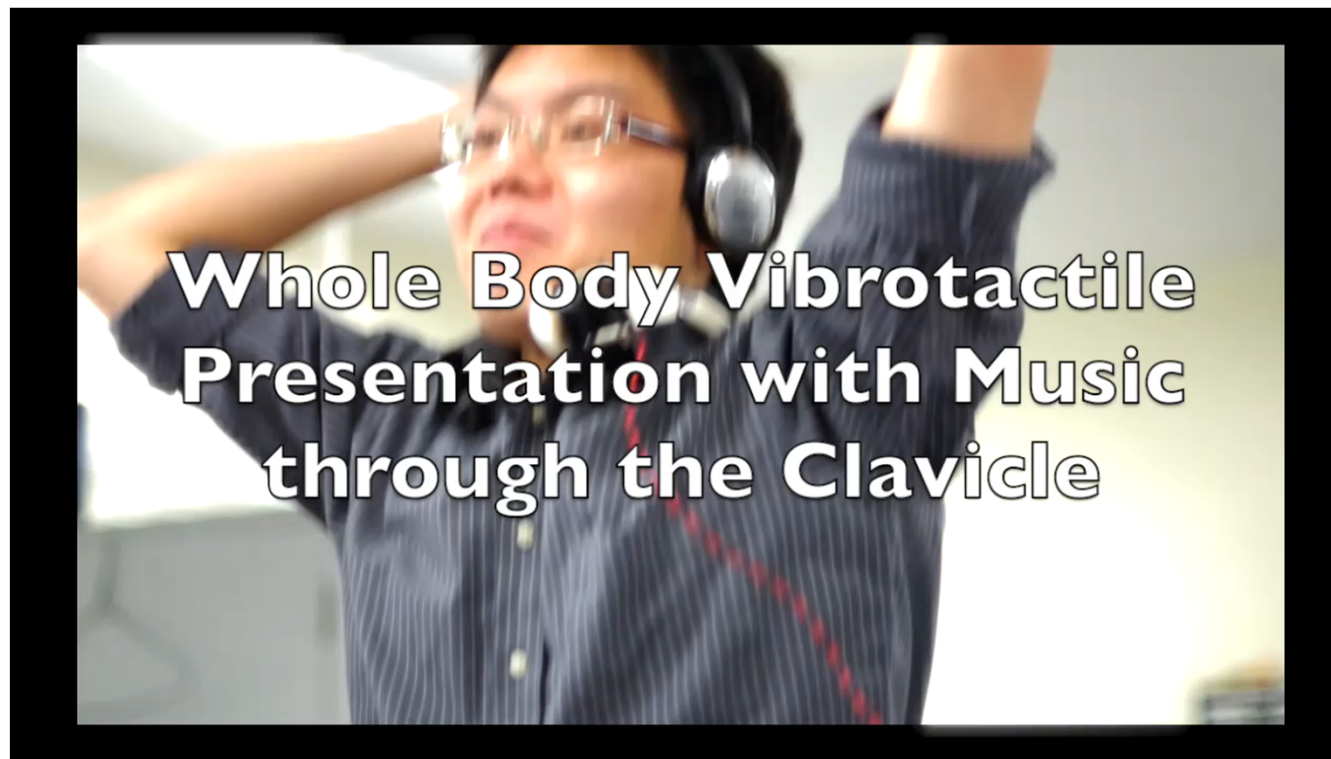
Synesthesia X1

<https://enhance-experience.com/synesthesia-lab>

Synesthesia suit Yukari Konishi, Nobuhisa Hanamitsu, Benjamin Outram, Youichi Kamiyama, Kouta Minamizawa, Ayahiko Sato, Tetsuya Mizuguchi, AsiaHaptics2016



コンパクトな臨場感：鎖骨経由の骨伝導 Use bone conduction



R. Sakuragi, S. Ikeno, R. Okazaki, H. Kajimoto: CollarBeat: Whole Body Vibrotactile Presentation via the Collarbone to Enrich Music Listening Experience, ICAT2015



The Bone Fone: Radio Shack's Attempt At Making Collarbones Musical

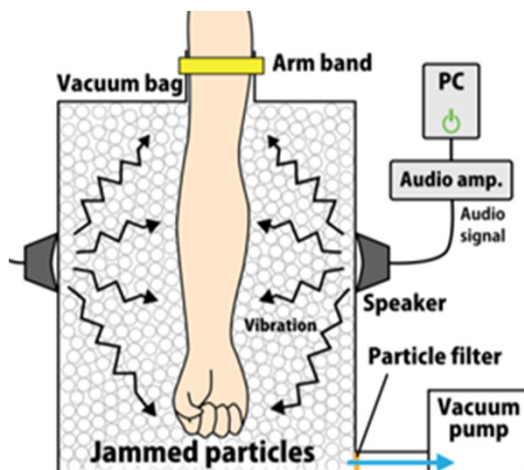
By James Grahame



The Bone Fone was a floppy fabric covered tube that housed an AM/FM radio and two speakers. It was designed to be worn around the neck like a scarf, with the speakers resting on your collarbone. The idea, of course, was that sound was transferred directly from the little speakers into your body. I played with one briefly as a kid, but can't recollect what it felt or sounded like. It was marketed through Radio Shack, and I'm beginning to wish that I'd kept my dad's copies of their catalogs from the early 1980s.



Jammed particles can efficiently transmit vibration to the skin.



Kurihara et al, "Large-Area Tactile Display Using Vibration Transmission of Jammed Particles," HS2014

Rotary switch feeling by passive haptics

カチカチッ!!

ラチェットによる「カチカチ感」。当初の狙い:「力覚」を提示するのは難しいので、「カチカチ感」を力覚と誤認させる。実際にはやる気デバイス。

Kinesthetic sensation is augmented by Adding Rotary Switch Feeling



Kurihara et al., "Augmentation of Kinesthetic Sensation by Adding "Rotary Switch Feeling" Feedback, AH2012.

ミズノ ダッシュドライバー (2015～)/ダッシュビート



ダッシュビートの特徴

ポイントが**たった1つ**だけ!
むずかしい履き・脱ぎはなし!
かんたんに履きてきて、
履きやすい!

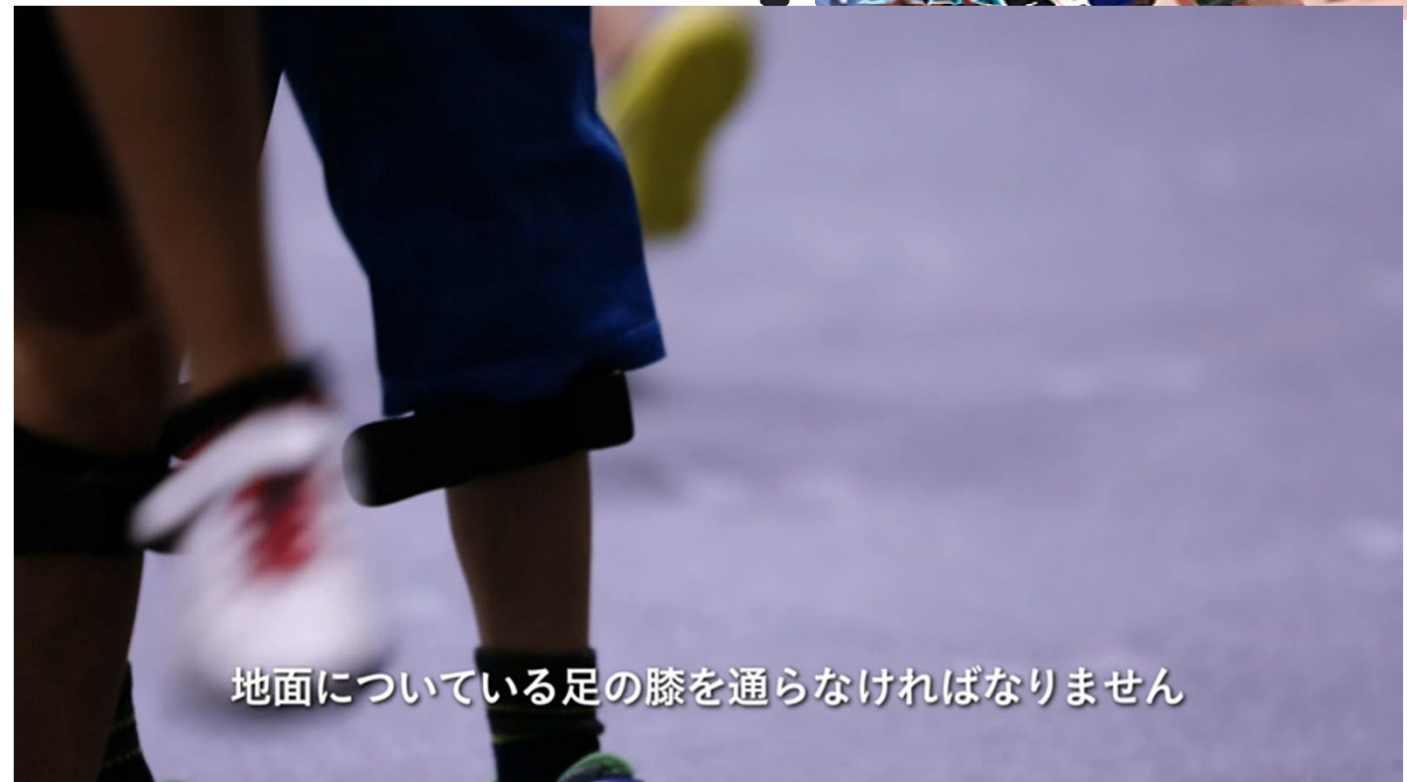
筑波大学との共同研究に
基づいた履きやすさを実現!

