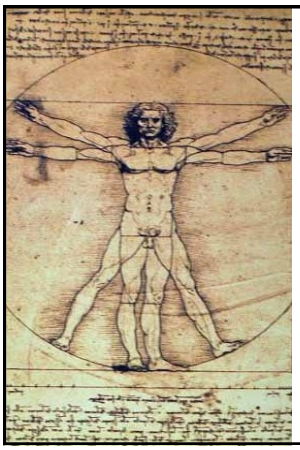


Interactive System
インタラクティブシステム特論(6)

Hiroyuki Kajimoto
kajimoto@hc.uec.ac.jp
Twitter ID kajimoto
Hash tag #itsys

Schedule

- 10/ 8 Lecture
- 10/15 Lecture
- 10/22 (Conference & Athletic Festival)
- 10/29 Lecture
- 11/ 5 Lecture
- 11/12 Lecture ※Changed!!
- 11/19 (Chofu-Sai)
- 11/26 (Conference)
- **12/ 3 Mini Test**
- 12/10 Lecture
- 12/17 Lecture
- 12/24 (Conference)
- 1/ 7 Special Lecture
- 1/14 Lecture
- 1/21 Lecture
- **1/28 Mini Test**
- 2/ 4 (Conference)

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

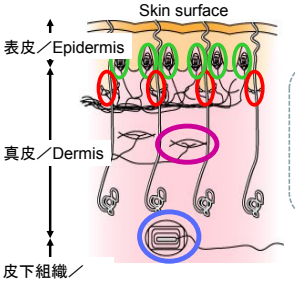
触覚＝接触によって生じる感覚
（Haptic＝「接触(Contact)」(ギリシャ語／in Greece)）
●皮膚表面の変形（皮膚感覚／Cutaneous Sense, Skin Sense)
●筋肉の伸縮，関節角（深部感覚・力覚／Proprioception, Force Sense）

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 Strunture (Hairless Parts)



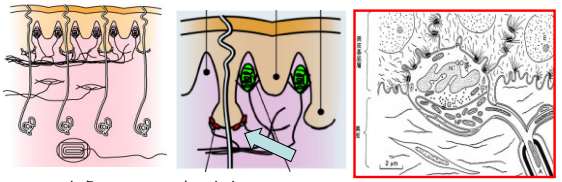
機械受容器：機械的変形に応答
Mechanoreceptor: Sense Mechanical Deformation

浅部／Shallow part
●マイスナー小体／MeissnerCorpuscle
●メルケル細胞／Merkel Cell

深部／Deep part
●ルフィニ終末／Ruffini Ending
●パチニ小体／Pacinian Corpuscle

その他／Misc
自由神経終末（痛覚、温度感覚）
FreeEnding (Pain, Temperature)

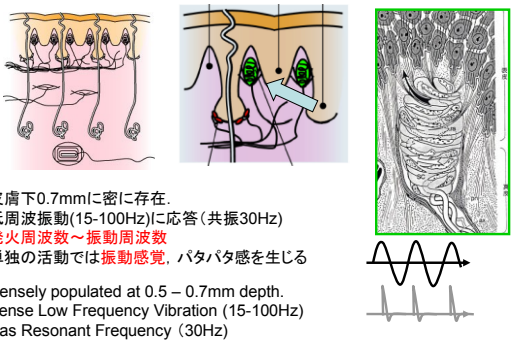
メルケル細胞／Merkel Cell



•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.

