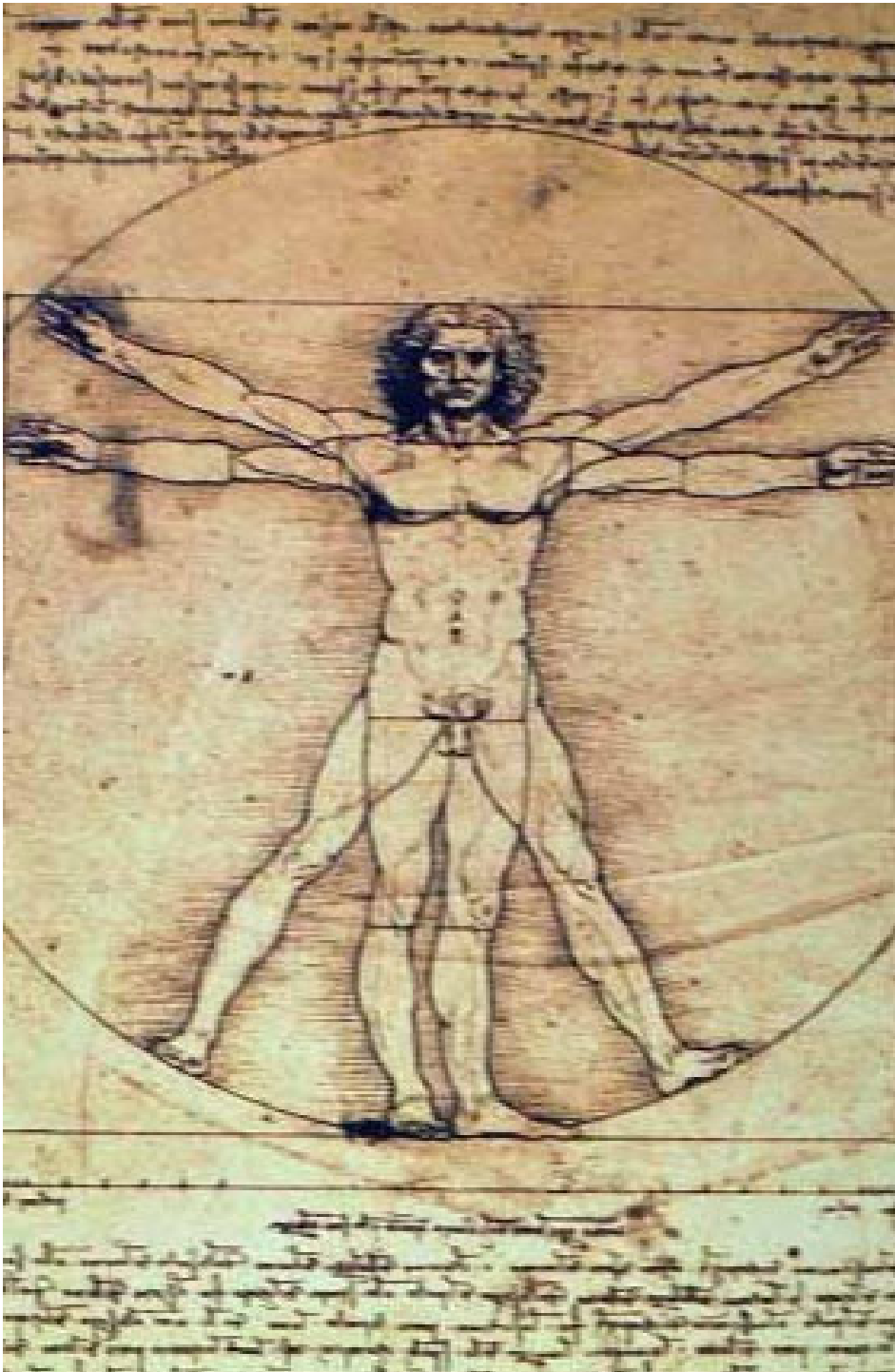




Interactive System インタラクティブ システム特論 (8)

Hiroyuki Kajimoto
kajimoto@uec.ac.jp
Twitter kajimoto



インタラクティブシステム特論
最終課題について: [Web参照](#)
準備を始めましょう

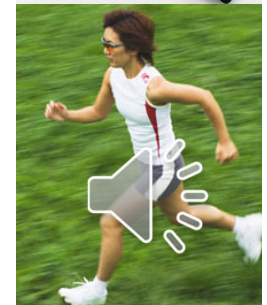
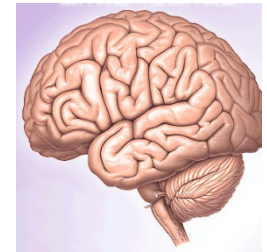
Please see [the web](#) for final
presentation-style report, and
start preparation.

