

Interactive System
インタラクティブシ
テム特論(6)

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Hash tag #itsys

Schedule

- 10/14 講義 Lecture
- 10/21 講義 Lecture
- 10/28 (Conference)
- 11/04 講義 Lecture
- 11/11 (Conference)
- 11/18 (Chofu-sai)
- 11/25 講義 Lecture
- 12/02 講義 Lecture
- 12/09 (Conference)
- 12/16 講義 Lecture / 発表論文選択
- 12/23 (holiday)
- 01/06 講義 Lecture
- 01/13 講義 Lecture
- 01/20 発表 Presentation
- 01/27 発表 Presentation
- 02/03 発表 Presentation
- 02/10 発表 Presentation

Outline

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. 小テスト／Mini Test
6. 聴覚、聴覚インタフェース／Auditory Interface
7. **触覚、触覚インタフェース／Tactile Interface**
8. 触力覚、触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
10. 最新のインタフェース研究／Recent Research
11. 小テスト／Mini Test



触覚＝体性感覚＋皮膚感覚

Haptic Sense = Proprioception + Cutaneous Sense



触覚＝接**触**によって生じる**感覚**

(Haptic＝「接触(Contact)」(ギリシャ語/in Greece))

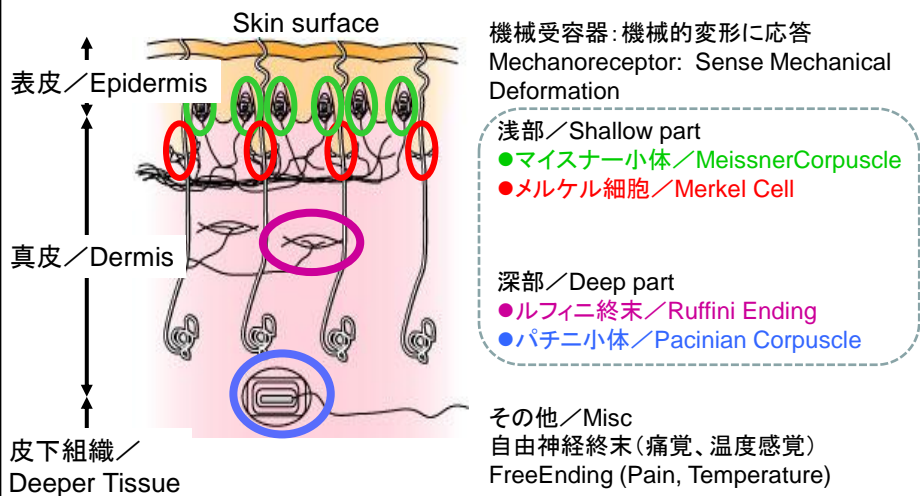
- 皮膚表面の変形(皮膚感覚/Cutaneous Sense, Skin Sense)
- 筋肉の伸縮, 関節角(深部感覚・力覚/Proprioception, Force Sense)

今日の話: 狭義の皮膚感覚/Today's Talk focuses on skin

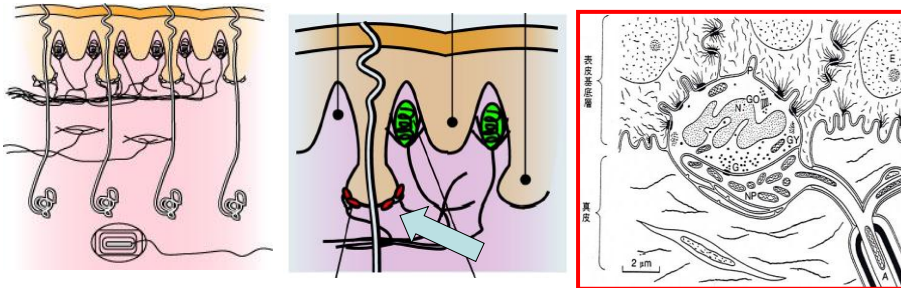
TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Perception & Illusion
3. Tactile Display
4. Tactile AR

Skin Structure (Hairless Parts)

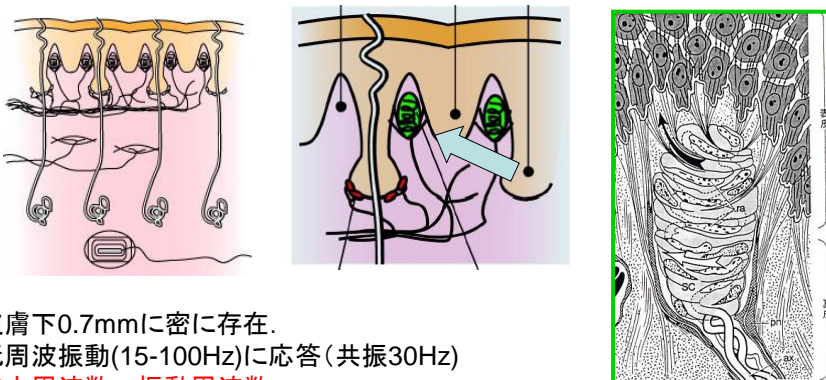


メルケル細胞／Merkel Cell



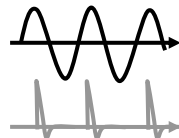
- 皮膚下0.9mmに密に存在.
- 唯一の細胞性受容器. 神経とシナプス接合
- 静的な歪に応答
- 発火頻度は歪の大きさに比例
- 単独の活動では純粋な圧覚を生成
- Densely Populated at 0.7 - 0.9mm depth.
- Sense Static Deformation.
- Pulse Frequency is Proportional to Deformation.
- When activated, Pure Pressure Sensation is generated.

マイスナー小体／Meissner Corpuscle

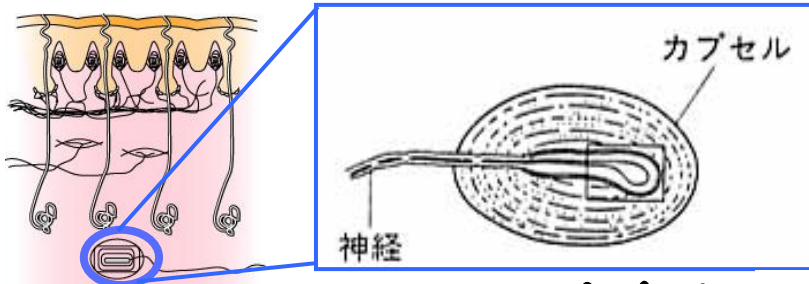


- 皮膚下0.7mmに密に存在.
- 低周波振動(15-100Hz)に応答 (共振30Hz)
- 発火周波数～振動周波数
- 単独の活動では振動感覚, パタパタ感を生じる

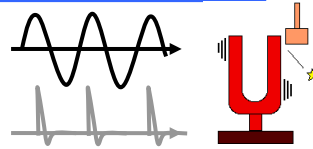
- Densely populated at 0.5 – 0.7mm depth.
- Sense Low Frequency Vibration (15-100Hz)
- Has Resonant Frequency (30Hz)
- Pulse Frequency ~ Vibration Frequency
- Single Activity Generates “Flutter” Vibratory Sensation



パチニ小体 / Pacinian Corpuscle

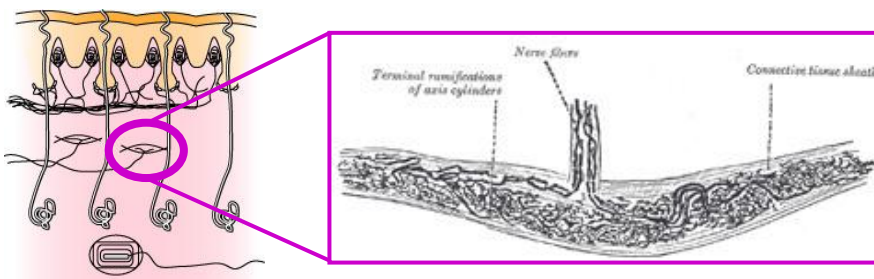


- 皮膚下2mm以上の深部にまばらに存在.
- 高周波振動に応答(60-800Hz)(共振250Hz)
- 発火周波数 ~ 振動周波数
- 単独の活動では音叉に触れたような振動感覚, 指全体の痺れ



- Sparsely populated at deep region (2mm ~)
- Sense High Frequency Vibration (60-800Hz)
- Has Resonant Frequency (250Hz)
- Pulse Frequency ~ Vibration Frequency
- Single Activity Generates "numb" sensation, just like touching a tuning fork or speaker

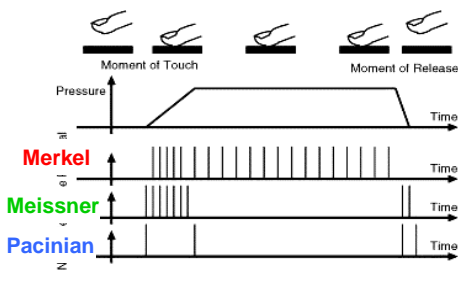
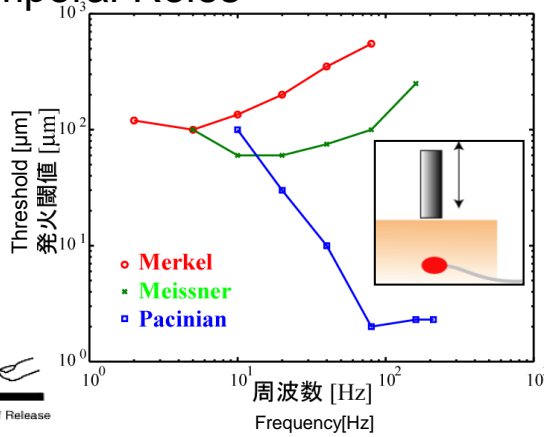
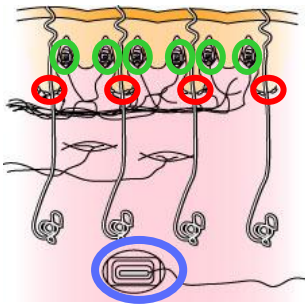
ルフィニ終末 / Ruffini Ending