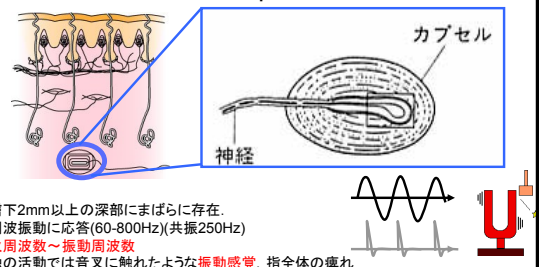
マイスナー小体／Meissner Corpuscle



•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

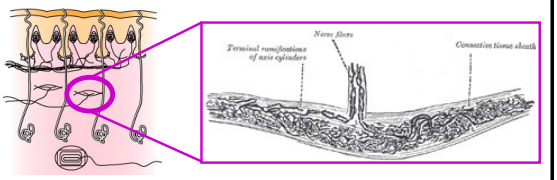
パチニ小体／Pacinian Corpuscle



•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 tuing fork or speaker

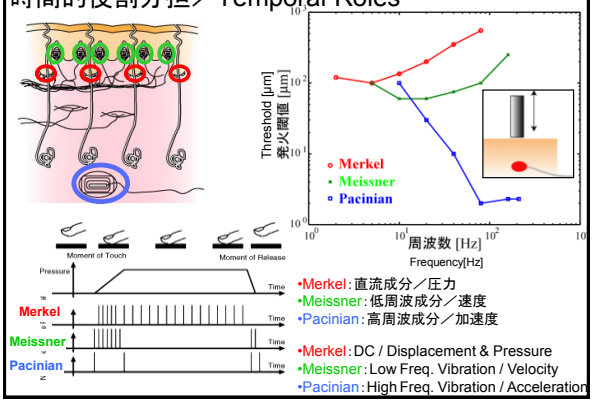
ルフィに終末／Ruffini Ending



•皮膚下2mm以上の深部に疎らに存在.
•静的な横ずれに応答
•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

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

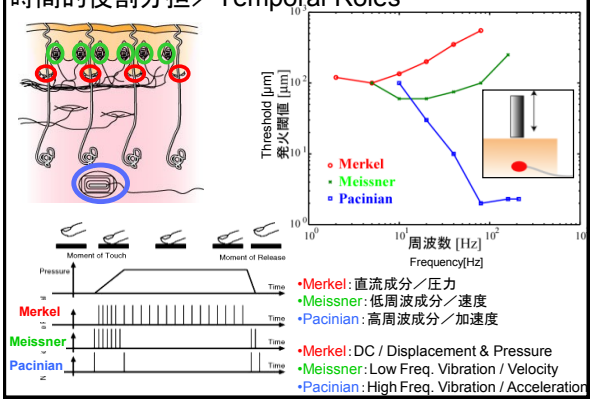
時間的役割分担／Temporal Roles



•Merkel：直流成分／圧力
•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

時間的役割分担／Temporal Roles



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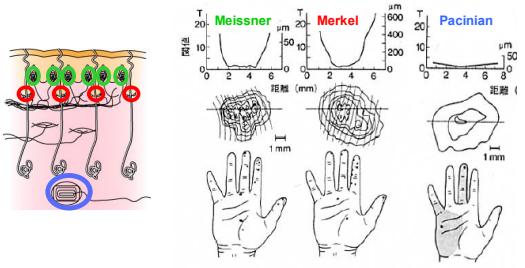
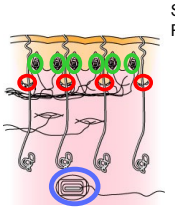
•Merkel：DC / Displacement & Pressure
•Meissner：Low Freq. Vibration / Velocity
•Pacinian：High Freq. Vibration / Acceleration

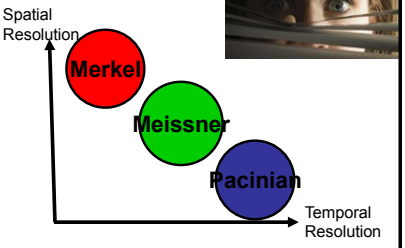
空間的役割分担／Spatial Roles



- 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

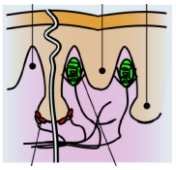




ポイント：時間的，空間的な相補性

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.

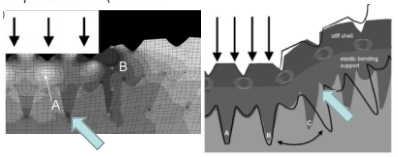
皮膚構造と受容器
Skin Structure and Mechanoreceptors



- 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.

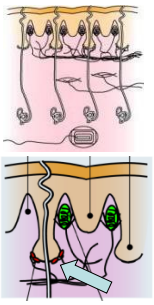


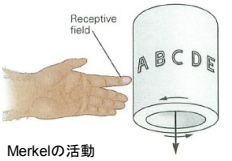
Stress is Concentrated at Merkel

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

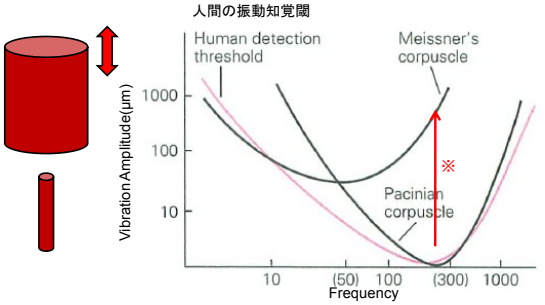




Merkelの活動

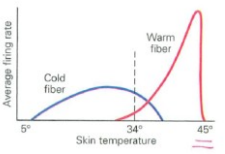
Meissnerの活動

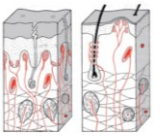
周波数は受容器の活動比率でコーディングされる
Frequency is mainly coded by combination of receptor activities.