http://kaji-lab.jp/ja/index.php?plugin=attach&refer=people%2Fkaji%2Finteractive&openfile=interactive_final_report.pdf



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

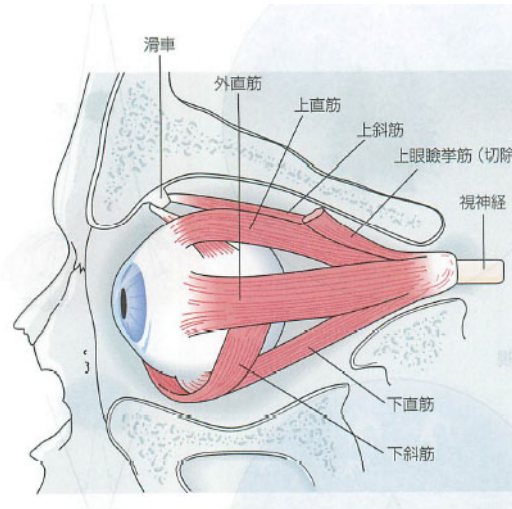


TODAY's TOPIC

1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface

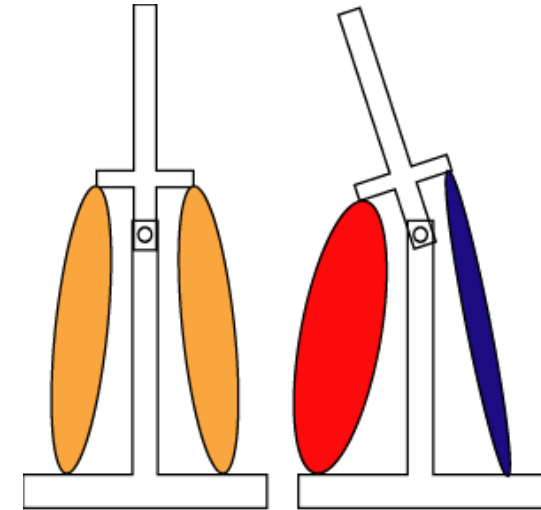


Antagonistic muscle pairs 拮抗筋



カandel神経科学(Principles of Neural Science)

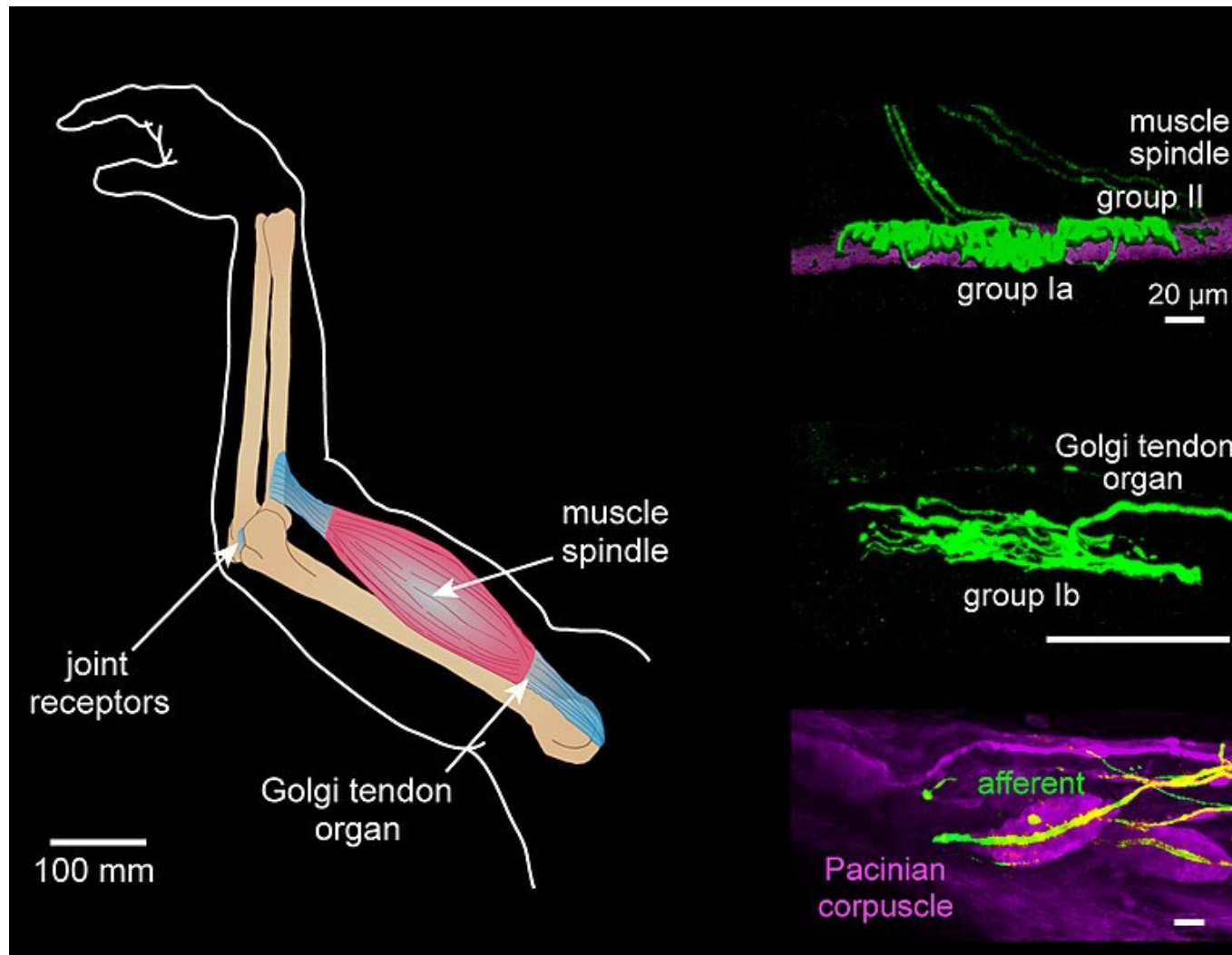
<https://www.medsci.co.jp/kandel/syousai/index.html>