- 皮膚下2mm以上の深部に疎らに存在.
- 静的な横ずれに应答
- 発火頻度は横ずれの大きさに比例
- 単独の活動では感覚を生じない

- Sparsely Populated in a deep region (2mm ~ depth)
- Senses Static Horizontal Deformation
- Pulse Frequency is Proportional to Horizontal Deformation.
- Single activation does not generate sensation

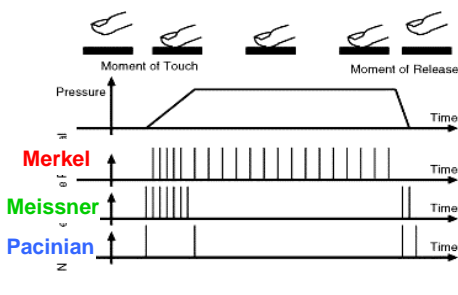
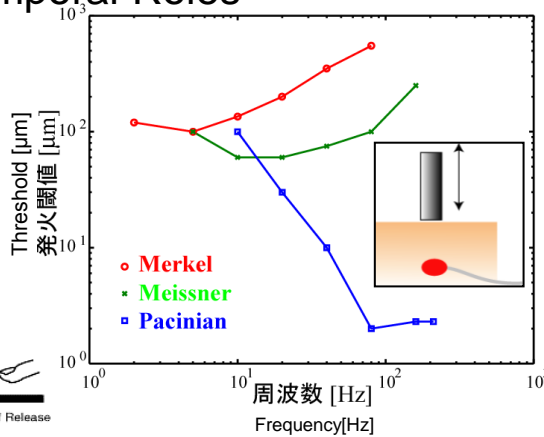
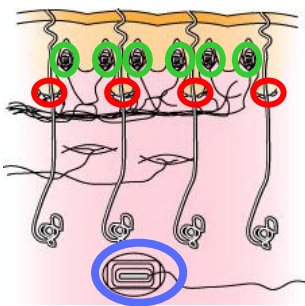
時間的役割分担 / Temporal Roles



- Merkel: 直流成分 / 压力
- Meissner: 低周波成分 / 速度
- Pacinian: 高周波成分 / 加速度

- Merkel: DC / Displacement & Pressure
- Meissner: Low Freq. Vibration / Velocity
- Pacinian: High Freq. Vibration / Acceleration

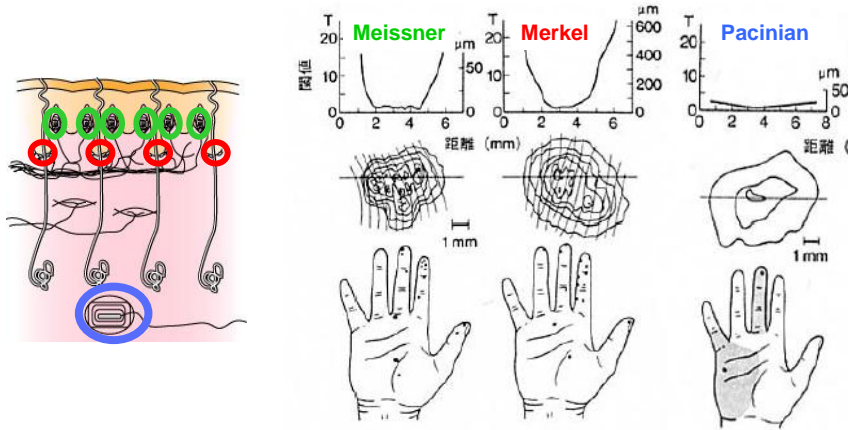
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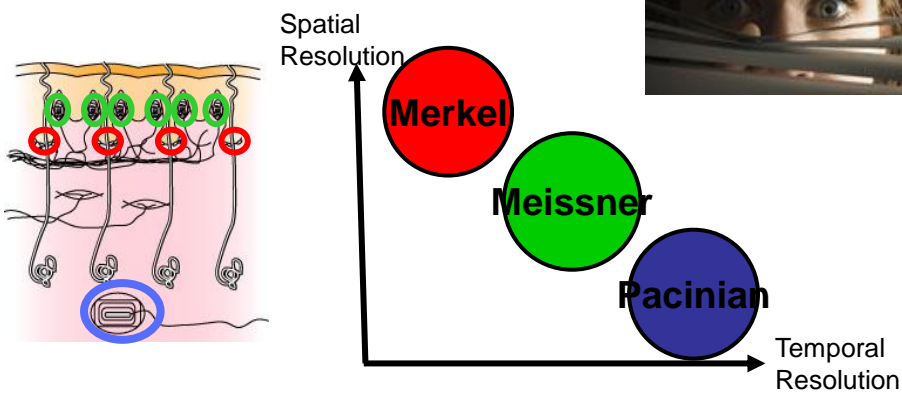
- Merkel: DC / Displacement & Pressure
- Meissner: Low Freq. Vibration / Velocity
- Pacinian: High Freq. Vibration / Acceleration

空間的役割分担 / Spatial Roles



- **Merkel**: 細かいパターン / Small Pattern
- **Meissner**: 皮膚上の細かい動き / Small Area Movement
- **Pacini**: 広い面積の動き / Large Area Movement

各機械受容器の役割分担 We only see through narrow slit

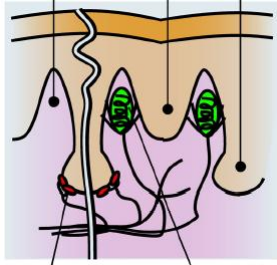


ポイント: 時間的, 空間的な相補性

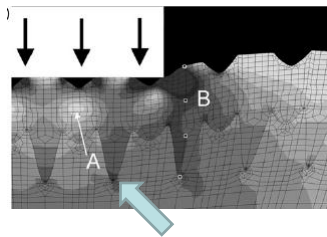
We combine “Spatially Fine, but Temporally Rough” sensation and “Spatially Rough, but Temporally Fine” sensation.
In other words, we “see” the world through very narrow slit.

皮膚構造と受容器

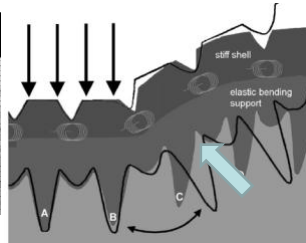
Skin Structure and Mechanoreceptors



- 表皮: 硬い
- 真皮: 柔らかい
- MerkelとMeissnerは境界に存在
- Epidermis: Hard
- Dermis: Soft
- Merkel and Meissner are at the interface of the two layers.



Stress is Concentrated at Merkel

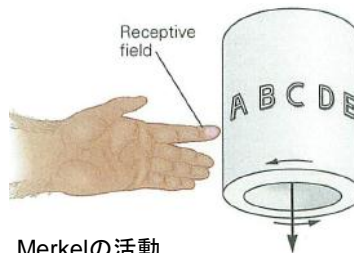
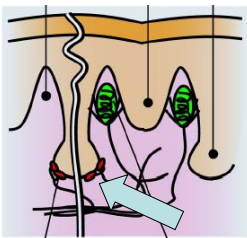
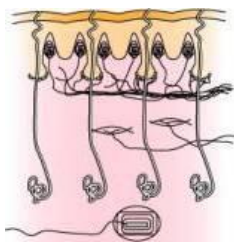


Strain is Largest at Meissner

Gregory J. Gerling, "Fingerprint lines may not directly affect SA-I mechanoreceptor response," Somatosensory and Motor Research 2008.

形状は主にMerkelによってコーディングされる

Shape is mainly coded by Merkel Cells



Merkelの活動

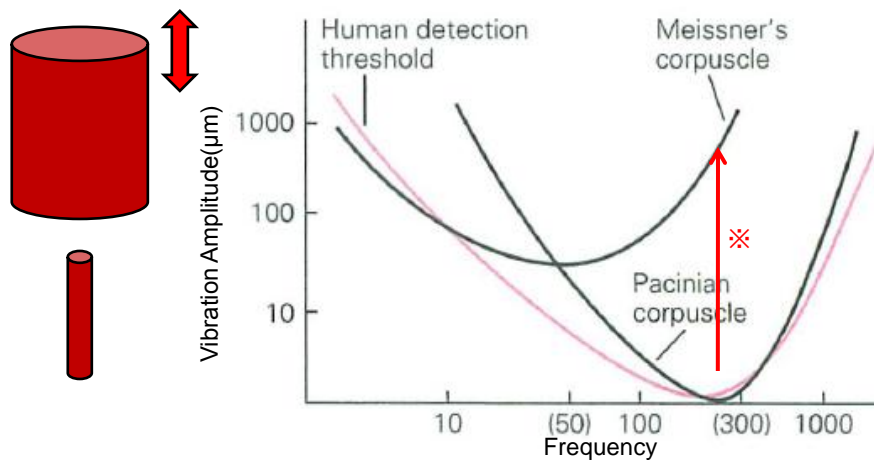
A B C D E

Meissnerの活動

A B C D E

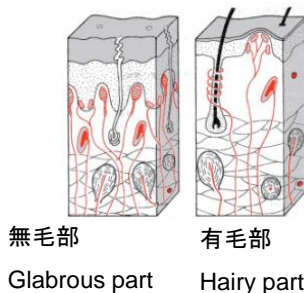
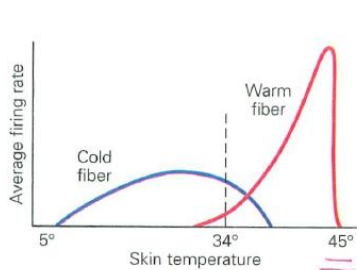
周波数は受容器の活動比率でコーディングされる
 Frequency is mainly coded by combination of receptor activities.