使用方法

履の下に装着した**ダッシュビート**を
後ろ足で蹴り上げるように走る。

1 2 3 4

※ 履きやすさのためには、履きしつかりと履いて、あたかも履き慣れた履き物に履き替えてください。
※ 履き慣れた履き物に履き替えてください。
※ 履き慣れた履き物に履き替えてください。



<http://www.mizuno.jp/dashdriver/>

<https://jpn.mizuno.com/ec/dispatch/attgrp/K3JKJ801/>

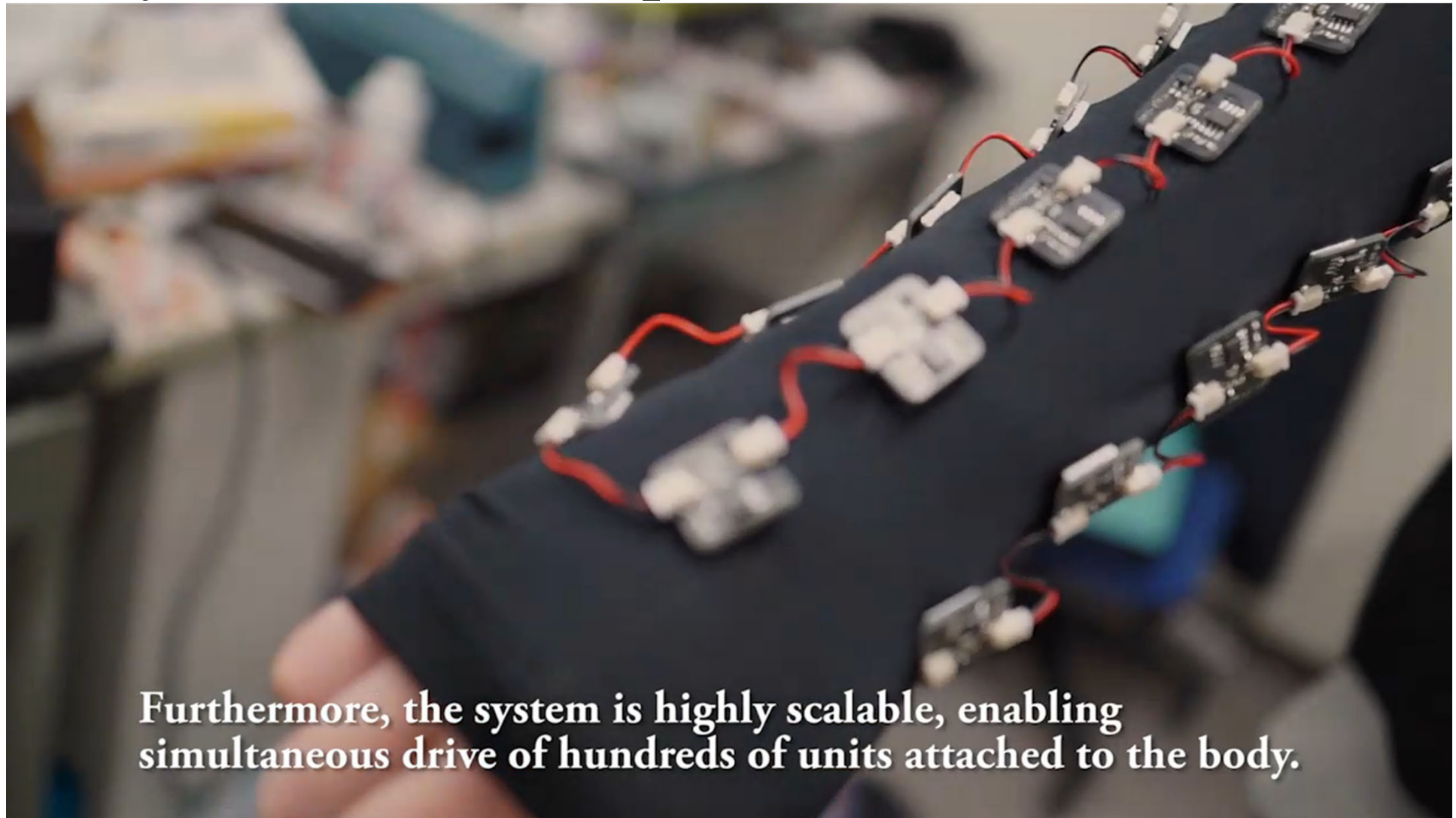
Using commodity: Shower



K. Hoshino, M. Koge, T. Hachisu, R. Kodama, H. Kajimoto, "Jorro Beat: Shower Tactile Stimulation Device in the Bathroom," In CHI 2015 Extended Abstracts on Human Factors in Computing Systems. ACM, 2015.4, Seoul, Korea



Projection based haptics



プロジェクション通信：世界座標系に情報を付与する簡便な方法。触覚の観点では、通信遅延をなくす手法とみなせる。Latency becomes critical issue in the whole-body haptics. Projection based haptics is solution.

Uematsu et al.: HALUX: Projection-based Interactive Skin for Digital Sports. SIGGRAPH'16

HaptoMapping: Visuo-Haptic Augmented Reality by Embedding User-Imperceptible Tactile Display Control Signals in a Projected Image Yamato Miyatake, Takefumi Hiraki, Daisuke Iwai, Kosuke Sato (TVCG2021)

HaptoMapping

Visuo-Haptic Augmented Reality by Embedding User-Imperceptible Tactile Display Control Signals into Projected Images

Yamato Miyatake Takefumi Hiraki

Daisuke Iwai Kosuke Sato

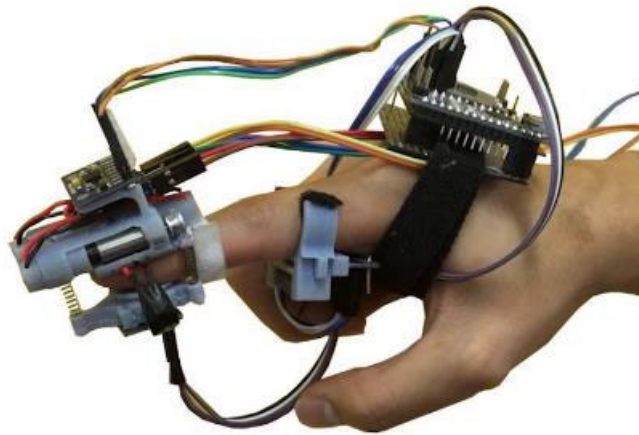


プロジェクションによる触覚テクスチャ通信 Projection based tactile-texture communication.

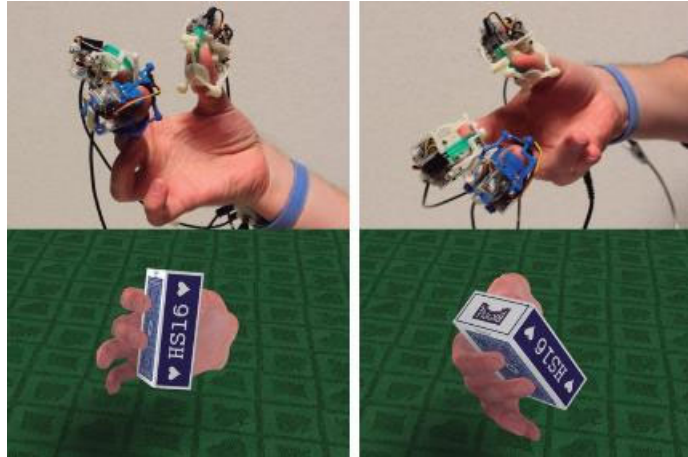
<https://www.youtube.com/watch?v=6Ch1j9zUWoU>

<https://doi.org/10.1109/TVCG.2021.3136214>

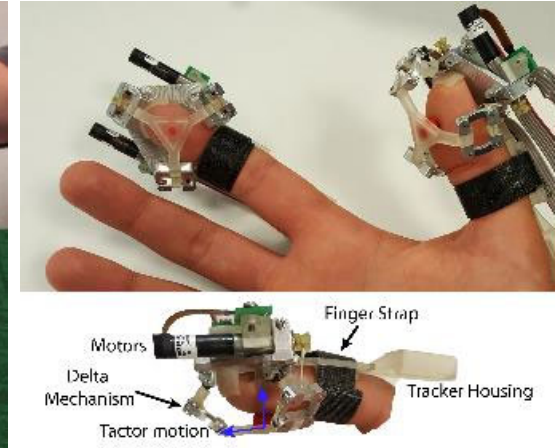
The whole-body haptics: the other merit



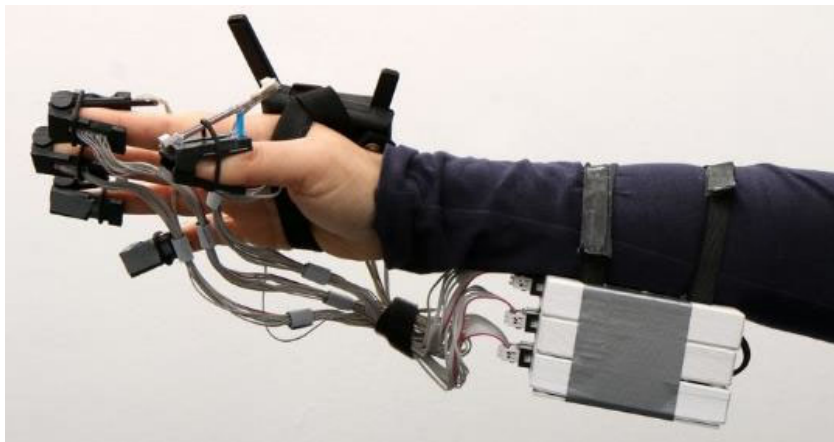
Kim et al., URAI2016



Wearable Haptics project by SIRS Lab



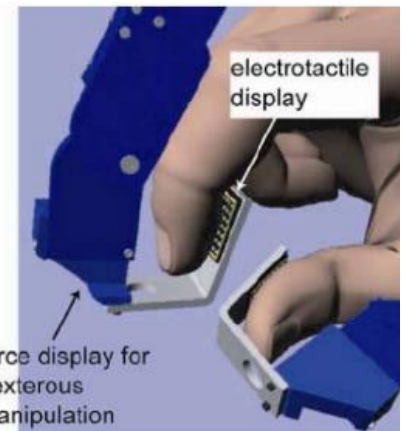
Schorr et al., IEEE ToH, 2017



Sagardia et al., IEEE Aerospace Conference, 2015



Sato et al., Siggraph2007



Fingertip might be too small for dexterous tactile display.