- 2つの拮抗筋ペアが一つの関節で協調動作
 - 筋は収縮側でしか力を発揮できないため
 - 制御自由度が2あることで、固さ(インピーダンス)と外力の2パラメータを決定できる
 - 主働筋の動作時に拮抗筋が弛緩する(相反神経支配)
- Two muscles are responsible for one joint.
 - Muscle can only exert force when it shrinks.
 - By Two muscles, “Force” and “Impedance(softness)” is independently presented.



Receptors around Muscle and Joint

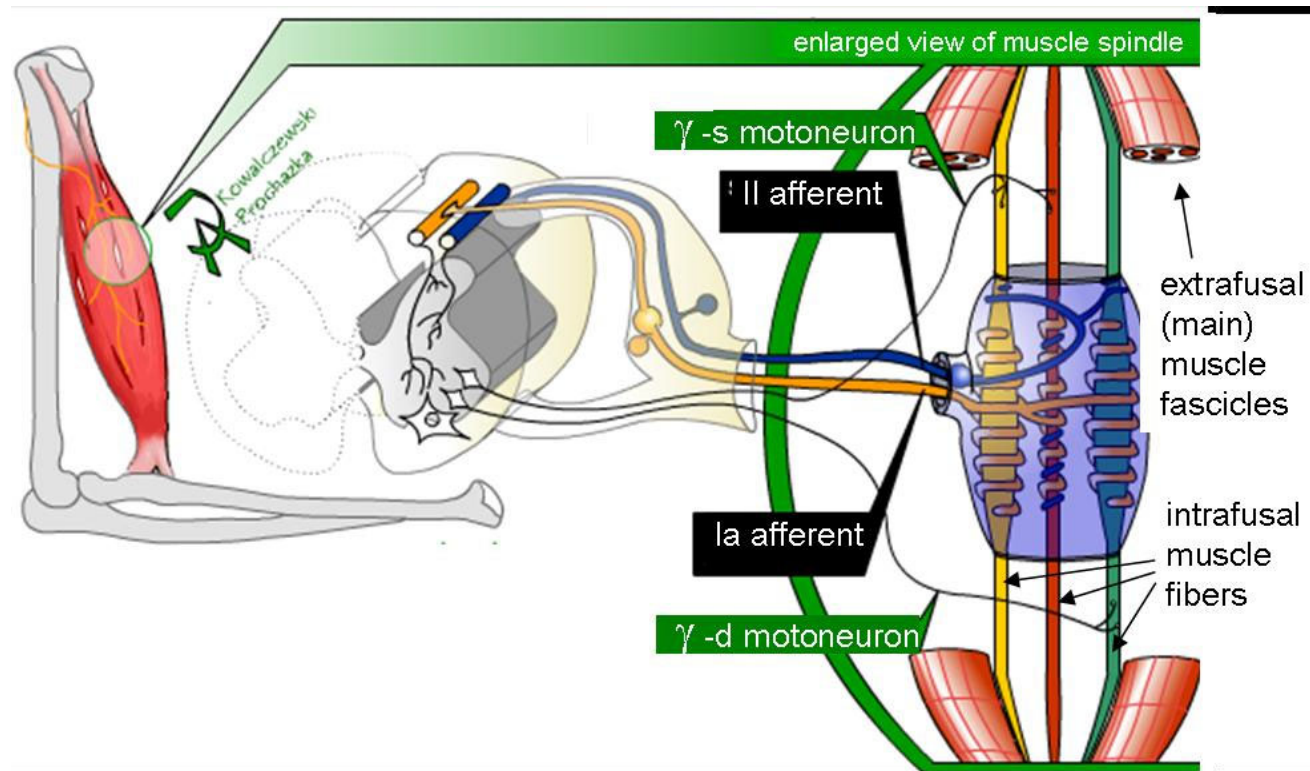


- 筋紡錘
Muscle Spindle
 - Inside Muscle
- ゴルジ腱器官
Golgi Tendon Organ
 - At the Tendon (Muscle-Bone Connection)
- 関節受容器
Joint Mechanoreceptor