人間の振動知覚閾



※振動子が小さいとPaciniの「空間加算」効果が無くなり、高周波が感じにくくなる
 If the vibrator size is small, high freq. threshold rises, because “**spatial summation effect**” of Pacinian corpuscle is reduced.

その他の触覚 / Other cutaneous sensations



皮膚表面付近の自由神経終末 (C繊維)

Free nerve ending near skin surface (C fiber)

- 温度感覚: 冷繊維と温繊維 / Temperature sensation by two fibers.
- 痛覚: 鋭痛と鈍痛はA γ 繊維とC繊維が担当 / Pain sensation by two fibers

有毛部 / Hairy skin

- 毛包受容器 / Follicle Receptor

毛の根元を取り巻き、毛が曲がる時のみ活動 (速度検出)

ただしこれに代わり、Meissner小体は無い。

Activated by low frequency vibration, substituting Meissner corpuscle

どうやって調べる／How we know?



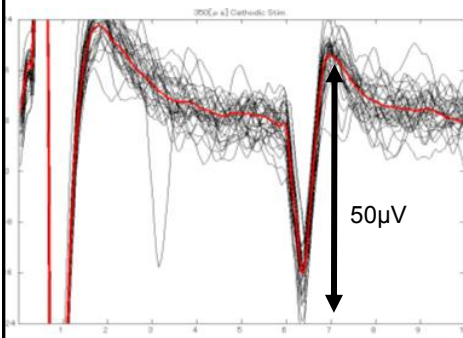
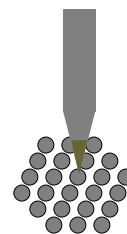
By using needle, we can directly measure nerve activities.

Vallbo, "Sensations evoked from the glabrous skin of the human hand by electrical stimulation of unitary mechanosensitive afferents," Brain Res., 1981.

Procedure

(Medical Doctor's License Required)

- (0) See where the nerve bundle is. (by ultrasonography)
- (1) Insert a needle ($\phi 0.1\text{mm}$), which is connected to Amp&Speaker
- (2) Identify Location and Type of Receptor by the Sound.
- (3) Do Experiment on that Location.



TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Perception & Illusion
3. Tactile Display
4. Tactile AR

触覚の(狭義の)錯覚: 錯触 Tactile Illusions

- アリストテレスの錯覚
- Barber Pole Illusion
- 滝の残効 (Motion Aftereffect)
- 仮現運動
- ファントムセンセーション (Funneling)
- ベルベットイリュージョン
- ラバーハンドイリュージョン
- …etc

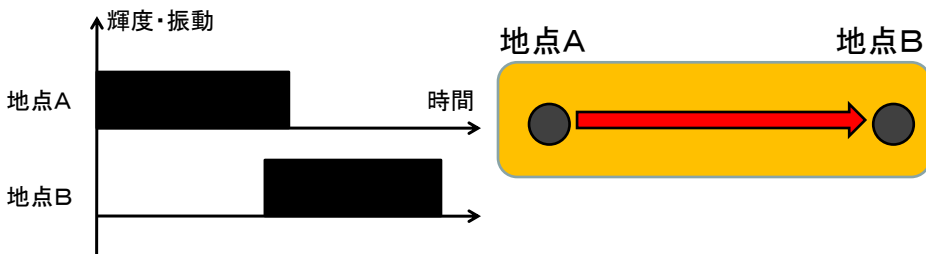
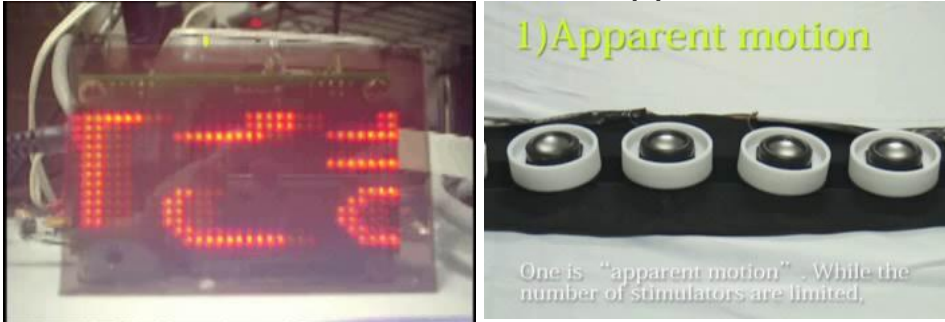


特に近年, 触覚研究の発展に伴って増加。
視覚研究者による研究多。

Recent works revealed new tactile illusions

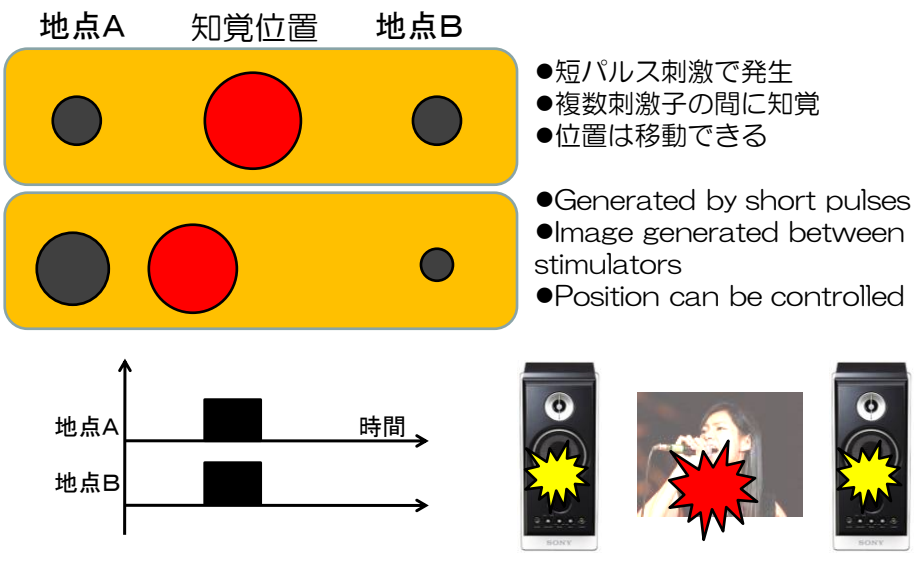
視覚で類推できる錯触例：仮現運動

Tactile Illusion similar to vision: Apparent motion



聴覚で類推できる錯触例：ファントムセンセーション

Tactile Illusion similar to audio: Phantom Sensation (Funneling)



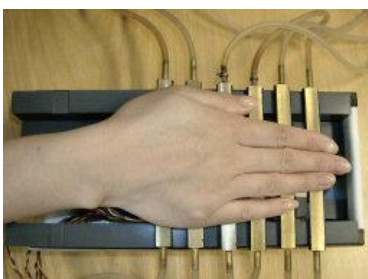
触覚独自の錯触:ベルベットイリュージョン Tactile Unique Illusion: Velvet Illusion



荒い網の目（テニスラケットなど）を両手で挟み、前後に動かすと、モワッとしたベルベット感を生じる。

Sandwiching coarse mesh of a net, such as tennis racket by two hands, and moves. Then, smooth surface like velvet is felt.

触覚独自の錯触:サーマル・グリル・イリュージョン Tactile Unique Illusion: Thermal Grill Illusion

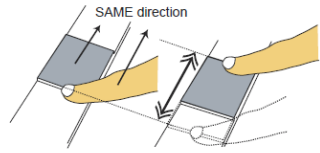


近い距離で温感と冷感を同時に提示すると痛覚を生じる
Close presentation of hot and cold temperature generates pain sensation.

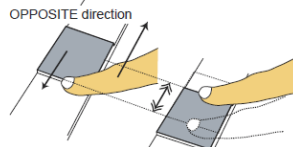
実験上、皮膚を損傷せずに痛みを生成するためによく用いられる
Used for the generation of pain sensation without skin damage.