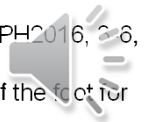
Transfer fingertip haptics to the other part (1)



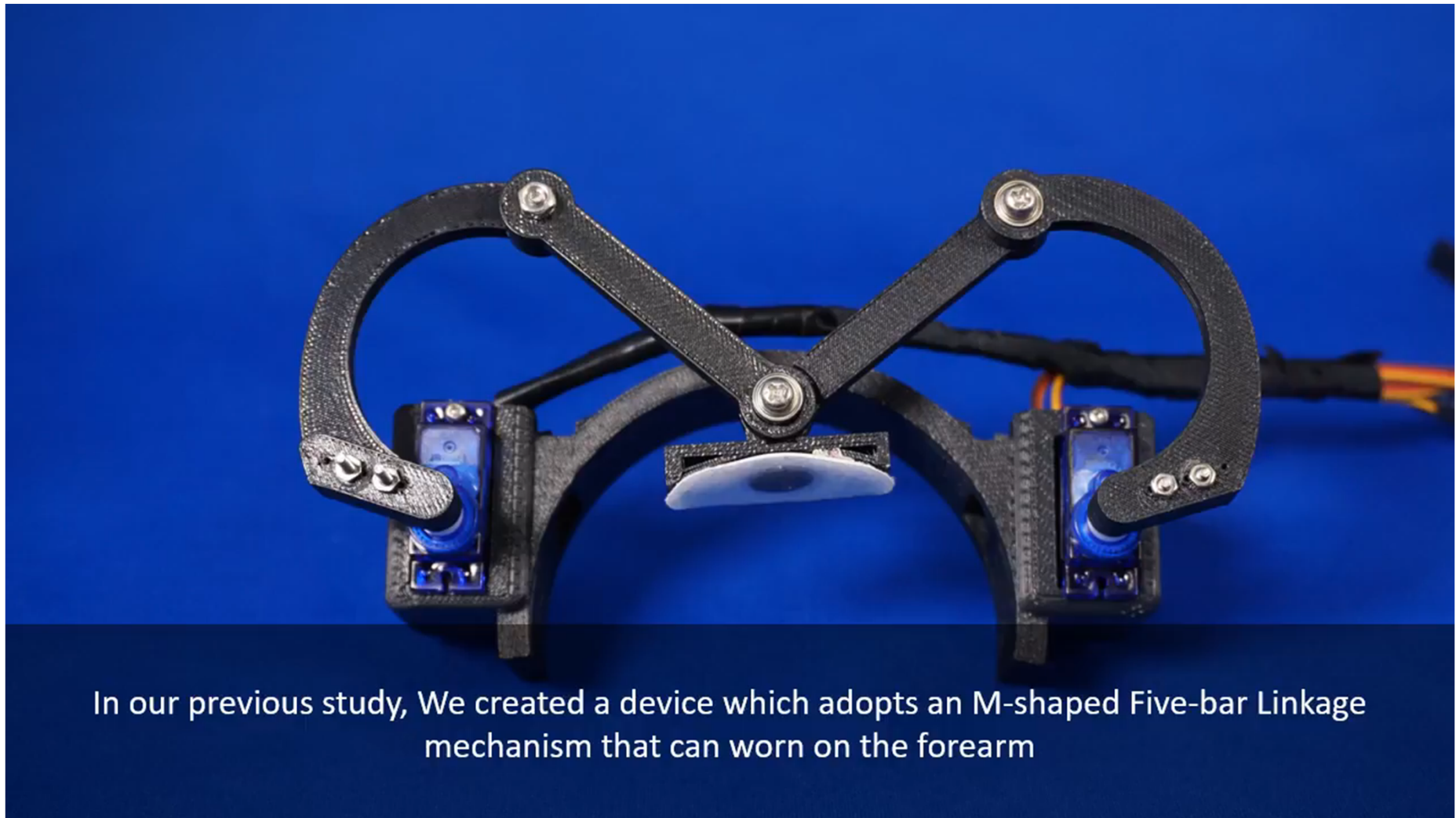
- Common approach for prosthetic arms.
- Transfer fingertip distributed tactile sensation to sole.

Tetsuhiro Okano, Koichi Hirota, Takuya Nojima, Michiteru Kitazaki, Yasushi Ikei: Haptic Feedback for Foot Sole Using Pneumatic Pressure Device; Proc. ASIAGRAPH2016, 2-6, 2016.3.

Keigo Hiki, Tetsuhiro Okano, Sho Sakurai, Takuya Nojima, Michiteru Kitazaki, Yasushi Ikei, Koichi Hirota: Substitution of hand-object pressure cues with the sole of the foot for haptic presentation using a tactile pin array; Proc. EuroHaptics 2018, LNCS 10894, 239-251, 2018



Transfer fingertip haptics to the other part (2)



- Common approach for prosthetic arms.
- Transfer fingertip force to forearm.



Transfer fingertip haptics to the other part (3)



- Common approach for prosthetic arms.
- Transfer fingertip force to face around HMD.



全身触覚からInterpersonal触覚へ／From the whole body to interpersonal

(HS2020) Interpersonal Vibrotactile Feedback Via Waves Transmitted through the Skin: Mechanics and Perception by Taku Hachisu, Gregory Reardon, Yitian Shao, Kenji Suzuki, and Yon Visell



https://www.youtube.com/watch?v=cJDaGbI0la0&feature=emb_logo

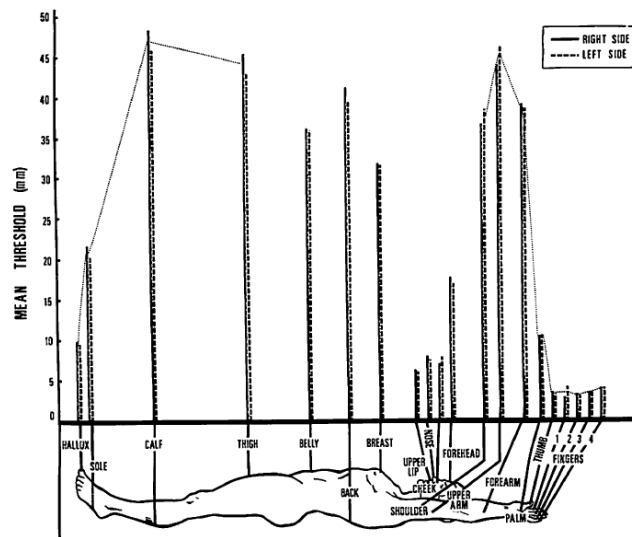
- 二人がそれぞれスマートブレスレットを装着する。振動が人から人に移動していく感覚（仮現運動）が生じる。（実際に機械的にも振動が伝搬している）。
- Two people each wear a smart bracelet. A sensation of vibrations moving from person to person occurs. (The vibrations are actually transmitted mechanically as well.)



指先よりも「高性能」な部位への提示

Is there a better location than fingertips?

Joseph C. Stevens & Kenneth K. Choo (1996) Spatial Acuity of the Body Surface over the Life Span, Somatosensory & Motor Research, 13:2, 153-166



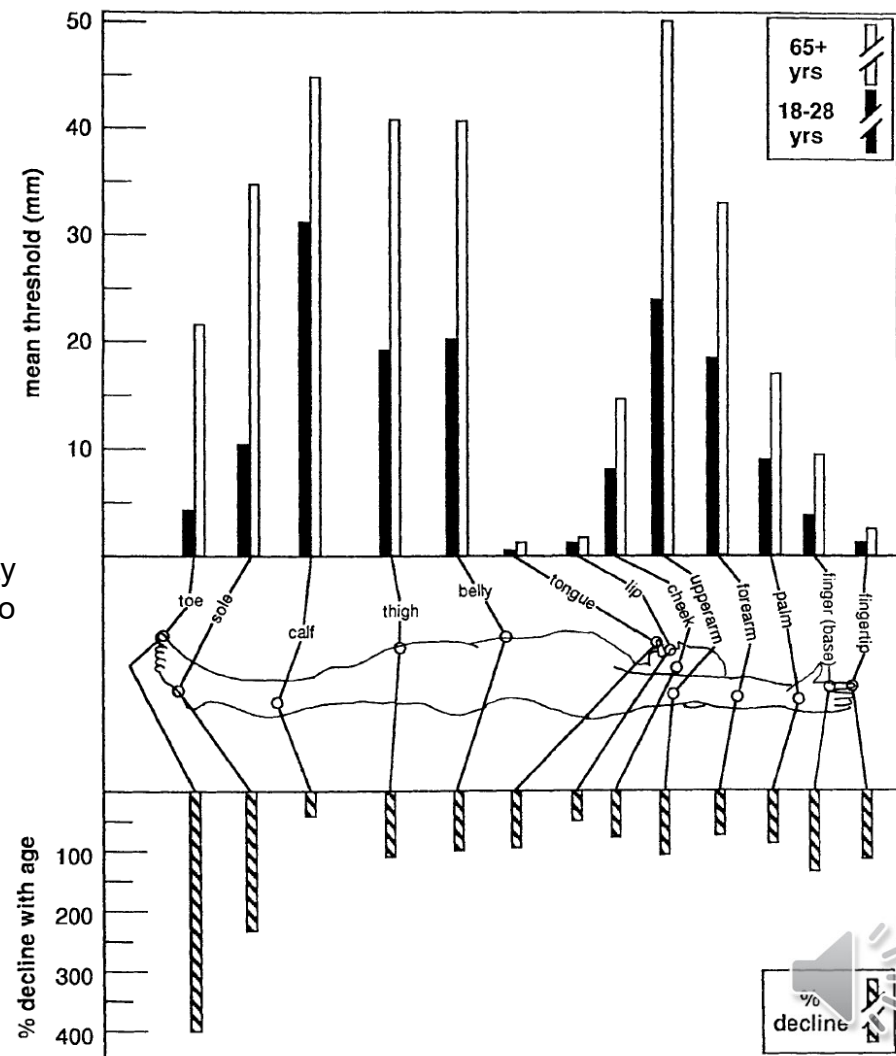
S. Weinstein, Intensive and Extensive Aspects of Tactile Sensitivity as a Function of Body Parts, Sex, and Laterality. In D. R. Kenshalo (Ed.), The skin senses, 1968.

解像度に関して唇、舌は指先よりも優れる。

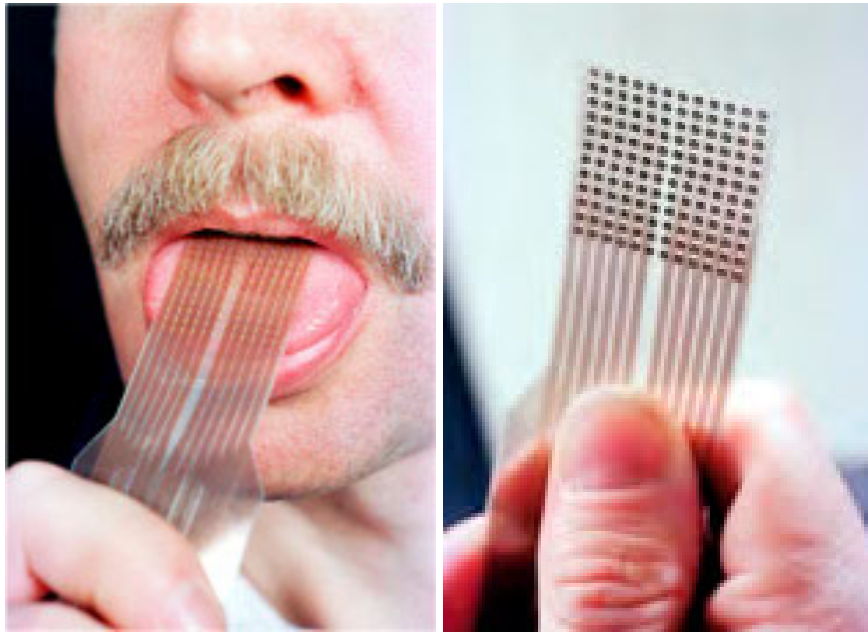
加齢の影響に関して、唇の減退は少ない。

In terms of resolution, lips and tongue are better than fingertips.