 - Inside Joint

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



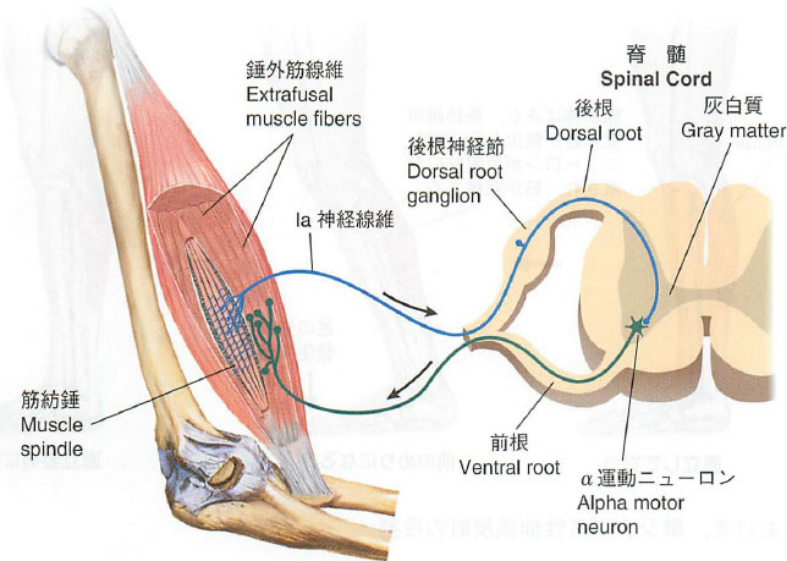
筋紡錘 Muscle Spindle



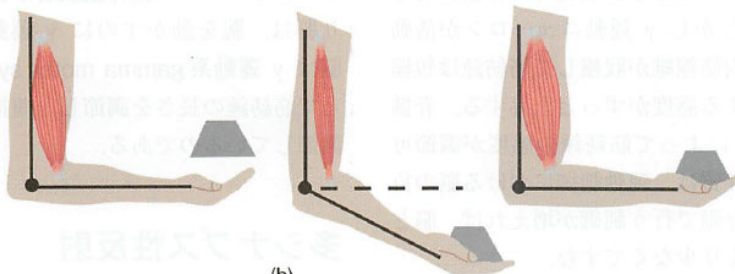
https://en.wikipedia.org/wiki/Muscle_spindle

- 筋肉の伸長→筋内繊維の伸長→感覚神経末端の物理的変形→活動
 - Ia繊維（直径12-20um）：伸びた長さおよび速度に反応（位置と速度。文献によっては速度）
 - II繊維（直径5-12um）：伸ばされた筋が伸び続けている場合に反応（文献によっては位置）
 - γ 運動ニューロン。筋伸縮のさいの筋内繊維の「ゆるみ」を防止する調整役（ α - γ 連関）。
 - Ia afferent mainly detects length and velocity. II afferent is for static length.