※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 rizes, 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Aγ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，毛が曲がるときのみ活動（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

TODAY's TOPIC

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

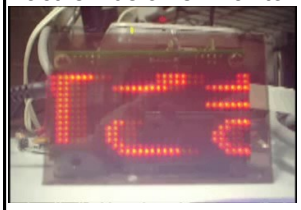
触覚の(狭義の)錯覚:錯触
Tactile Illusions

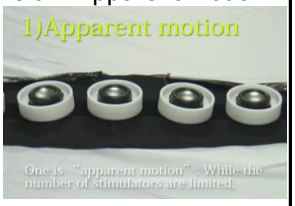
- ●アリストテレスの錯覚
- ●Barber Pole Illusion
- ●滝の残効(Motion Aftereffect)
- ● 仮現運動
- ●ファントムセンセーション(Funneling)
- ●ベルベットイリュージョン
- ●ラバーハンドイリュージョン

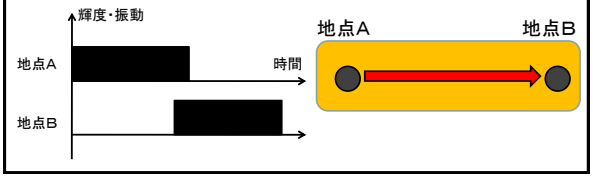
…etc

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

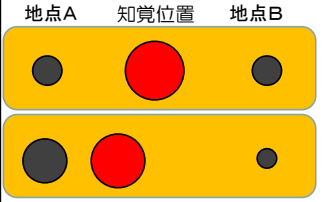
視覚で類推できる錯触例:仮現運動
Tactile Illusion similar to vision: Apparent motion





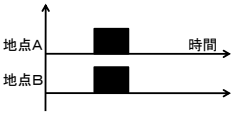


聴覚で類推できる錯触例:ファントムセンセーション
Tactile Illusion similar to audio: Phantom Sensation(Funneling)



- ●短パルス刺激で発生
- ●複数刺激子の間に知覚
- ●位置は移動できる

- ●Generated by short pulses
- ●Image generated between stimulators
- ●Position can be controlled

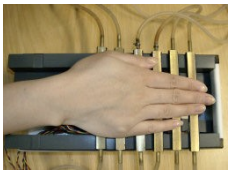


触覚独自の錯触:ベルベットイリュージョン
Tactile Unique Illusion: Velvet Illusion

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.

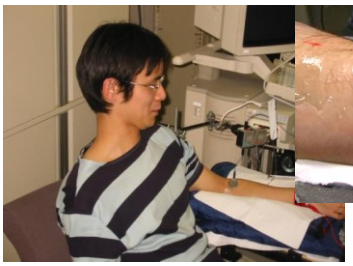
触覚独自の錯触:サーマル・グリル・イリュージョン
Tactile Unique Illusion: Thermal Grill Illusion



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.

どうやって調べたか／How we knew?



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 mechanoseisitive afferents," Brain Res., 1981.

Procedure

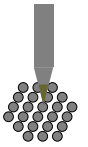
(Medical Doctor's License Required)

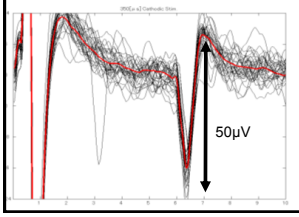
(0)See where the nerve bundle is. (by ultrasonography)

(1)Insert a needle (φ0.1mm), 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

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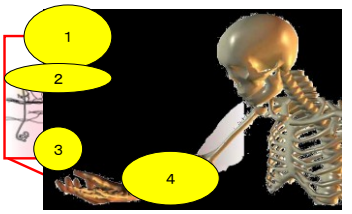
触覚を再構築するには
How to produce Touchable Illusion?