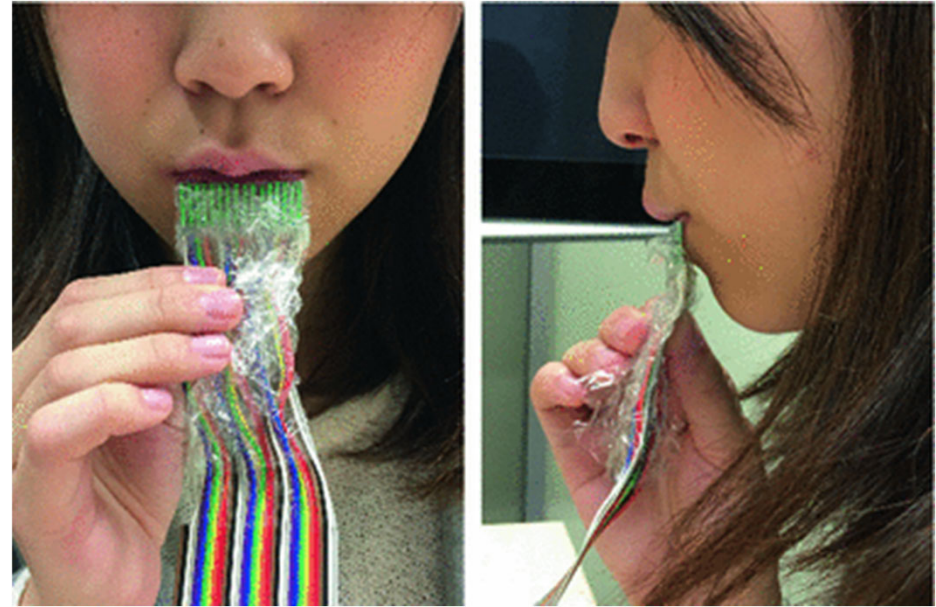
In terms of aging effect, lips are better than fingertips.



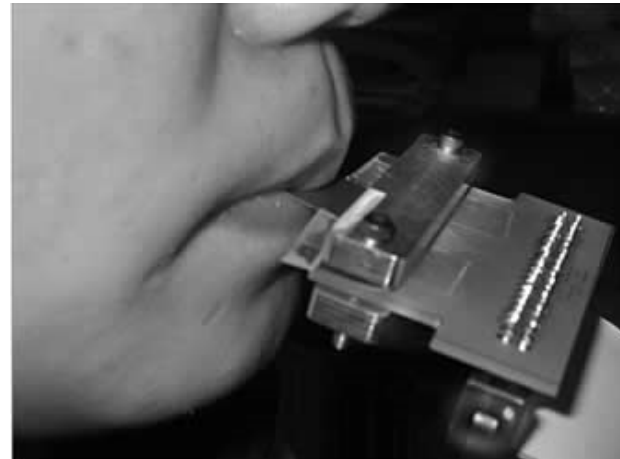
指先よりも「高性能」な部位への提示: 舌、唇



The tongue display unit (TDU) for electrotactile spatiotemporal pattern presentation. Kakzmarek, Scientia Iranica, 18(6) (2011)



High-Resolution Tactile Display for Lips, Yuhei Tsutsui, Koichi Hirota, Takuya Nojima, Yasushi Ikei, HIMI2016



An initial study on lip perception of electrotactile array stimulation
Wei Liu, MS; Hui Tang, Journal of Rehabilitations Research & Development (2005)

(CHI2023) LipIO: Enabling Lips as both Input and Output Surface“, Arata Jingu, Yudai Tanaka, Pedro Lopes

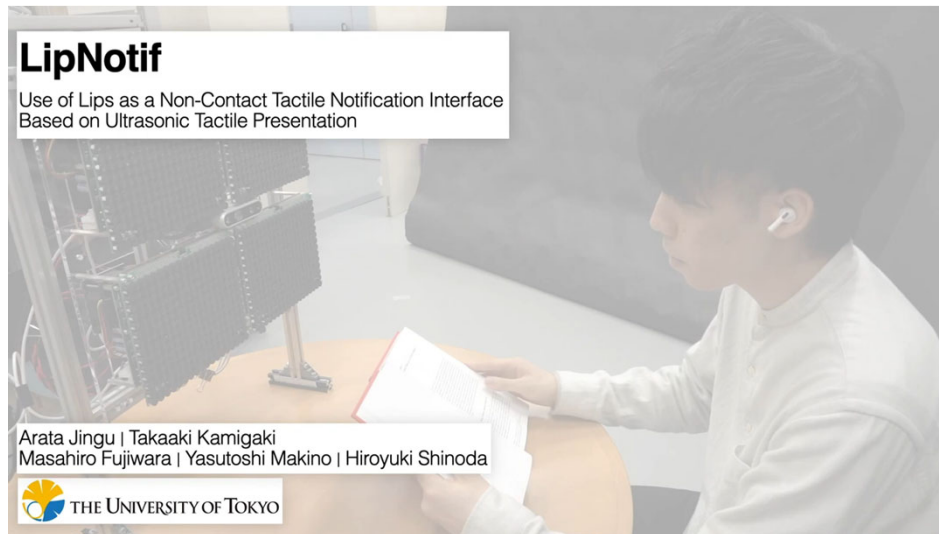
LipIO: enabling lips as both
input and output surface

arata jingu, yudai tanaka, pedro lopes



<https://www.youtube.com/watch?v=eooxckEgJZA&t=1s>

超音波触覚による唇への触覚提示 Presentation to lips by ultrasound



(UIST2021) LipNotif: Use of Lips as a Non-Contact Tactile Notification Interface Based on Ultrasonic Tactile Presentation

<https://www.youtube.com/watch?v=4dkOTClYWfo>

(CHI2022) Mouth Haptics in VR using a Headset Ultrasound Phased Array Vivian Shen, Craig Shultz, Chris Harrison

<https://www.youtube.com/watch?v=LsGnpBoEWdk>

衛生面の問題解決 + 敏感な唇への提示 + HMDとの親和性
Solving hygiene issues + presentation to sensitive lips + compatibility with HMD

触覚ディスプレイの応用分野の方向性

Elements of application for tactile display

- **Touch Panel & Mobile**
 - 市場が巨大。差別化要素としての触覚
- **Emotion, Affection**
 - 触覚は驚きから愛情まで、幅広い情動へ働きかけることが出来る
- **Navigation, Instruction**
 - 触覚は身体座標に直接提示できる。また無意識の運動も誘導できる
- **Reality, Multimodal**
 - 触覚が視聴覚に加わることで存在感、現実感を上げることが出来る
- **The Whole Body**
 - 身体全体への触覚提示により、触覚にも臨場感を生じる
- **Tactile AR**
 - 触覚を現実世界で使うことでAR化する



簡便な触覚AR: クリック感の付与

Simplest Tactile AR: Adding Clicking Sensation

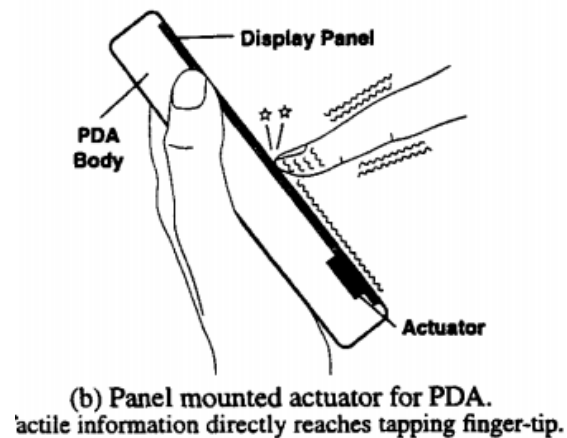
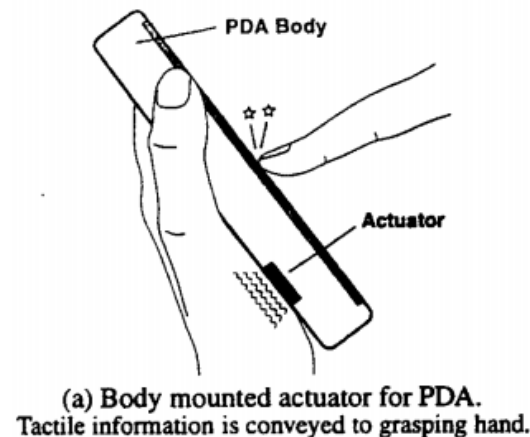
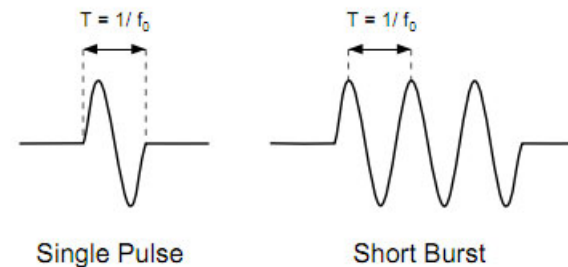


図 1: アクチュエータの設置状況
PDA の筐体に貼り付けている。



クリック音のかわりに短時間の振動を与える。

接触という元の触覚にクリック触覚が追加されているという意味では触覚AR

Fukumoto et al., Active click: tactile feedback for touch panels CHI2001



Almost bare finger augmentation

(UIST2018) Tacttoo: A Thin and Feel-Through Tattoo for On-Skin Tactile Output

Anusha Withana, Daniel Groeger, Jürgen Steimle

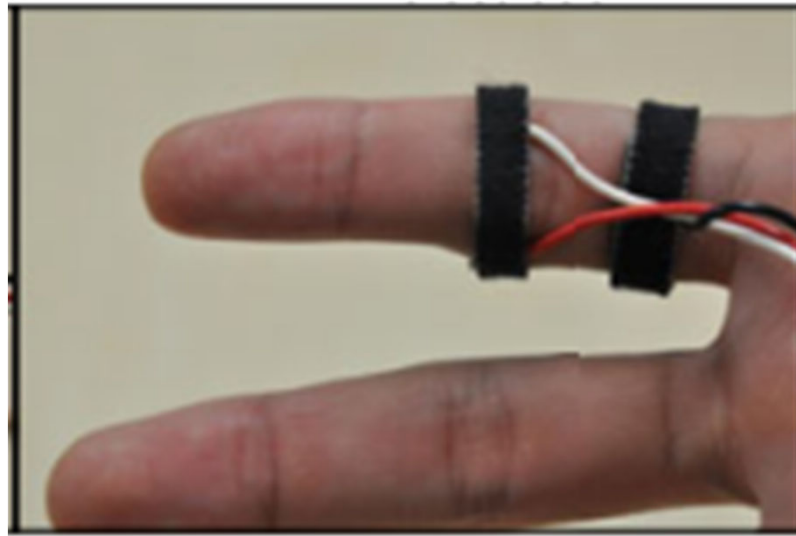


<https://www.youtube.com/watch?v=LcYvjkyKKaM>

- 電気触覚ディスプレイで入れ墨のような触覚提示を実現. 実際の触覚を阻害しない.