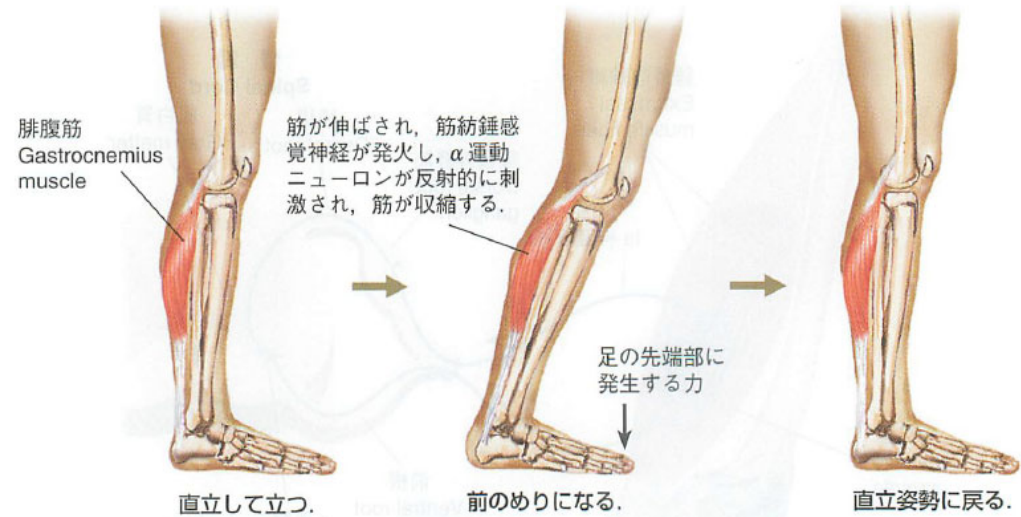
伸長反射 Stretch Reflex



(a)



(b)

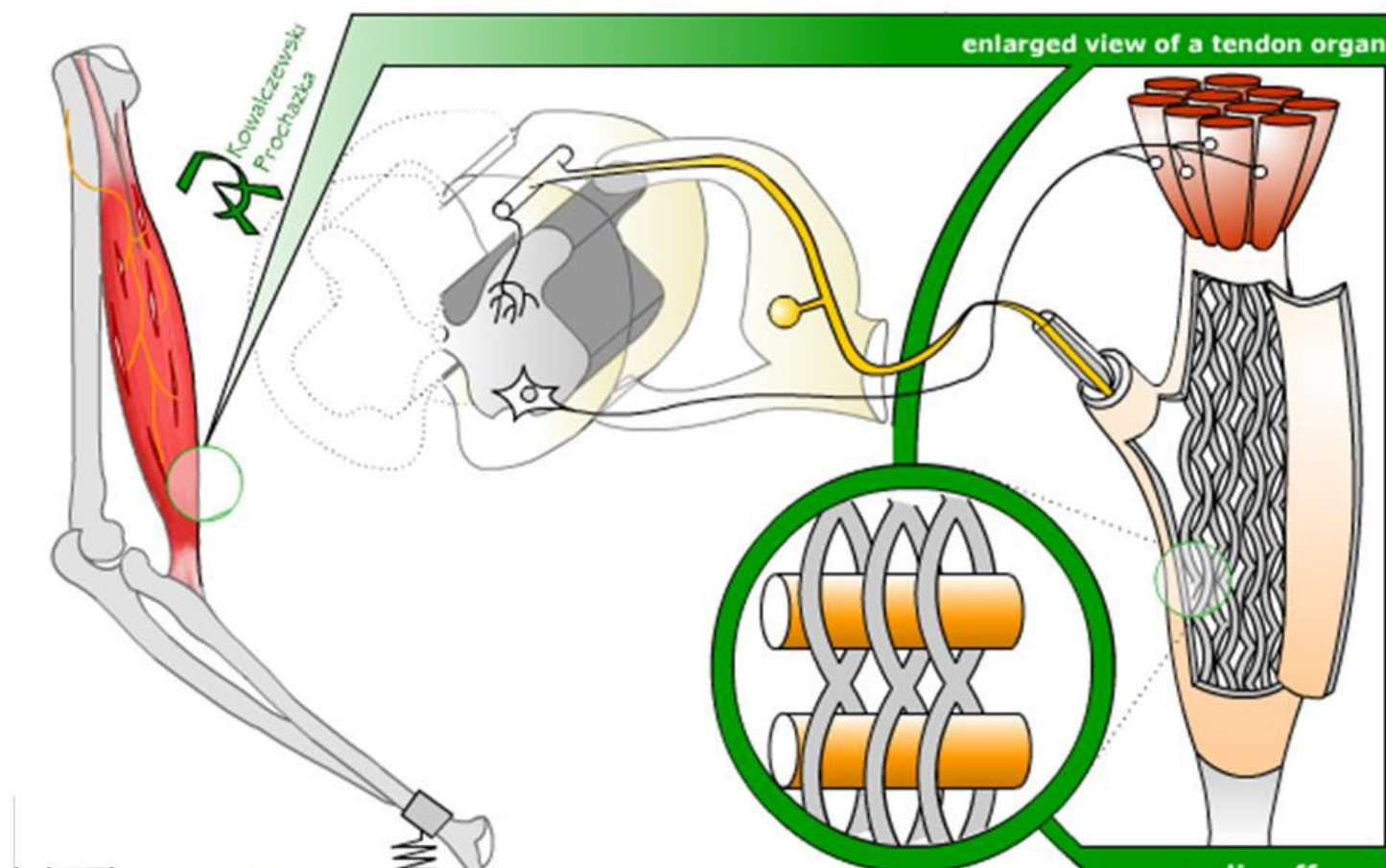


カールソン神経科学テキスト (Physiology of Behavior)
<https://www.maruzen-publishing.co.jp/item/b294439.html>