動きによる皮膚感覚の錯覚(1)

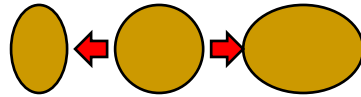
Finger movement & **Static** object
-> (Usual experience)



(a) Perceptually elongated width



(b) Perceptually shrunk width

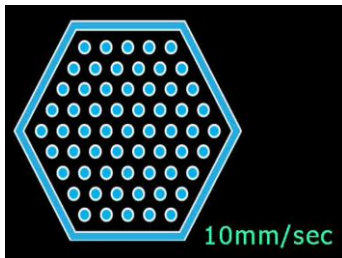


Ando H. et al., Novel Tactile Contour Presentation: Embossed Touch Display, ACM SIGGRAPH 2006 Sketches

- 物体をなぞると同時に物体を動かす。
 - 物体の動きとは知覚できず、物体の形状の変化として認識。
- つまり

皮膚上の運動と腕の運動の統合はかなり大まか

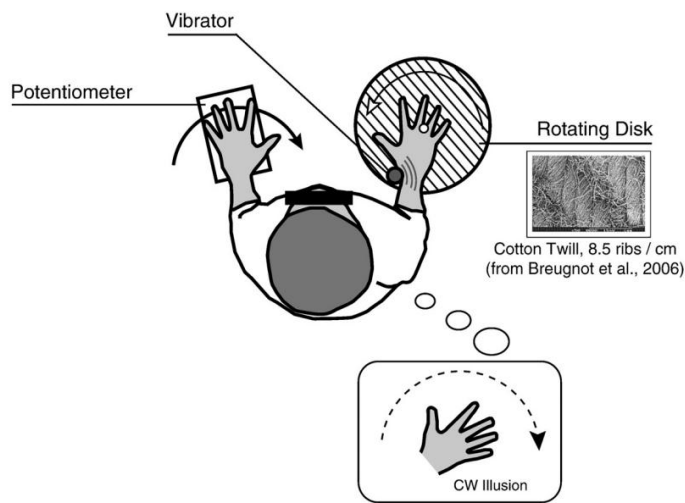
(逆)皮膚感覚による動きの錯覚(1)



力と同時に触覚的な「流れ場」を提示すると、指の「運動(ぬめり・滑り)」を感じる

Okabe et al., Fingertip Slip Illusion with an Electrocutaneous Display, ICAT2011

(逆)皮膚感覚による動きの錯覚(2)



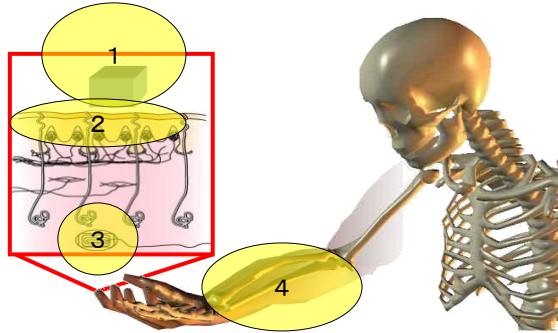
- 手のひらへの回転状触刺激＋振動による筋活動⇒手首が「回
転し続ける」錯覚。

●Blanchard et al., Combined contribution of tactile and proprioceptive feedback to hand movement perception, Brain Res. 2011.

TODAY's TOPIC

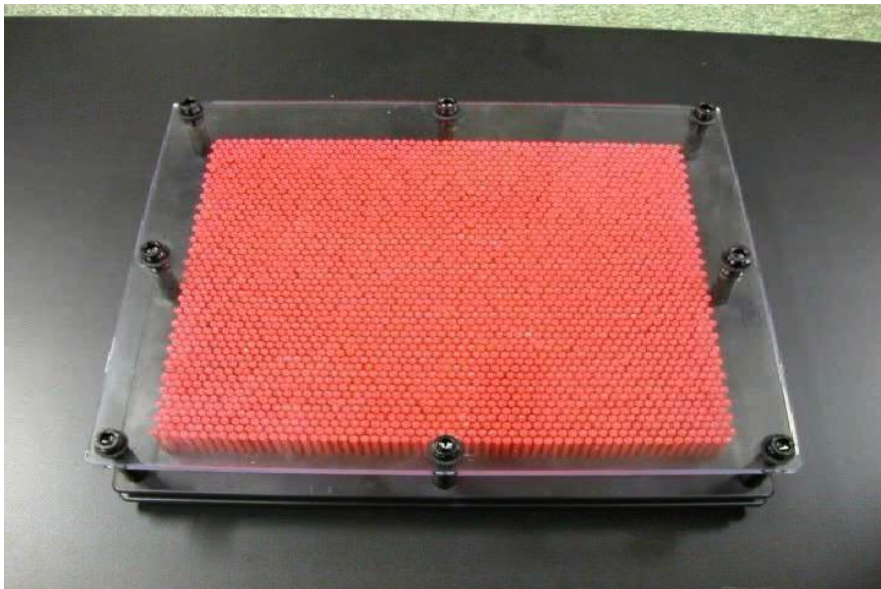
1. Skin Sensation Mechanism
2. Tactile Perception & Illusion
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触覚を再構築するには How to produce Touchable Illusion?



- (1)世界(の表面)を再構築／Reproduce the World Surface
- (2)皮膚の変形を再構築／Reproduce Skin Deformation
- (3)受容器活動を再構築／Reproduce Receptor Activity
- (4)神経活動を再構築／Reproduce Nerve Activity

Reproduce the World (Shape)



インタラクティブシステム特論

Tactile Display for the blind

ドットビューDV-2

KGS株式会社

- 大量の高密度実装→アクチュエータの小ささ、安さが鍵
- Numerous, dense arrays→Actuator needs to be small and cheap

Xmen,2000

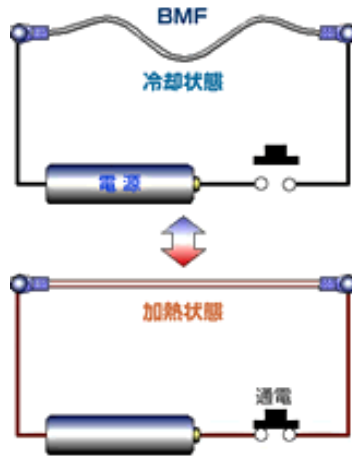
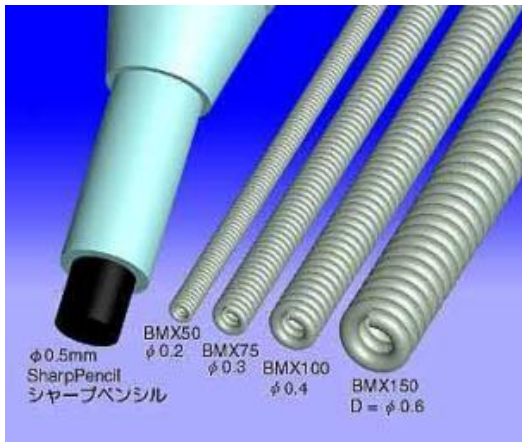


より細かいアクチュエータ = 形状記憶合金？

Thinnest actuator = SMA?

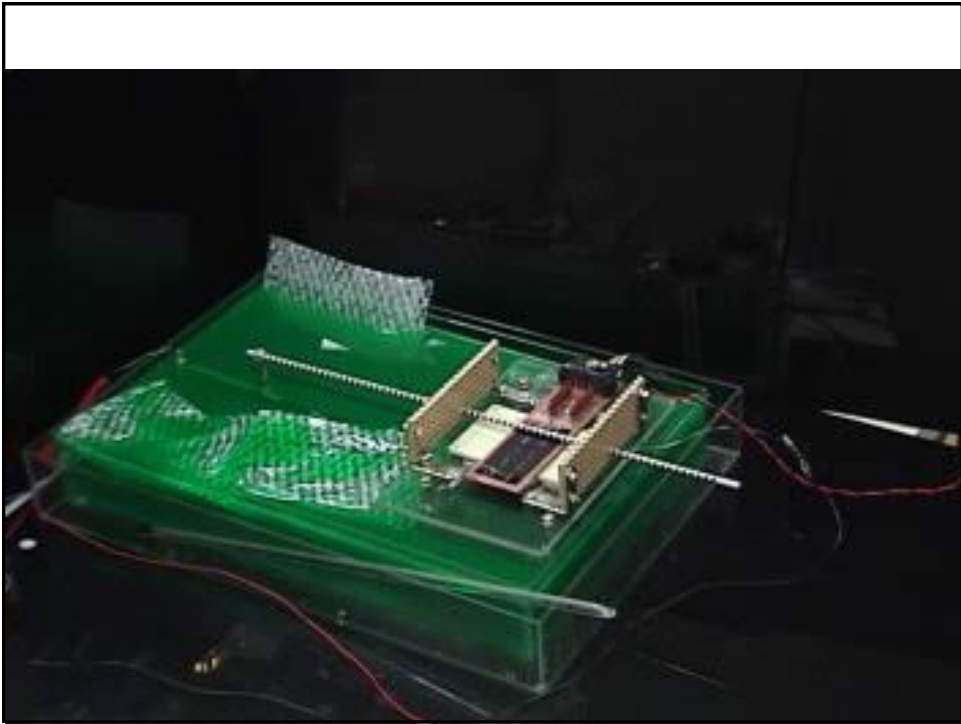
Coil-Type SMA (Shape Memory Alloy)