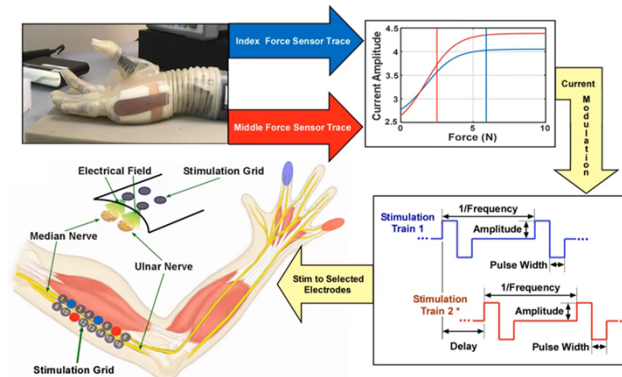
指を「素手」に保つ / Keep fingers uncovered



[EuroHaptics2014] Roughness Modulation of Real Materials Using Electrotactile Augmentation Shunsuke Yoshimoto et al.,
指の中節、基節間の電気刺激によって指先への触覚提示を行う
Tactile presentation to the fingertips by electrical stimulation between the middle and basal segments of the finger



Methods (Set-Up)



Joint Department of
BIOMEDICAL
ENGINEERING

3



UNC
CHAPEL HILL

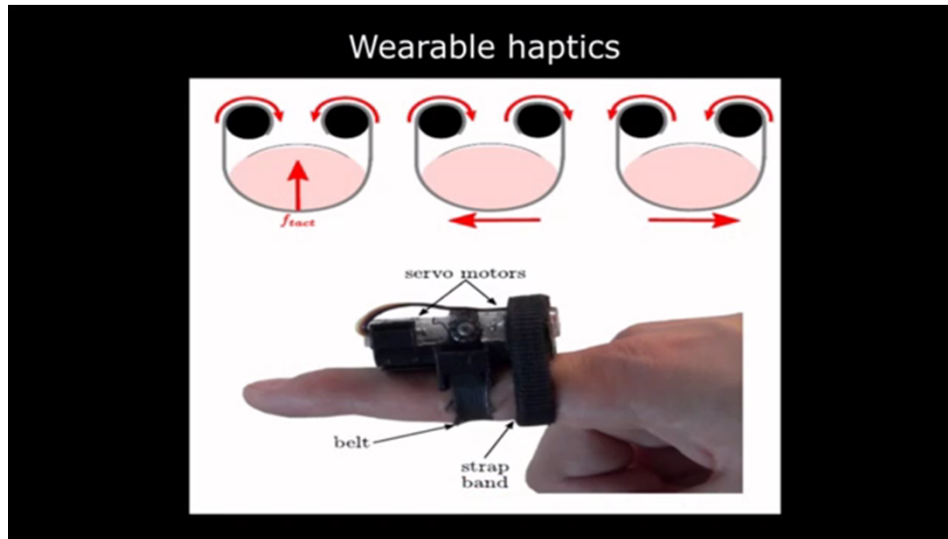
NC STATE
UNIVERSITY

https://www.youtube.com/watch?v=Oj_Gh9Wpg1Y

[Haptics Symposium 2020] Object Shape and Surface Topology Recognition using Tactile Feedback Evoked through Transcutaneous Nerve Stimulation by Luis Vargas, He (Helen) Huang, Yong Zhu, and Xiaogang Hu
腕の複数の電極で、指の感覚神経を個別に刺激。これを義手の感覚フィードバックに用いる
Electrodes on the arm stimulate the sensory nerves of the fingers individually. For prosthetic hand.

(CHI2023) Full-hand Electro-Tactile Feedback without Obstructing Palmar Side of Hand Yudai Tanaka, Alan Shen, Andy Kong, Pedro Lopes
手の甲側からの電気刺激により掌側に触覚を生起させる
Electrical stimulation from the back of the hand generates tactile sensations on the palm side

Bare finger augmentation. Modulate real tactile sense.



指中節への触覚提示で、指先の触覚を変調できる(硬柔感)

Xavier de Tinguy, Claudio Pacchierotti, Maud Marchal, Anatole Lécuyer. Enhancing the Stiffness Perception of Tangible Objects in Mixed Reality Using Wearable Haptics. IEEE VR 2018

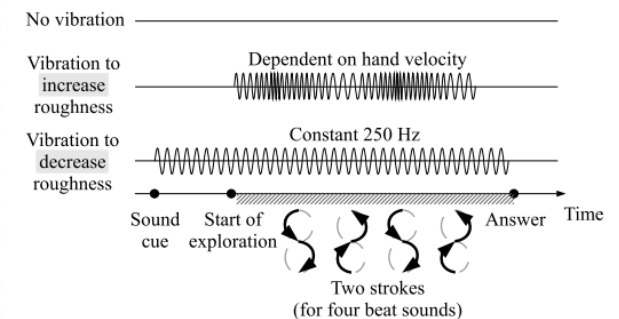
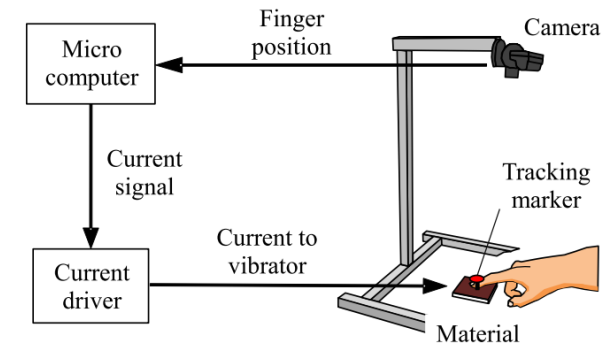
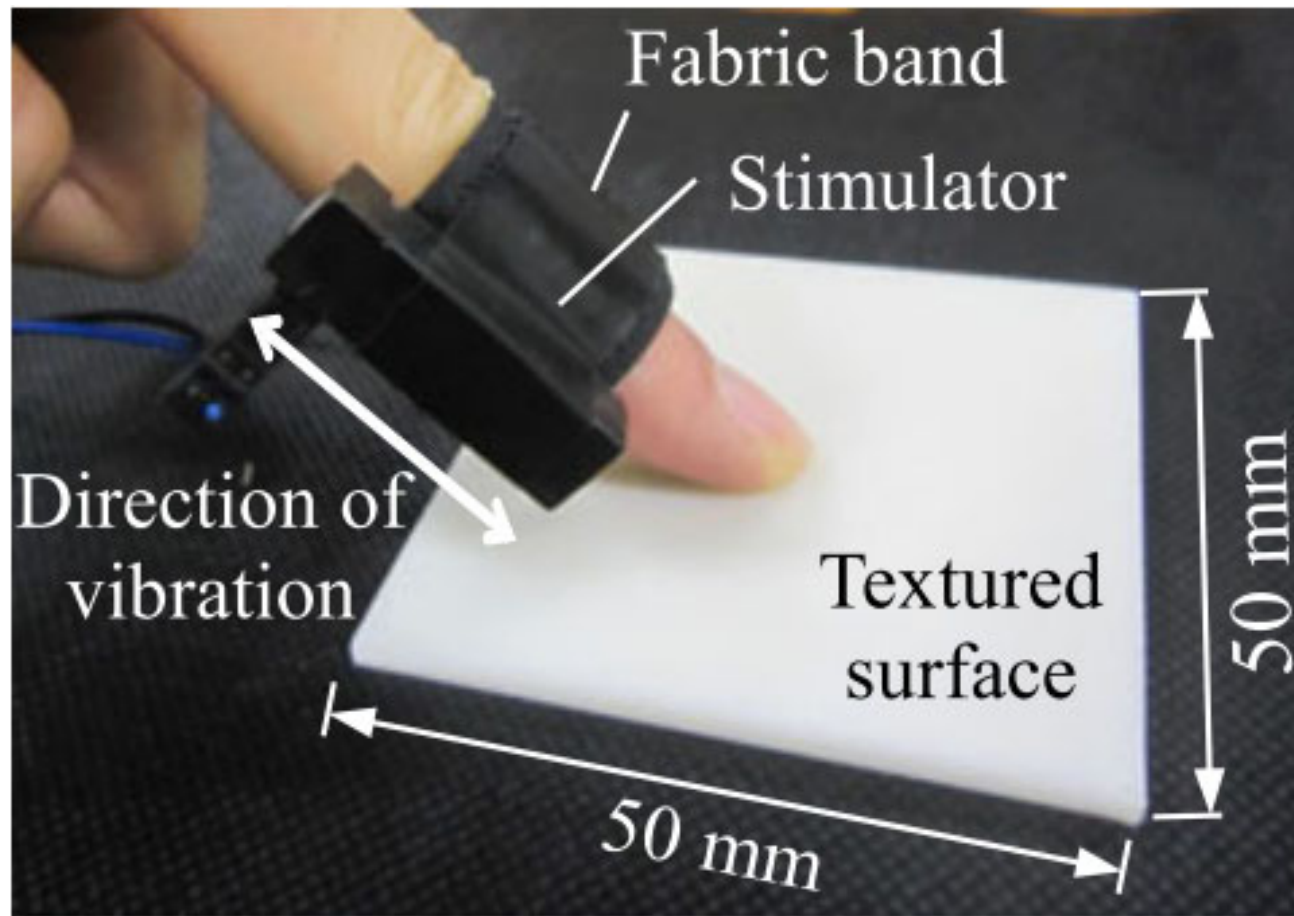
<https://www.youtube.com/watch?v=qA4xr8IV4WA>

指中節への触覚提示で、指先の触覚を変調できる(硬柔感、摩擦感、形状)

Steeven Villa Salazar, Claudio Pacchierotti, Xavier de Tinguy, Anderson Maciel, Maud Marchal. "Altering the Stiffness, Friction, and Shape Perception of Tangible Objects in Virtual Reality Using Wearable Haptics," 2020. <https://www.youtube.com/watch?v=3CSqcOUeUeA>