(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

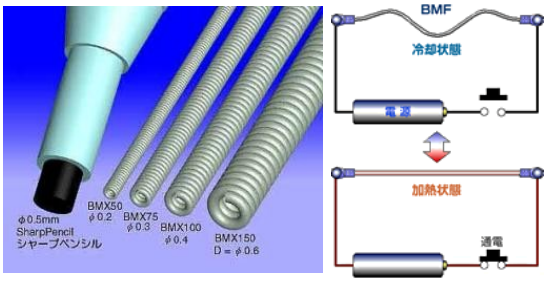
KGS株式会社

●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

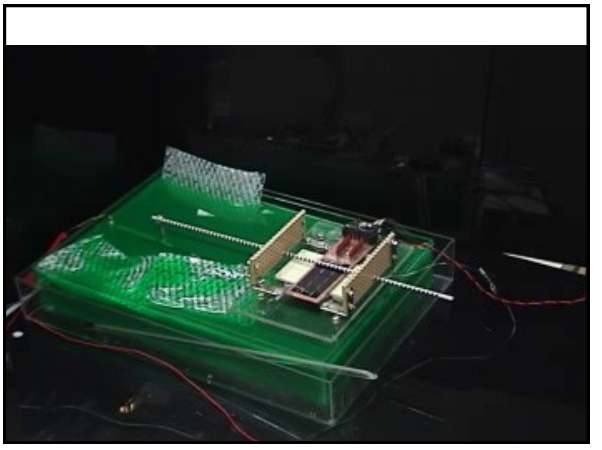
Xmen,2000

より細いアクチュエータ＝形状記憶合金？
Thinnest actuator = SMA?

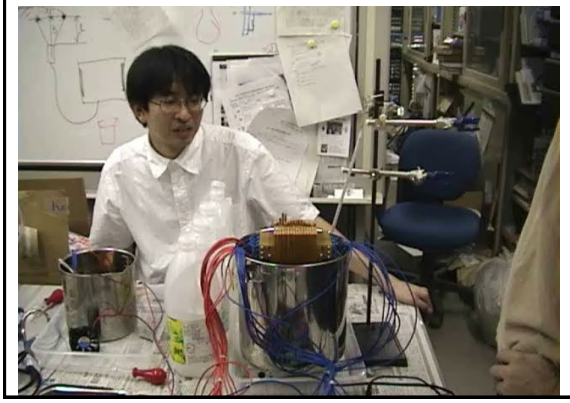
Coil-Type SMA（Shape Memory Alloy）
Extremely thin and moves large



Biometal Demo



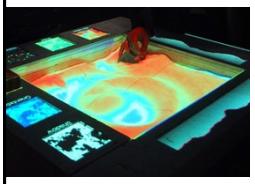
PopUp(Nakatani et al, 2005)

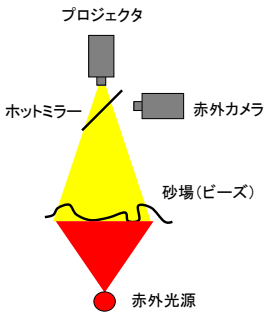


Lumen (Ivan Poupyrev, 2005)

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

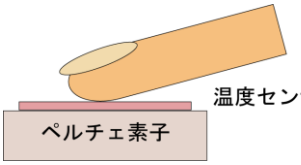
Is Actuator really necessary?：SandScape
(Yao Wang et al., 2002)

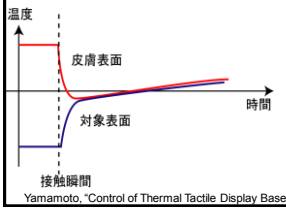




http://tangible.media.mit.edu/projects/sandscape/

温度感覚ディスプレイ／Thermal Display





接触瞬間から2～3秒間の温度変化が材質感推定の強力な手がかり

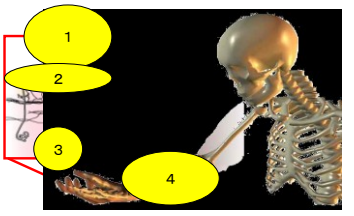
2 to 3s temperature change is the key to detect object property.
Peltier device with temperature sensor is used to reproduce the time course.

Yamamoto, "Control of Thermal Tactile Display Based on Prediction of Contact Temperature," ICRA2004

Thermoesthesia (Kushiyama, 2006)

http://www.youtube.com/watch?v=fMwOSM_G1Ys

How to produce Touchable Illusion?



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

Reproduce Skin Deformation

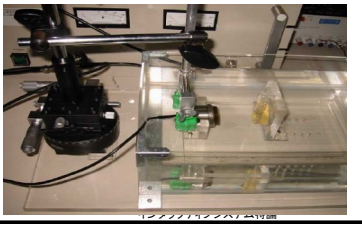
"Carpet is expensive. Shoes are enough!" Lets Wear.