Extremely thin and moves large

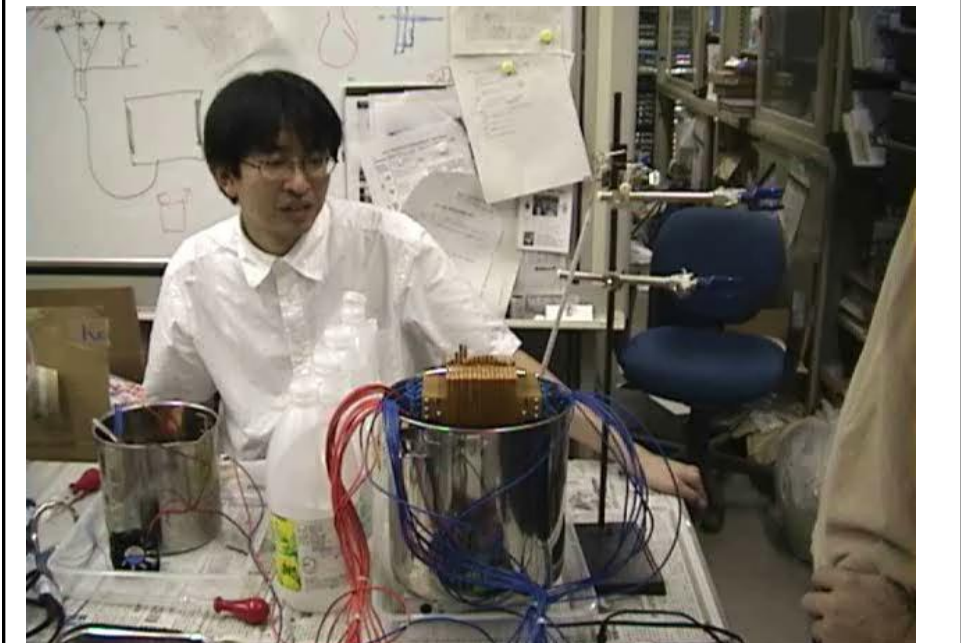


Biometal Demo





PopUp(Nakatani et al, 2005)



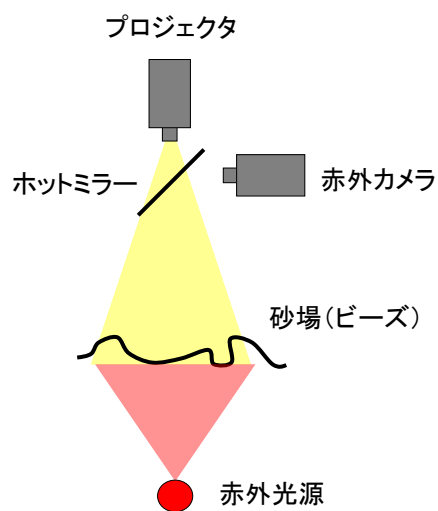
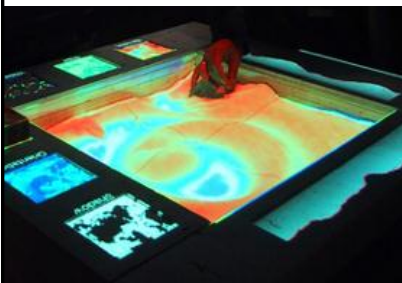
Lumen (Ivan Poupyrev, 2005)



<http://ftp.csl.sony.co.jp/person/poup/projects/lumen.html>

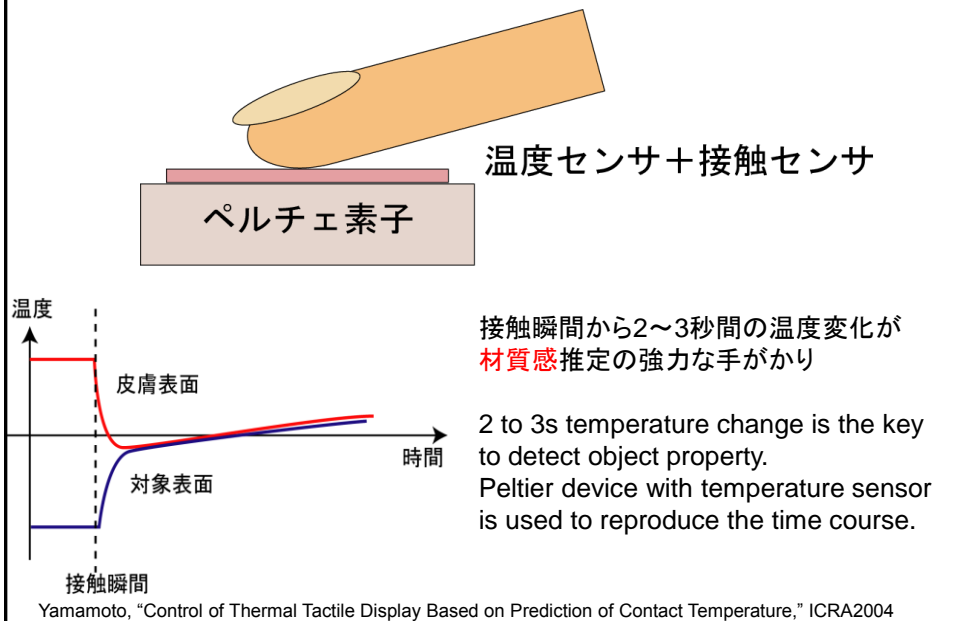
Is Actuator really necessary? : SandScape

(Yao Wang et al., 2002)



<http://tangible.media.mit.edu/projects/sandscape/>

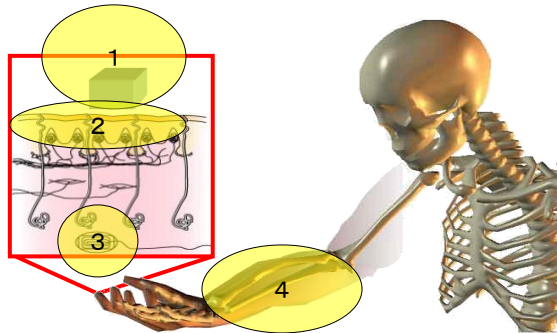
温度感覚ディスプレイ／Thermal Display



Thermoesthesia (Kushiyama, 2006)



How to produce Touchable Illusion?



- (1) Reproduce the World (Shape)
- (2) Reproduce Skin Deformation
- (3) Reproduce Receptor Activity
- (4) Reproduce Nerve Activity

インタラクティブシステム特論

Reproduce Skin Deformation

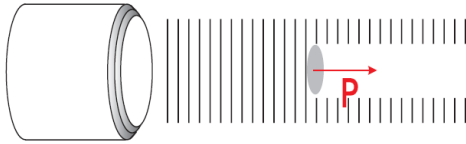
“Carpet is expensive. Shoes are enough!” Lets **Wear**.



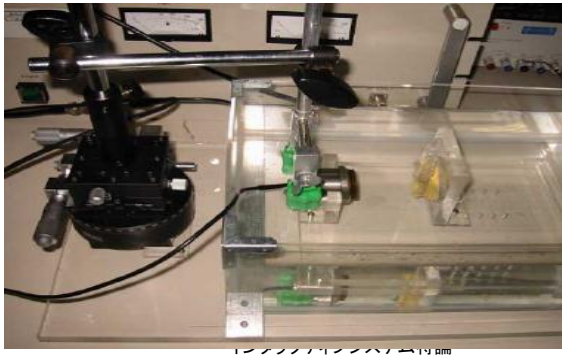
Small and light-weight tactile display (KAIST)
<http://www.youtube.com/watch?v=CT4WZexTloo>

Problem: How can the actuator be so small and dense? (again)

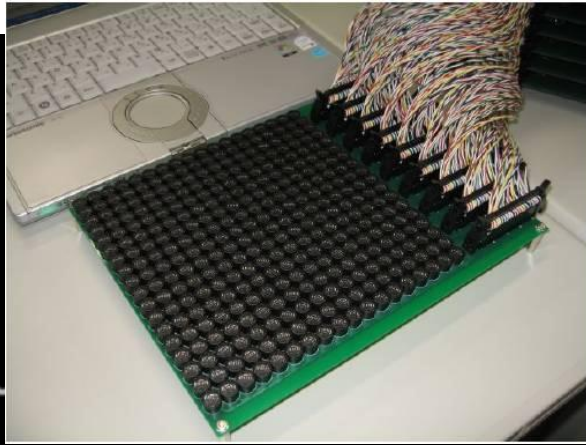
Actuator should disappear?



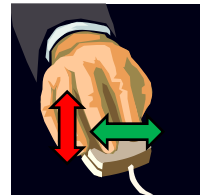
Ultrasound generates Static Pressure
Iwamoto "Focused ultrasound for tactile feeling display," In Proc. of ICAT2001.



Airborne U



上下変位とは限らない Vertical Deformation is not Enough



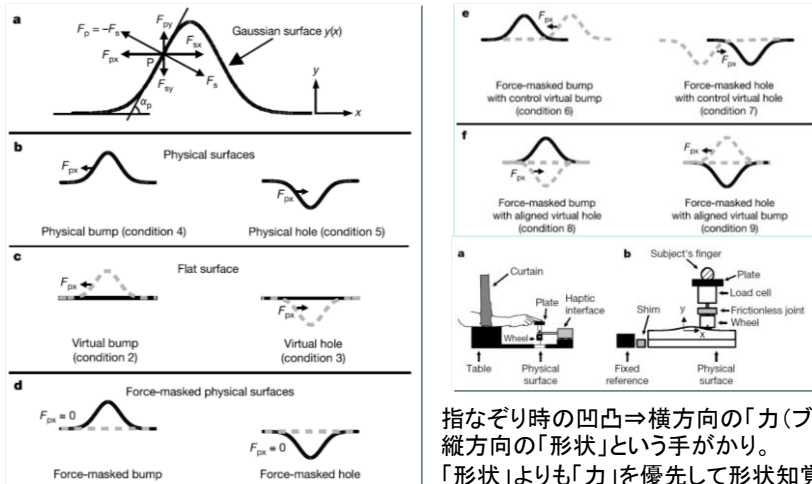
出発点: 触覚ディスプレイ研究者の共通疑問
「なぜ現行の触覚ディスプレイでザラザラ感が出せないのか？」

Although many researchers made “dense” tactile displays,
No one succeeded to reproduce “texture” sensation.