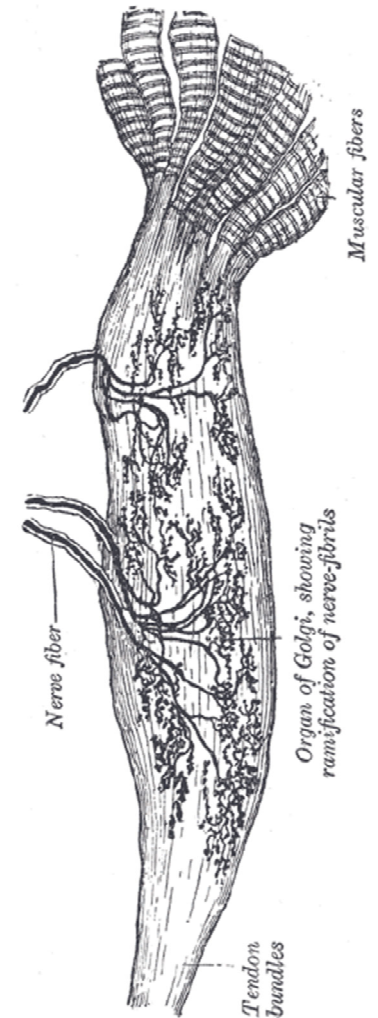
- 筋が受動的に引き伸ばされた際にその筋が収縮する反射。
 - 唯一の単シナプス反射。
 - いわゆる膝蓋腱反射もこの一種。
 - 姿勢の維持に貢献
 - 同時に拮抗筋の活動が抑制される(1a抑制反射)



ゴルジ腱器官 Golgi Tendon Organ



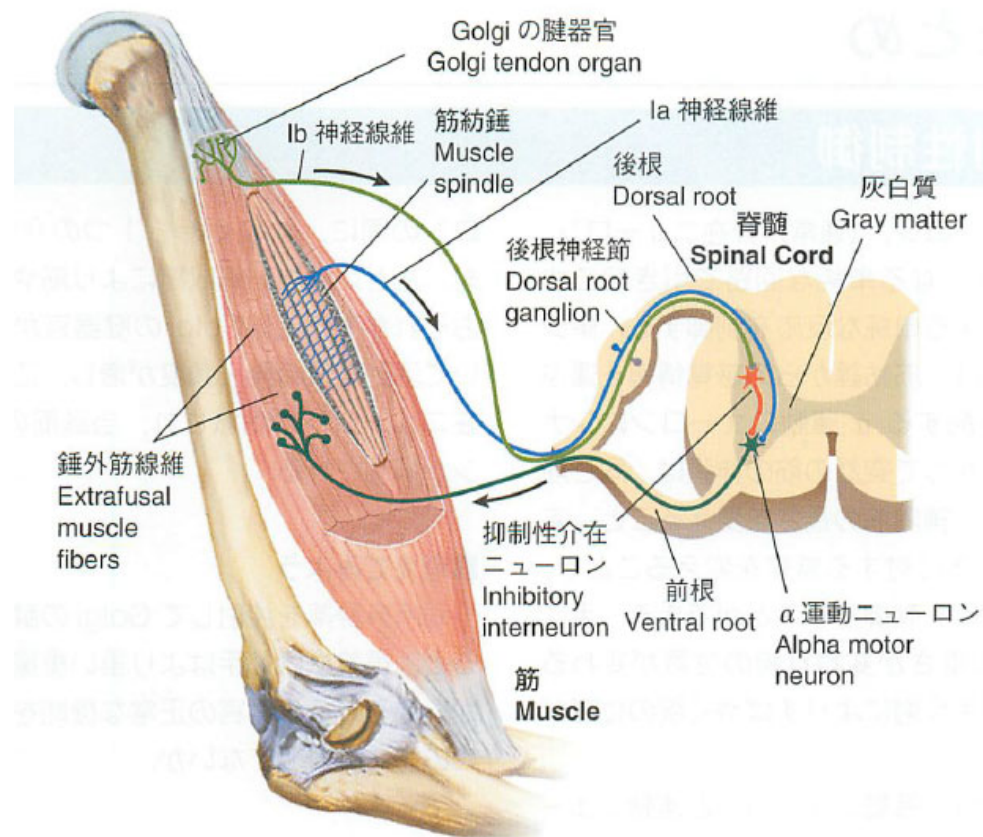
https://en.wikipedia.org/wiki/Golgi_tendon_organ