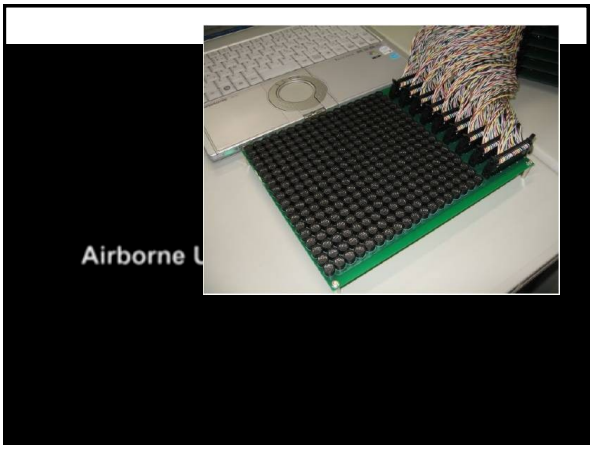
Small and light-weight tactile display (KAIST)
http://www.youtube.com/watch?v=CT4WZexTIoo

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

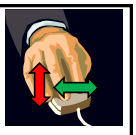
Actuator should dissappear?

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





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??

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.

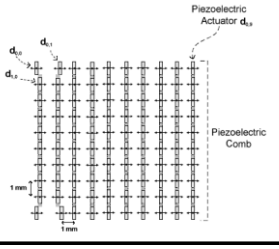
●受動的手法：摩擦係数を変化、皮膚が動いて初めて知覚
Passive type: friction coefficient is controlled, and perceived by skin motion.

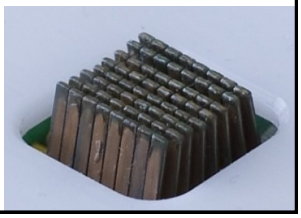
✓環境型に向く／
Good for environmental type.

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.

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

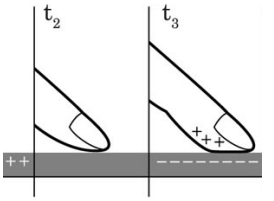
- スクイーズ効果：高周波振動で摩擦係数が減少する
  Squeeze effect: friction is reduced by high freq. vibration
- 指位置計測と組み合わせ、摩擦係数の提示が可能
  Combined with pos. sensing, friction distribution is displayed.

- 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)

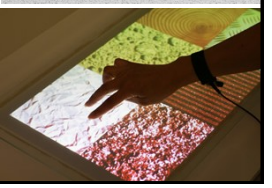
http://lims.mech.northwestern.edu/projects/TPaD/index.htm

Passive type Horizontal Display
高圧電極と皮膚の電気的吸引利用
Using adhesion between skin and electrode by high voltage



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

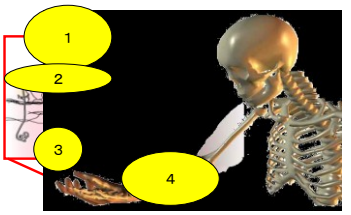
Olivier Bau et al., "TeslaTouch: Electrovibration for Touch Surfaces," UIST2010



TeslaTouch (2010)

http://www.teslatouch.com/

How to produce Touchable Illusion?



(1)Reproduce the World (Shape)
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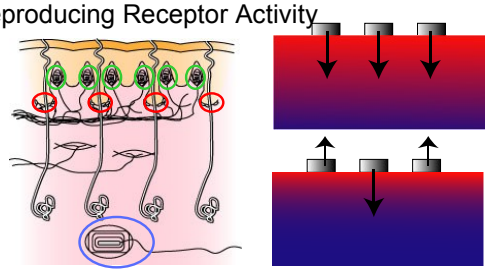
(4)Reproduce Nerve Activity

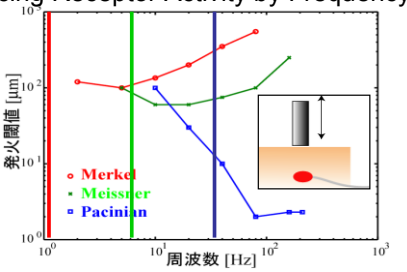
受容器活動再現型ディスプレイ
Reproducing Receptor Activity



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.