皮膚一対象間のすべりが触覚の本質ではないか？
Horizontal “Slip” is Essential??

凹凸感にとって重要なものは何か(1/2)

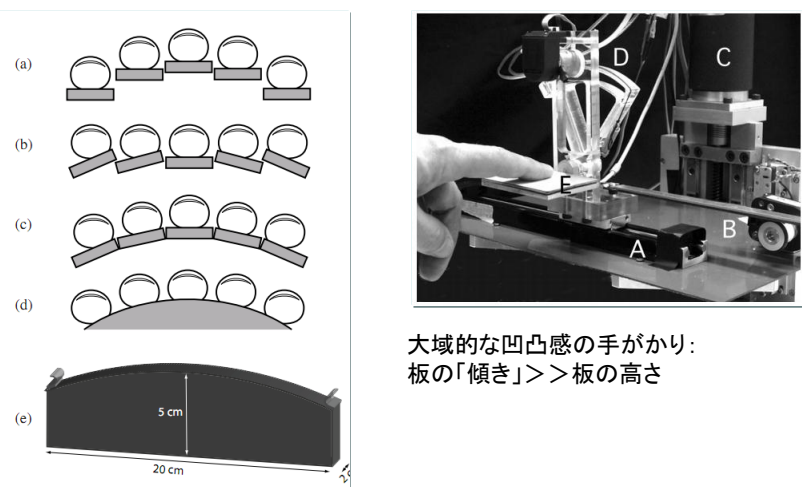
What is essential for bump sensation?



Gabriel Robles-De-La-Torre & Vincent Hayward: Force can overcome object geometry in the perception of shape through active touch Nature 2001.

凹凸感にとって重要なものは何か(2/2)

What is essential for bump sensation?



Maarten W. A. Wijnntjes, Akihiro Sato, Vincent Hayward, Astrid M. L. Kappers
Local Surface Orientation Dominates Haptic Curvature Discrimination, Trans. On Haptics, 2009.

水平変位の実現 Moving skin horizontally.

- 能動的手法: 皮膚を水平に駆動
Active type: actively drive skin horizontally.



✓装着型に向く／Good for wear type.

- 受動的手法: 摩擦係数を変化、皮膚が動いて初めて知覚
Passive type: friction coefficient is controlled, and perceived by skin motion.

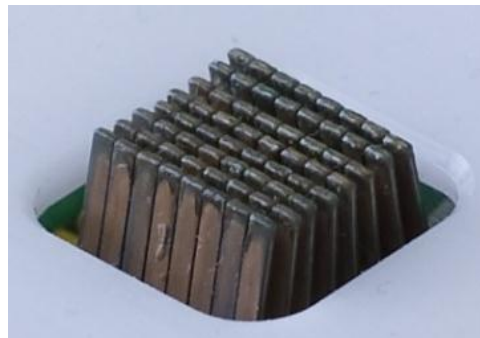
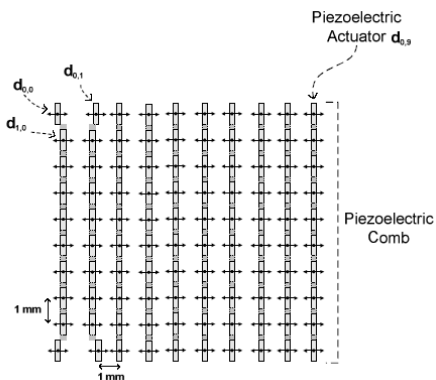
✓環境型に向く／
Good for environmental type.

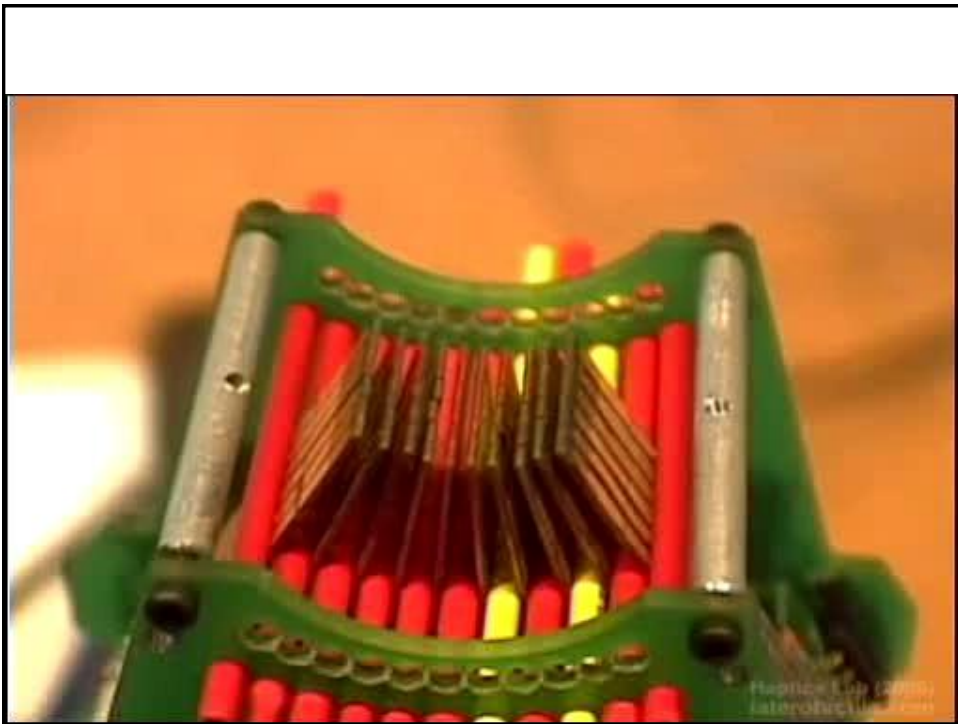


Active type Horizontal Display

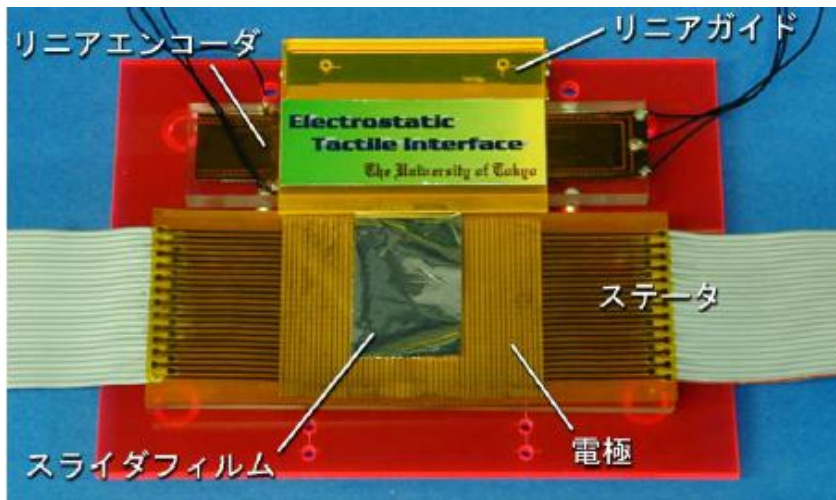
- Horizontal Vibration is achieved by Micro-Machine

Hayward, "Tactile display device using distributed lateral skin stretch," ASME, DSC, 2000.





Active type Horizontal Display

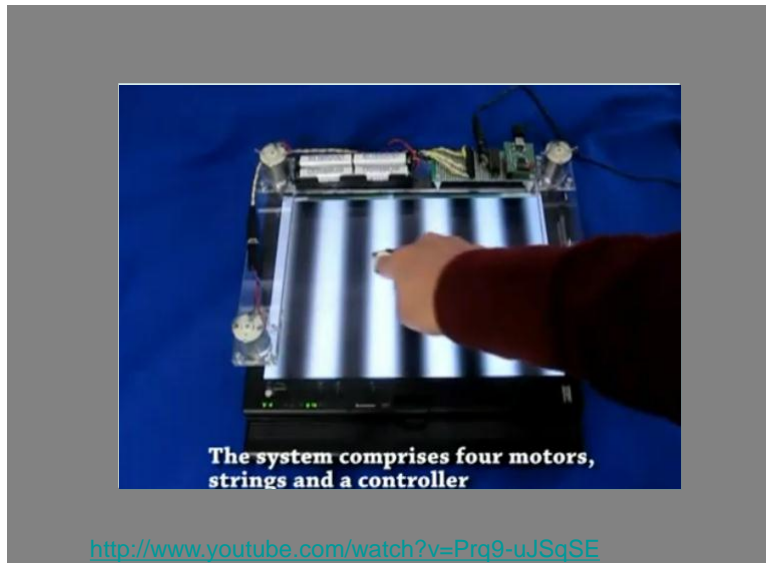


静電アクチュエータによる皮膚水平方向力の生成

Horizontal force generated by electro-static actuator

山本「静電気力による摩擦力制御とフィルム移動子を用いた薄型皮膚感覚ディスプレイ」日本VR学会大会 2002.