現実の触感を調整する Modulate real texture

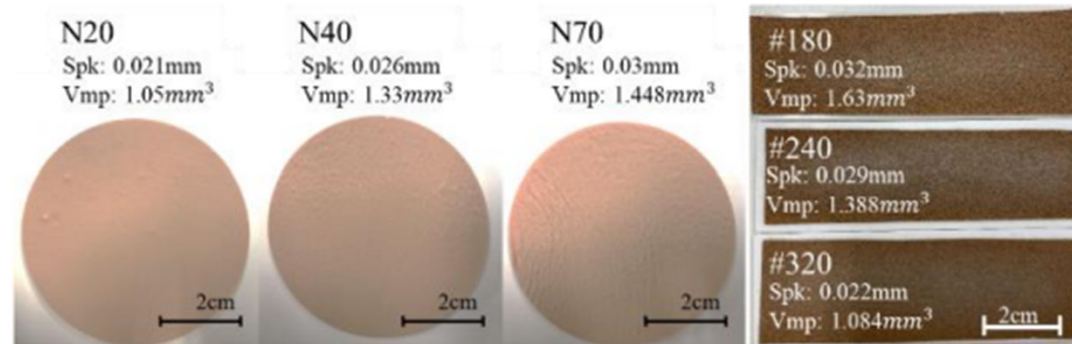
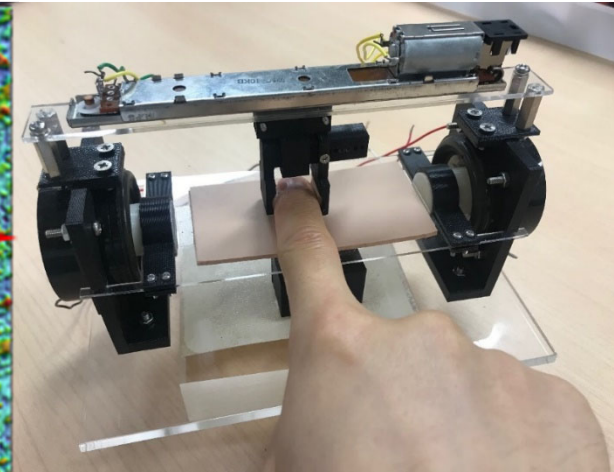
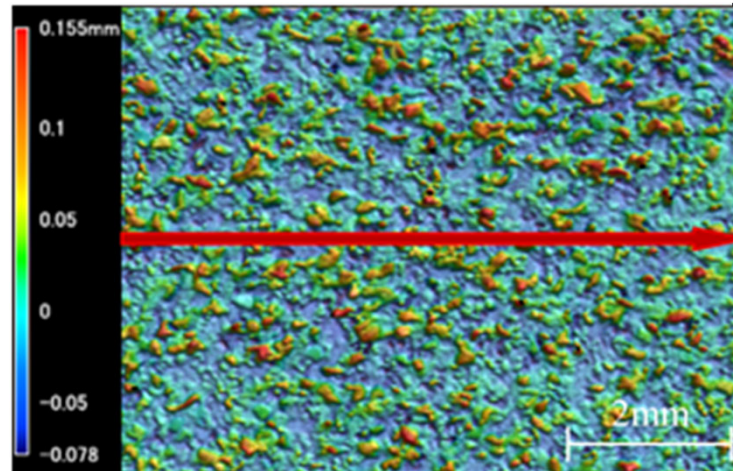


テクスチャを持つ表面の粗さを、振動によって変調。

指の動きに応じた振動で粗さを増し、定常的な高周波振動で粗さを減らす。

Vibrotactile Stimulation to Increase and Decrease Texture Roughness. Shuhei Asano, Shogo Okamoto, and Yoji Yamada, IEEE Trans. Human-Machine Systems (2014)

現実の触感を調整する Modulate real texture



Jianyao Zhang, Hiroyuki Kajimoto: A Robust Approach for Reproducing the Haptic Sensation of Sandpaper With Different Roughness During Bare Fingertip Interaction
Frontiers in VR, 2022.

<https://www.frontiersin.org/articles/10.3389/frvir.2022.829946/full>

Jianyao Zhang, Hiroyuki Kajimoto: Haptic Reproduction of Different Human Skins and Comparison of Rendering Approaches, 日本バーチャルリアリティ学会論文誌, 27(3), pp.231-234, 2022.

https://www.jstage.jst.go.jp/article/tvrsj/27/3/27_231/_pdf/-char/ja

異なる年齢の人肌、異なる紙やすりの粗さ、を再現。表面形状を計測して加速度振動に変換。

Reproduce human skin of different ages, different sandpaper roughness, and Measure surface topography and convert to acceleration vibration.

(UIST2021) Altering Perceived Softness of Real Rigid Objects by Restricting Fingerpad Deformation Yujie Tao, Shan-Yuan Teng, Pedro Lopes



指の側面を圧迫することで皮膚変形が変化し、結果として対象物の硬さ知覚を変化させる
Pressure on the side of the finger changes the skin deformation and consequently
changes the object's perception of hardness

<https://www.youtube.com/watch?v=pLVi9Sy9vO8&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=26>

(CHI2024) vARitouch: Back of the Finger Device for Adding Variable Compliance to Rigid Objects

Gabriela Vega, Valentin Martinez-Missir, Dennis Wittchen, Nihar Sabnis, Audrey Girouard, Karen Anne Cochrane, Paul Strohmeier

<https://www.youtube.com/watch?v=qTc6QyUaD08>

Exploration #1

Is compliance perceived from the back-of-finger?

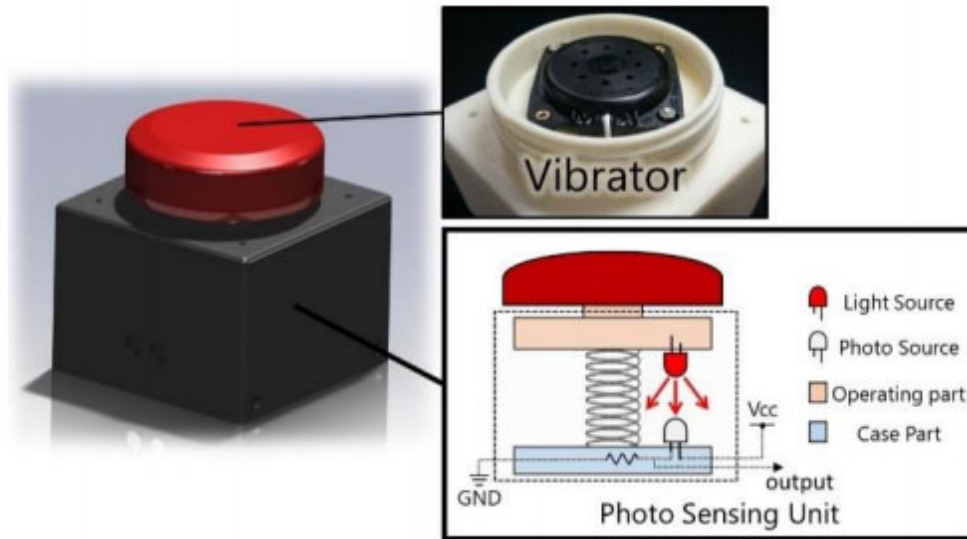
How does it relate to stimulation parameters?

How strong is it?



- 指の爪への振動(Grain Vibration)で実物の柔らかさを変える。爪光センサで圧力を計測。
- Vibration to the finger nail to modulate real-object softness. Nail mounted sensor also enables pressure measurement.

実際のボタンに振動を付与することで感覚を拡張 Physical Button + Vibration

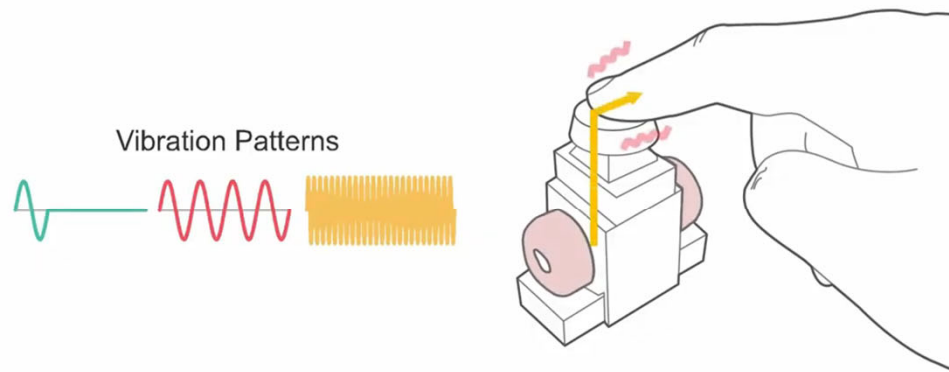


D. Ogawa, V. Yem, T. Hachisu, H. Kajimoto:
Multiple texture button by adding haptic
vibration and displacement sensing to the
physical button, ACM SIGGRAPH Asia 2015
Haptic Media And Contents Design, 2015,

<https://dl.acm.org/doi/10.1145/2818384.2818394>

https://www.gizmodo.jp/2015/11/haptic_media_and_contents_desi.html

AUGMENTING PHYSICAL BUTTONS



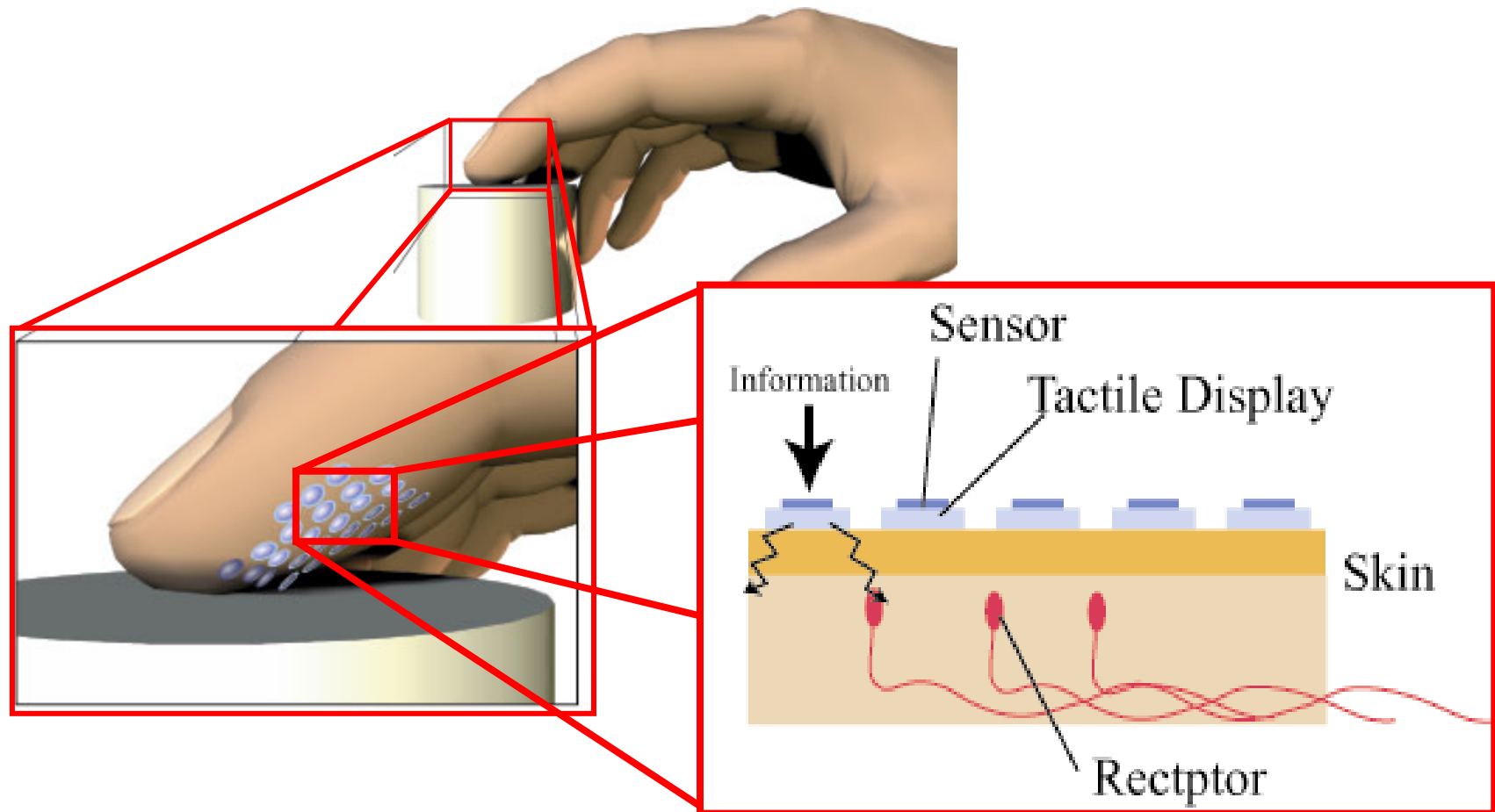
(UIST2020) Augmenting
Physical Buttons with
Vibrotactile Feedback for
Programmable Feels Chaeyong
Park, Jinhyuk Yoon, Seungjae
Oh, Seungmoon Choi