- 骨格筋と腱の移行部に存在。筋の力に応じて活動。
 - Ib繊維(直径12-20um)
 - 腱反射のような殴打する刺激に対しては筋紡錘のみ活動。
 - 筋張力を一定に保つ。



Ib抑制反射 Golgi tendon reflex



カールソン神経科学テキスト (Physiology of Behavior)

<https://www.maruzen-publishing.co.jp/item/b294439.html>

- ゴルジ腱器官に伸張刺激が加わると刺激が加わった筋の緊張が低下する
- 同時に拮抗筋の活動も生じる
- When a stretching stimulus is applied to the Golgi tendon organ, the tension in the stimulated muscle is reduced. Antagonistic muscle activity occurs simultaneously.



錯触（皮膚感覚に対する錯触のぞく）の一部 Haptic Illusions (other than purely cutaneous illusion)

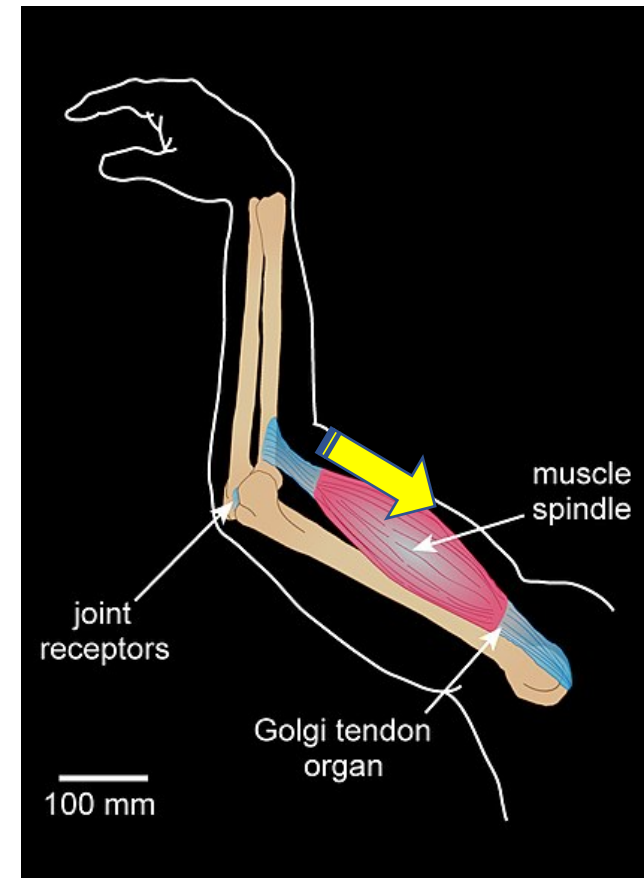
1. 深部受容器自体の刺激
2. 視覚＋深部感覚 Vision + Haptics
3. 皮膚感覚＋深部感覚 Cutaneous + Haptics



腱振動による運動錯覚 kinetic illusion by tendon vibration



Leonardis, Haptics Symposium, 2012

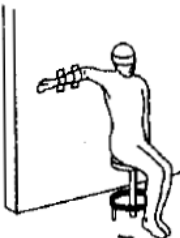


- 腱に80Hzの振動を打ち込むと関節が曲がって感じられる (Goodwin 1972)
- 振動伝播により**筋紡錘**を刺激していると考えられている(Burke1976他)
- インタフェースとしての提案多(友田2009, Roll2009, Leonardis2012)
- **強力な振動子が必要**⇒強烈な振動感