モータによる水平力提示



嵯峨他、剪断力を用いた2.5次元触覚ディスプレイにおける定量的凹凸感提示手法、VR学会大会2011

Passive type Horizontal Display

超音波振動による摩擦係数変化の利用

Controlling friction coefficient by ultrasonic vibration



- スクイズ効果: 高周波振動で摩擦係数が減少する
Squeeze effect: friction is reduced by high freq. vibration
- 指位置計測と組み合わせ、摩擦係数の提示が可能
Combined with pos. sensing, friction distribution is displayed.
- Nara et al., "Surface Acoustic Wave Tactile Display", IEEE CG&A, 2001.
- Winfield et al., "TPaD: Tactile Pattern Display Through Variable Friction Reduction", World Haptics Conf. 2007



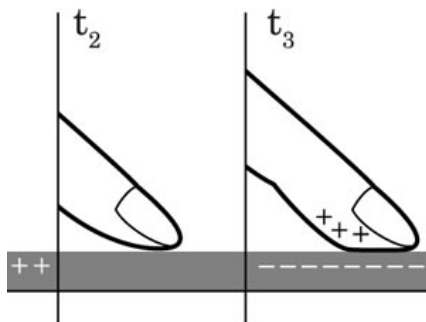
TPaD(Laura Winfield, 2007)

<http://lims.mech.northwestern.edu/projects/TPaD/index.htm>

Passive type Horizontal Display

高压電極と皮膚の電氣的吸引利用

Using adhesion between skin and electrode by high voltage



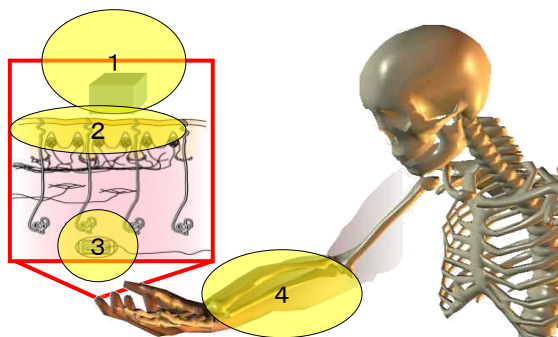
Kaczmarek et al., "Polarity Effect in Electro-vibration for Tactile Display," IEEE Trans. Biomedical Engineering., 2006.

Olivier Bau et al., "TeslaTouch: Electro-vibration for Touch Surfaces," UIST2010

TeslaTouch (2010)

<http://www.teslatouch.com/>

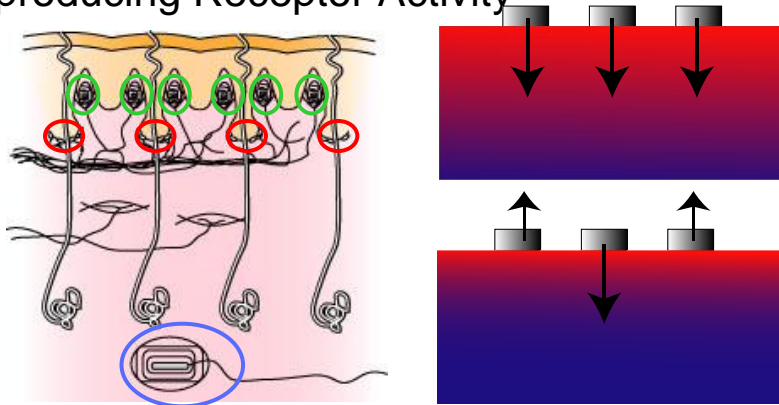
How to produce Touchable Illusion?



- (1) Reproduce the World (Shape)
- (2) Reproduce Skin Deformation
- (3) Reproduce Receptor Activity
- (4) Reproduce Nerve Activity

インタラクティブシステム特論

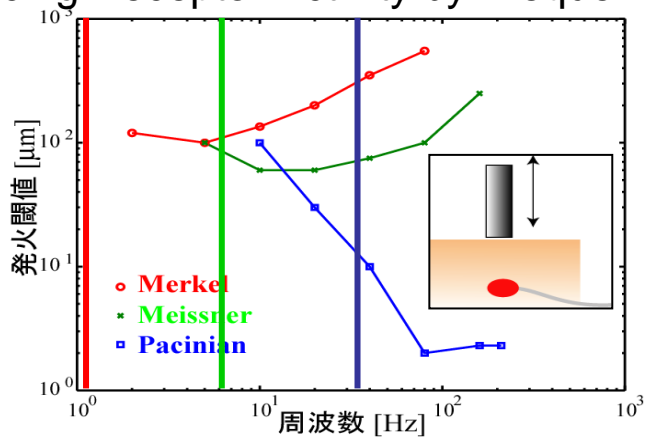
受容器活動再現型ディスプレイ Reproducing Receptor Activity



歪到達深度調整による選択刺激(従来の上下に「引っ張り」付与)
Depth Selective Stimulation by vibrators' paired movement

Asamura, "A method of selective stimulation to epidermal skin receptors for realistic touch feedback," IEEE VR, 1999.

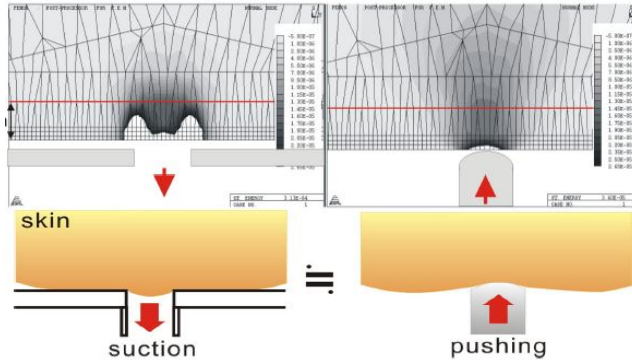
周波数特性に着目した受容器活動再現 Reproducing Receptor Activity by Frequency



受容器の共振周波数を利用
Utilizing each receptor's resonant frequency

Konyo, "Tactile feel display for virtual active touch," IEEE Int. Conf. Intelligent Robotics & Systems, 2003.

ひずみエネルギー再現に着目した受容器活動再現 Reproducing Receptor Activity by Strain Energy



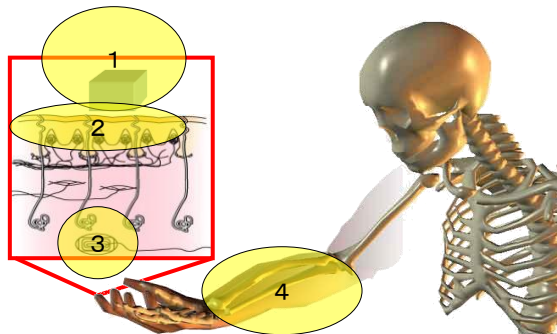
空気吸引による圧覚生成 / Using air suction

吸引と押下で、受容器位置に生じる歪エネルギーが同じ→人は区別できない

Suction and push produces the same amount of strain energy, so that human cannot distinguish.

Makino "A cutaneous feeling display using suction pressure," SICE Annu. Conf., 2003.

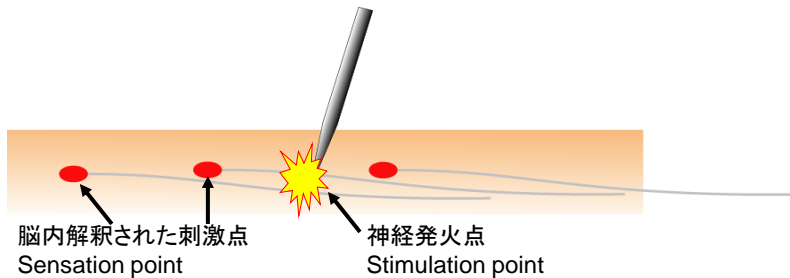
How to produce Touchable Illusion?



- (1) Reproduce the World (Shape)
- (2) Reproduce Skin Deformation
- (3) Reproduce Receptor Activity
- (4) Reproduce Nerve Activity

電気刺激により神経活動を再現

Reproducing Nerve Activity by Electrical Stimulation

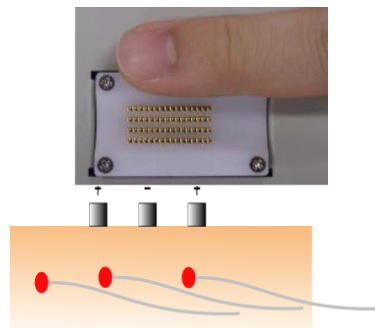


- 利点: エネルギー効率 / 機械的脆弱性・共振特性から開放
- 課題: 空間的なマッピング・選択刺激の実現

- Good point: Energy efficient, no mechanical parts so mechanical resonance free.
- Bad point: Stimulation point and Sensation point is different

皮膚表面からの電気刺激

Electrical Stimulation from Skin Surface



神経末端の刺激され易さから空間マッピング実現
各受容器の神経配置の特徴を利用した選択刺激

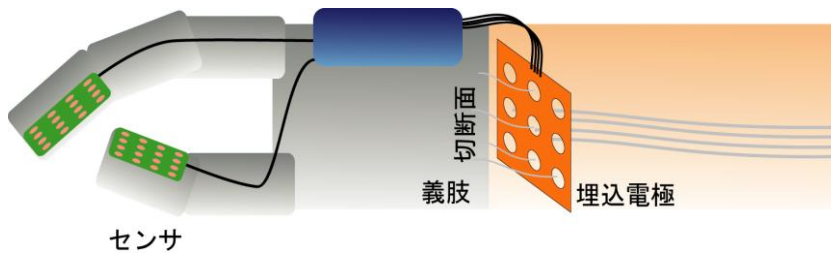
Electrical Stimulation from Surface: Stimulate Nerves directly.