<https://www.youtube.com/watch?v=GIMEwPrSew0>



能力拡張としての触覚AR

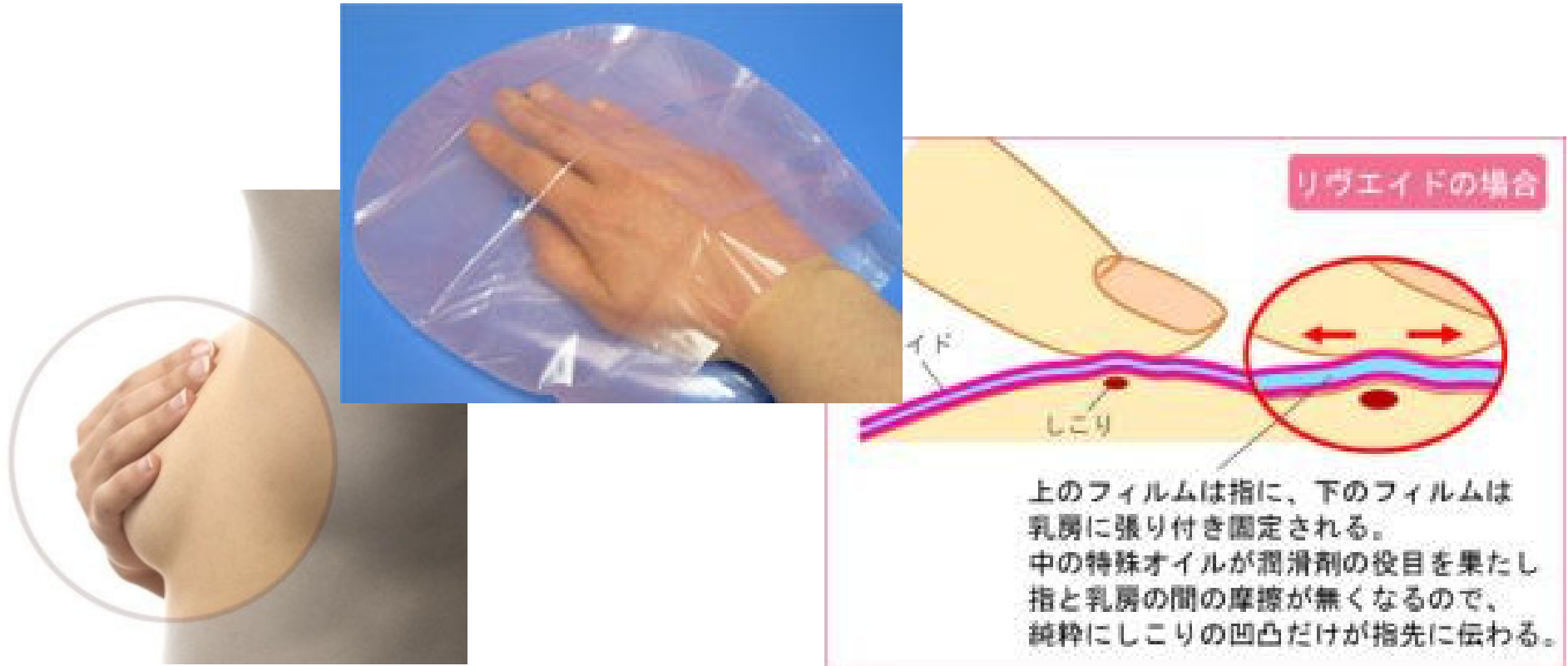
Tactile AR as ability augmentation



新しい人工受容器として機能
Works as a new artificial receptor



触覚ARとしての乳がん診断具／ Breast Cancer Checker as Tactile AR



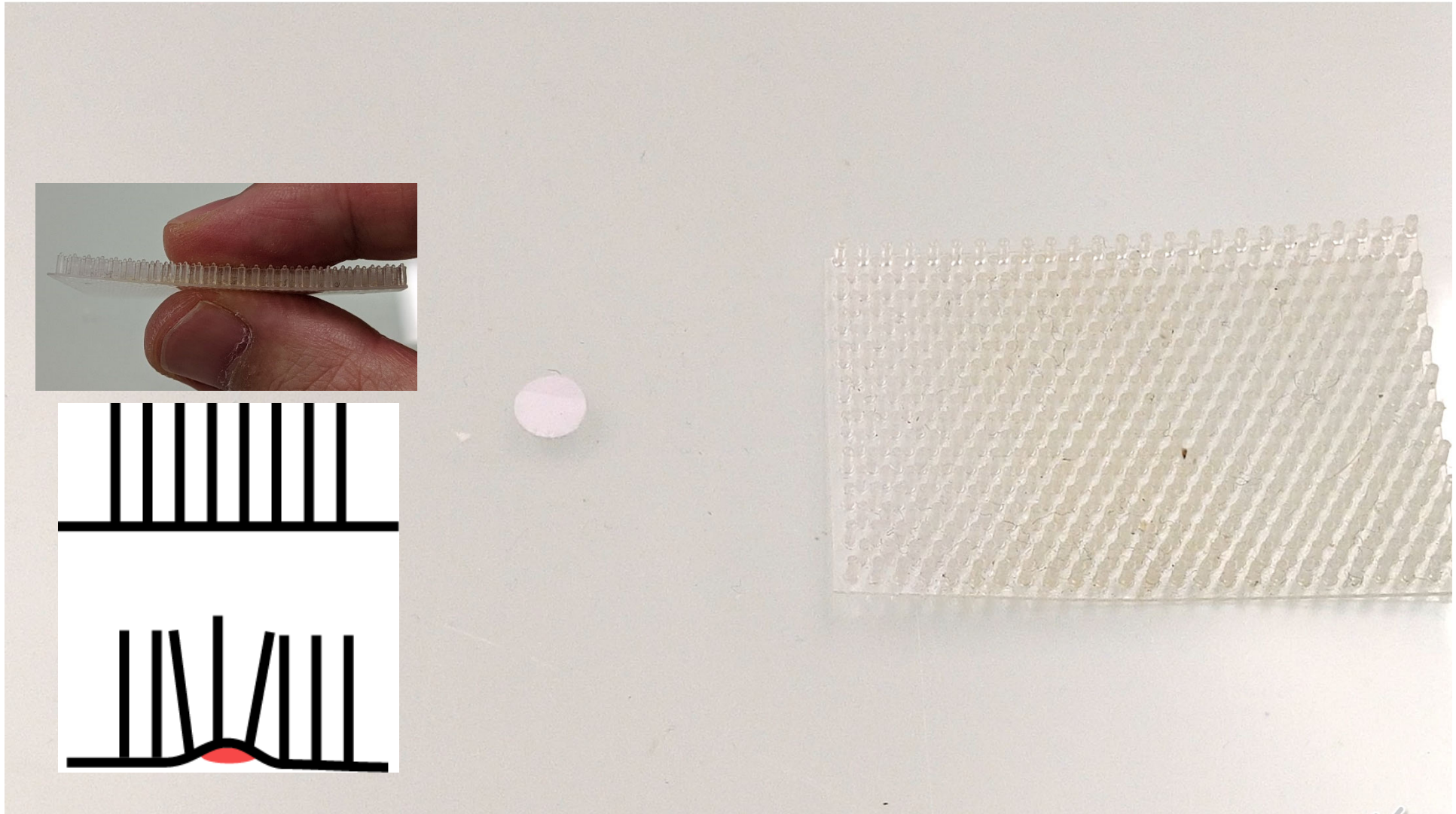
乳がん自己診断具／Checking Breast Cancer

潤滑オイルの入った袋ごしに撫でると、表面のテクスチャに依存せず内部のしこり(腫瘍、tumor)を知覚できる

Rub breast through oil-contained thin plastic bag. The oil reduces surface texture, and internal tumor can be observed



触覚のAR: 触覚コンタクトレンズ Tactile Contact Lens as Tactile AR

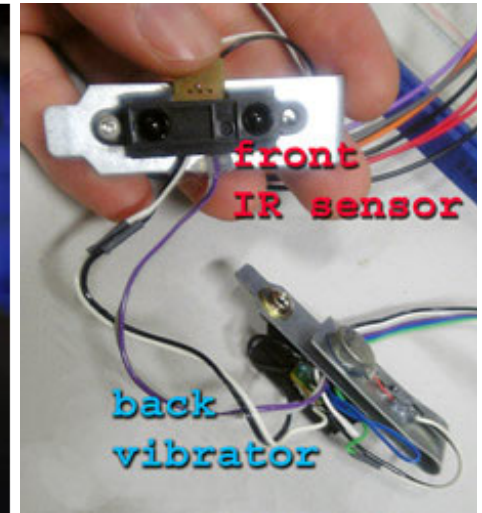


Sano, A., Mochiyama, H., Takesue, N., Kikuuwe, R., & Fujimoto, H. (2004). TouchLens: Touch enhancing tool. TExCRA2004



Sensing->Display

Haptic Radar



Cassinelli, A., Reynolds, C. and Ishikawa, M. *"Haptic Radar"*. SIGGRAPH2006



Sensing -> Display at fingertip: SmartFinger



Ando, H., Miki, T., Inami, M., & Maeda, T. (2002). Smartfinger: Nail-mounted tactile display. : *ACM SIGGRAPH 2002*