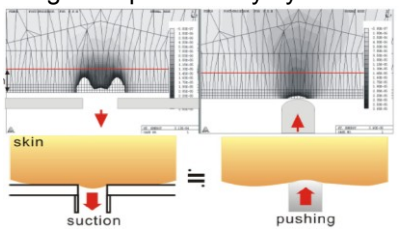
周波数特性に着目した受容器活動再現
Reproducing Receptor Activity by Frequency



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.

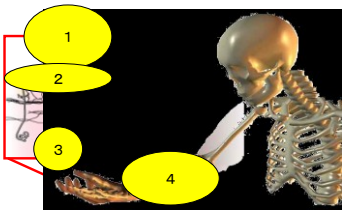
ひずみエネルギー再現に着目した受容器活動再現
Reproducing Receptor Activity by Strain Energy



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?



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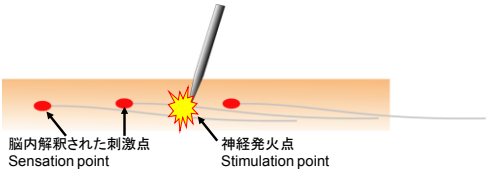
インタラクティブシステム特論

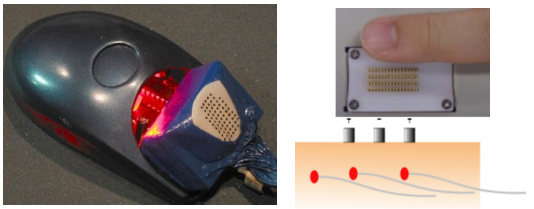
電気刺激により神経活動を再現
Reproducing Nerve Activity by Electrical Stimulation



•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 efficienty, no mechanical parts so mechanical resonance free.
•Bad point: Stimulation point and Sensation point is different

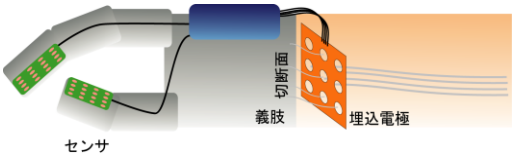
皮膚表面からの電気刺激
Electrical Stimulation from Skin Surface



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



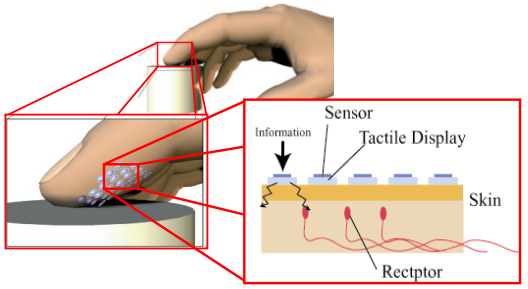
•埋め込み型マトリクス電極。神経再生時に電極を通過して学習による空間マッピング.
•福祉用途
•Matrix electrodes (holes) are embedded, and nerve will grow into the holes.

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?



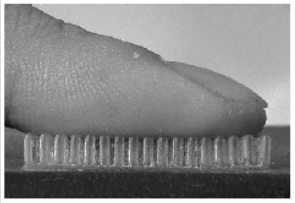
新しい人工受容器として機能

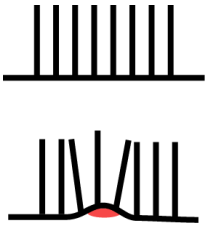
63

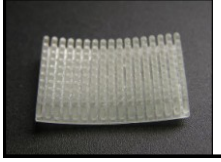
触覚ARとしての乳がん診断具／
Breast Cancer Checker as Tactile AR

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



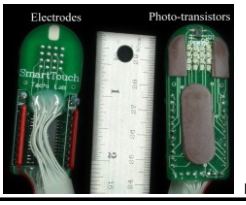


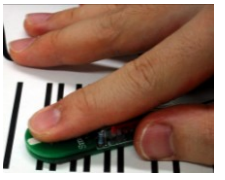


佐野他：触覚コンタクトレンズ (ROBOMEC'04)

触覚のAR／Tactile AR

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

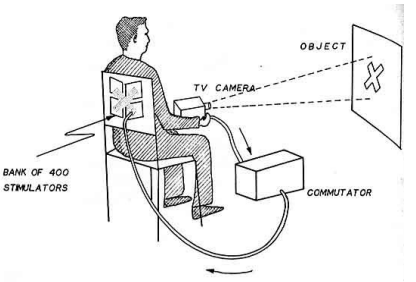




Kajimoto et.al, *SmartTouch*, SIGGRAPH2003.

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

使用状況

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，未だ世の中に無い．

•無いだけでなく，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, reseachers 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.

•Todays 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.