If we can “Selectively” Stimulate the Nerves, we can generate ANY tactile Sensations.

Just Like we make colors by mixing primary colors.

梶本「皮膚感覚神経を選択的に刺激する電気触覚ディスプレイ」電子情報通信学会誌, 2001.

神経束への電気刺激 Stimulation to nerve bundle



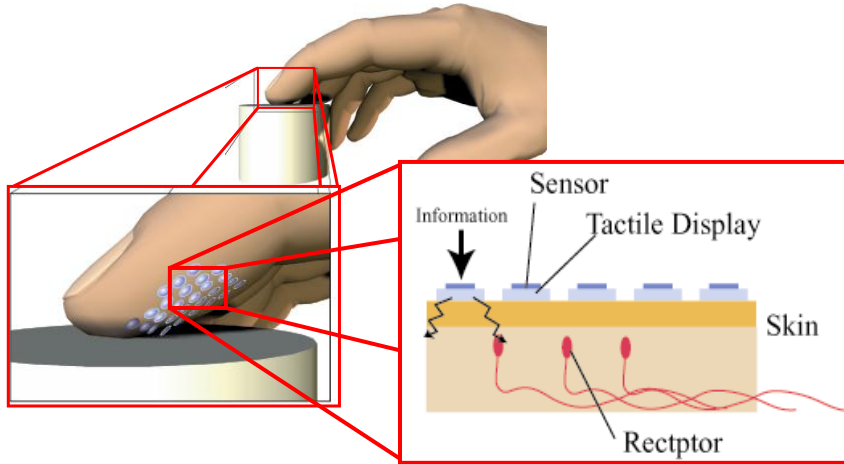
- 埋め込み型マトリクス電極。神経再生時に電極を通過して学習による空間マッピング。
- 福祉用途
- Matrix electrodes (holes) are embedded, and nerve will grow into the holes.

鈴木「神経再生型電極に関する研究」東京大学博士論文, 1998

TODAY's TOPIC

1. Skin Sensation Mechanism
2. Tactile Perception & Illusion
3. Tactile Display
4. Tactile AR

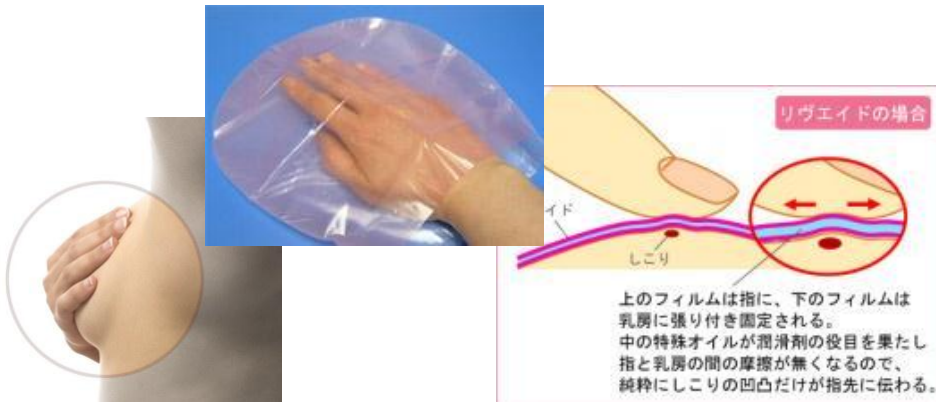
触覚のAR? / Tactile AR?



新しい人工受容器として機能

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

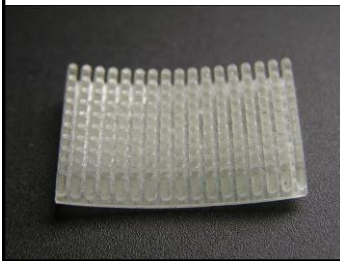
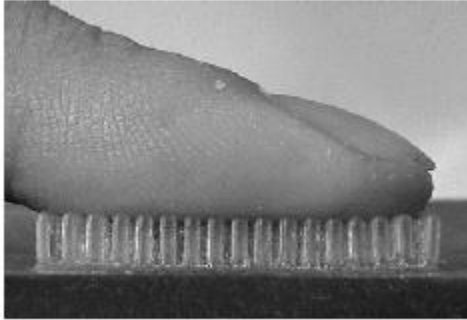


乳がん自己診断具 / Checking Breast Cancer

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

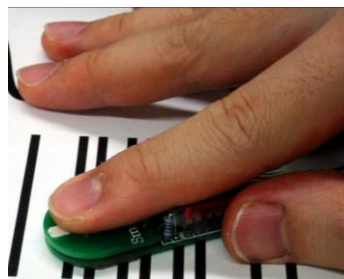
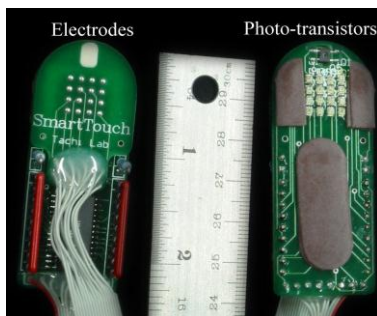


佐野他: 触覚コンタクトレンズ (ROBOMECH'04)

触覚のAR / Tactile AR



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



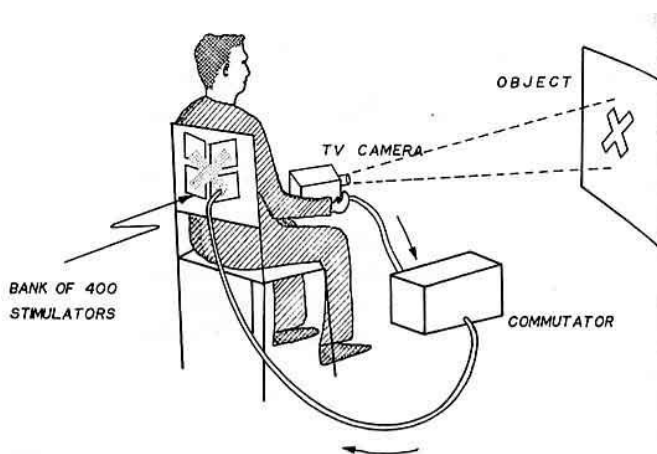
Kajimoto et.al, SmartTouch, SIGGRAPH2003.

SmartTouch(Kajimoto 2003)



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.

事例紹介: Forehead Retina System

2005年夏～ (株)アイプラスプラスとの共同研究

電気刺激: 小型、軽量、低消費電力
→ 携帯型視覚触覚変換装置の開発



使用状況



簡便な触覚AR: クリック感の付与 Simplest Tactile AR: Adding Clicking Sensation

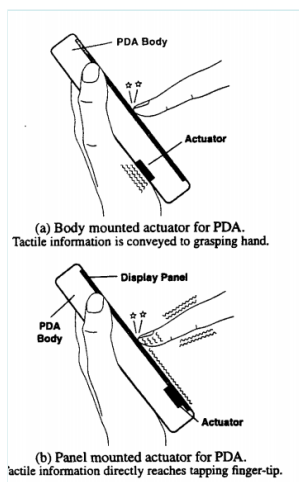
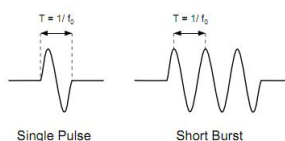


図 1: アクチュエータの設置状況
PDA の筐体に貼り付けている。



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

まとめ

- リアルな「さわった感覚」を提示できる皮膚感覚（触覚）ディスプレイは、未だ無い。
- 提示原理そのものが研究段階
- 現在の触覚ディスプレイ研究は、**触覚そのものの解明**と歩調をあわせて取り組んでいる、アクロバティックな分野である。

Summary

- Until today, researchers tried to generate realistic tactile sensations. Partially, it was achieved. But not yet enough (Not Hi-Fi enough)
- Tactile sensation itself has many unknown features, especially about psychophysics.
- Today's tactile research is a combination of science (why) and engineering (how). It is ideal for researcher who want to be scientist and engineer at the same time.

小テスト／Mini Test 次回開始まで

以下の全てに100字以内程度で解答せよ／Answer all questions within 50 words

1. メルケル細胞の役割について説明せよ Explain role of Merkel cell
2. マイスナー小体の役割について説明せよ Explain role of Meissner corpuscle.
3. パチニ小体の役割について説明せよ Explain role of Pacini corpuscle.
4. ルフィニ終末の役割について説明せよ Explain role of Ruffini ending
5. 温度感覚の仕組みについて説明せよ Explain mechanism of thermal sensation.
6. 触覚の仮現運動について説明せよ Explain tactile apparent motion
7. ファントムセンセーションについて説明せよ Explain Phantom Sensation
8. ベルベットイリュージョンについて説明せよ Explain velvet illusion
9. サーマルグリルイリュージョンについて説明せよ Explain thermal grill illusion

【重要】 論文紹介について

これまでに講義のレポートを出したメール宛に、論文の所在と、応募の方法(google form)をメールします。(12/18(日))

月曜になってもメールを受け取らなかったら梶本(kajimoto@hc.uec.ac.jp)までメールください

早い者勝ちで決めますので、返信は早めに。
ただし第三希望まで書かれていないものは受け取りません。