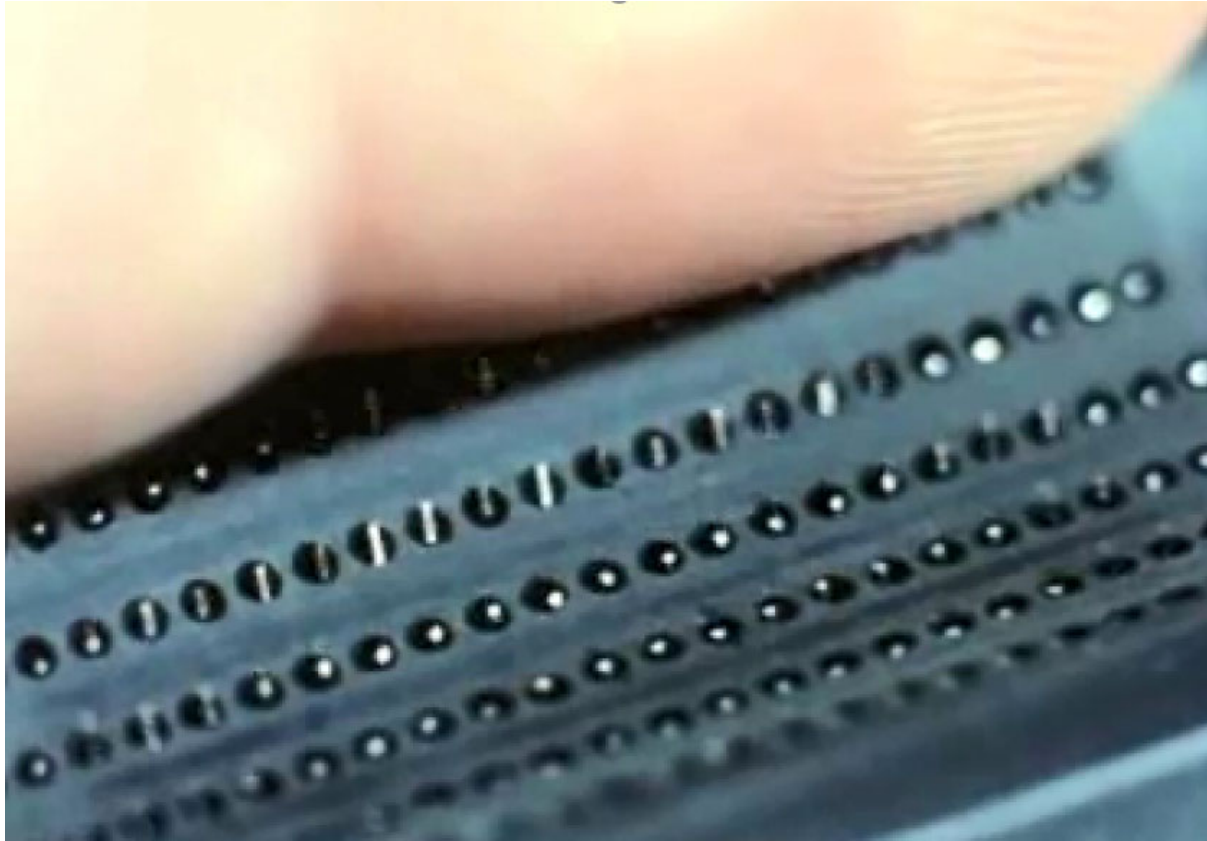


Sensing -> Display at fingertip: SmartTouch



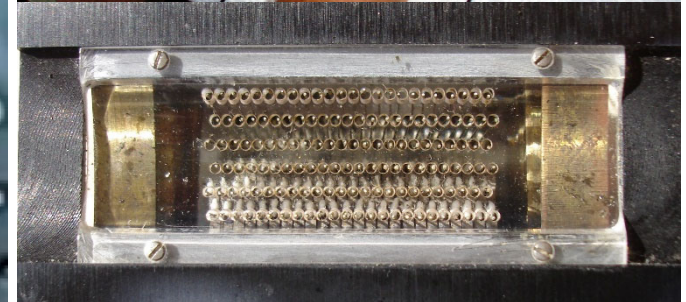
Kajimoto, H., Kawakami, N., Tachi, S., & Inami, M. (2004). SmartTouch: Electric Skin to Touch the Untouchable. *IEEE Computer Graphics and Applications*

オプタコン: 視触覚変換装置／ Optacon: Vision-Tactile Converter (1976)



Braille Display (Optacon), Linville 1976

<https://www.youtube.com/watch?v=ghsXhqu8FCY>

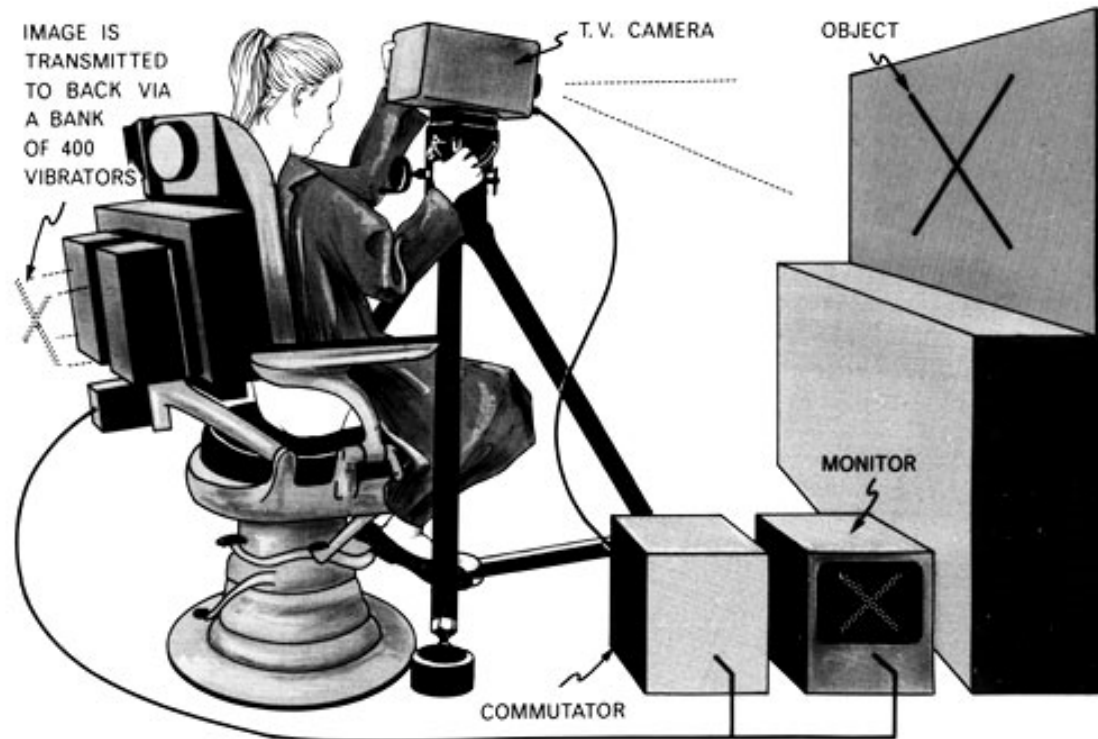


<https://en.wikipedia.org/wiki/Optacon>



視覚-触覚変換

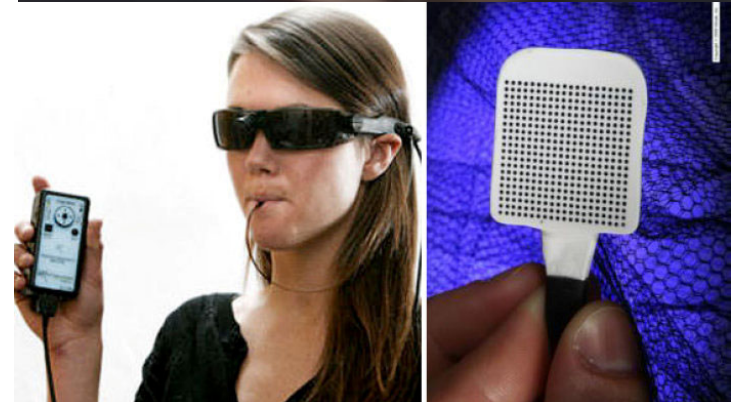
Vision-Tactile Conversion for the blind



- Collins, “Tactile television - mechanical and electrical image projection,” IEEE Man-Machine Systems, 1970.



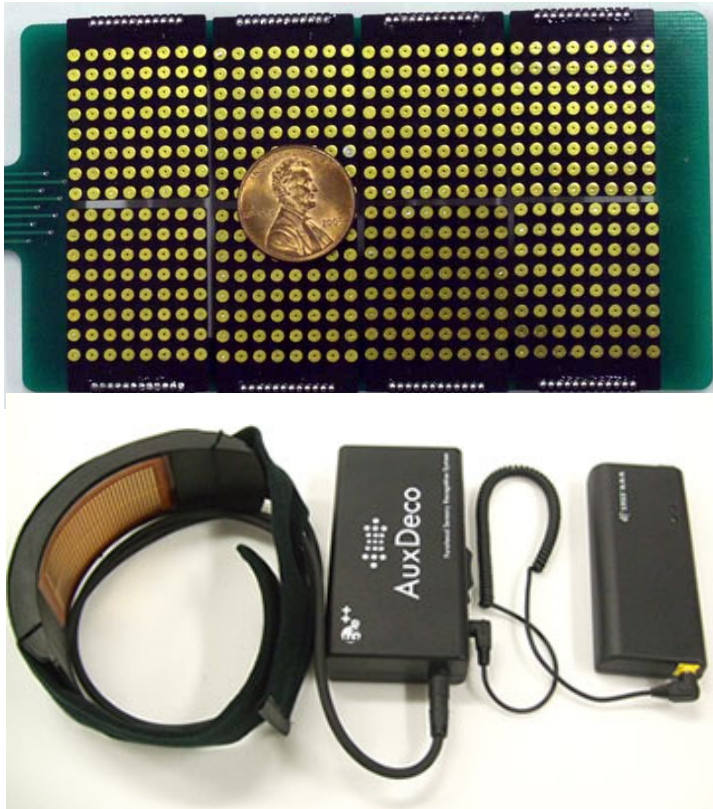
BrainPort: Tongue display for the blind



<https://www.youtube.com/watch?v=CNR2gLKnd0g>



Forehead



Tactile-vision substitution system (TVSS) for visually handicapped.
Forehead was used for intuitive understanding
(what you are facing is what you are feeling on your face).

Kajimoto et al., "Forehead Electro-tactile Display for Vision Substitution," EuroHaptics 2006



低コスト感覚代行: HamsaTouch



Kajimoto et al., HamsaTouch: Tactile Vision Substitution with Smartphone and Electro-Tactile Display , CHI 2014



小テスト：一週間以内に提出

Mini Test: Submit in one week

今回は下記でお願いします。成績に関係しません。

(B4以上) 所属する研究室と、自分の研究内容を教えてください。

(B3以下) 受講理由を教えてください。

(全員) 授業の感想を教えてください。

Please do the following this time. It does not affect your grade.

(B4 or above) Please tell us the laboratory you belong to and your research.

(B3 and below) Please tell us your reason for taking the class.

(All) Please tell us your impressions of the class.