運動錯覚による身体変容

Influences of body shape and orientation by

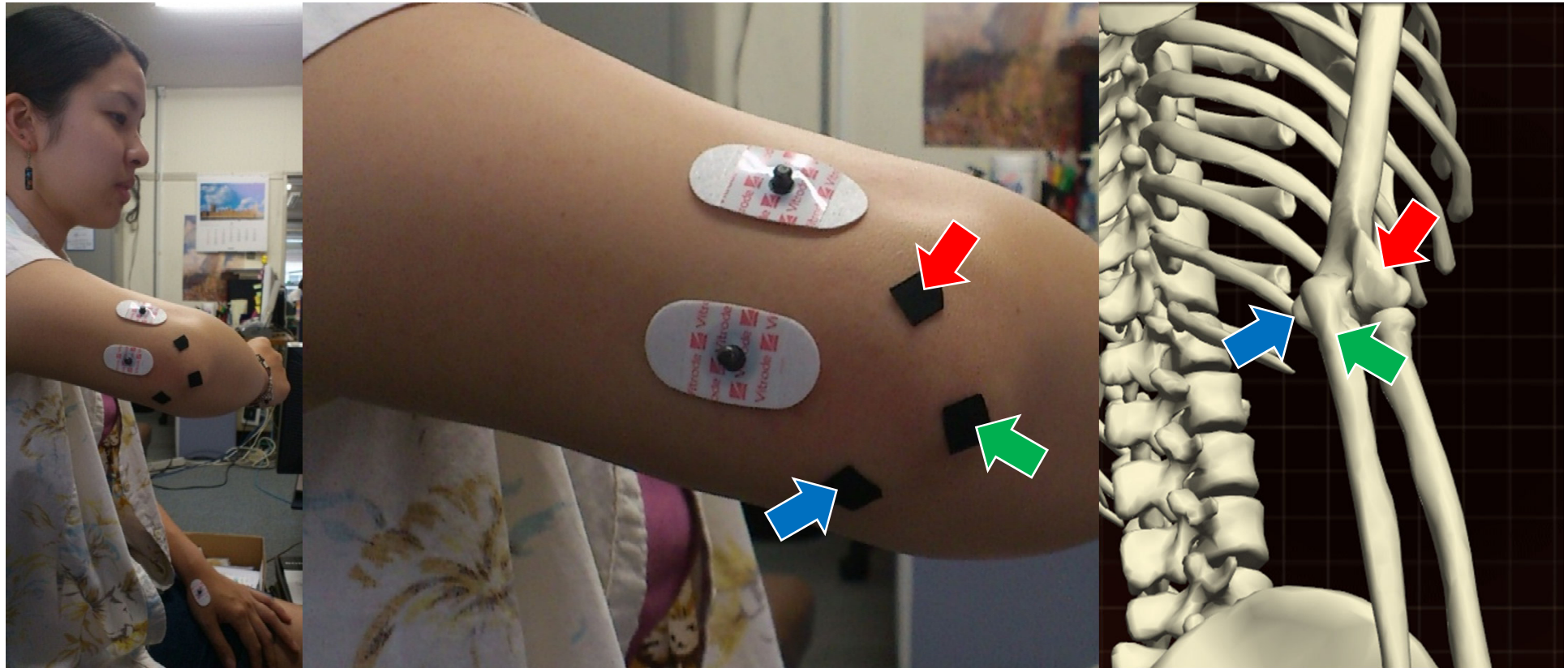
	Test configuration A	Experienced pattern	Test configuration B	Experienced pattern
1				
2				
3				
4				

[Some Proprioceptive Influences on the Perceptual Representation of Body Shape and Orientation," J. R. Lackner, 1988, Brain](#)

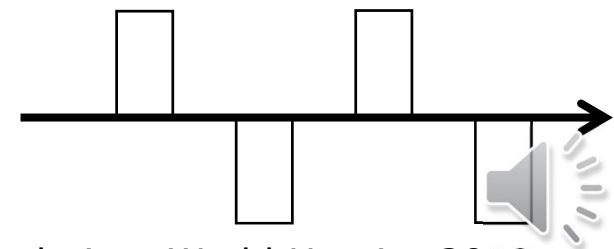
- 例えば鼻先をつまんだ状態で振動刺激を加えて肘伸展の運動錯覚を引き起こすと、鼻が物理的に伸びたに違いないと解釈する。
- If a vibrating stimulus is applied to the nose while the tip of the nose is pinched to induce the kinetic illusion of elbow extension, the nasal sensation is interpreted that the nose must have been physically stretched



電気刺激による運動錯覚 Electrical stimulation to tendon part also induce kinesthetic illusion



- 上腕三頭筋の肘側の**腱**を電気刺激
 - ✓ 100Hz、500usの両極性パルス
 - ✓ 電流値は被験者自身が調整。最大10mA
 - ✓ 10秒程度の刺激で腕姿勢を回答



Kajimoto: Illusion of Motion Induced by Tendon Electrical Stimulation. World Haptics 2013

右腕を刺激、左腕で姿勢を模擬（閉眼）



閉眼、右腕腱刺激、なるべく力を抜いて腕を前に突き出す



視覚によるハプティック錯覚 (1)：サイズ-重さ錯覚 Vision Induced Haptics(1): Size-Weight Illusion



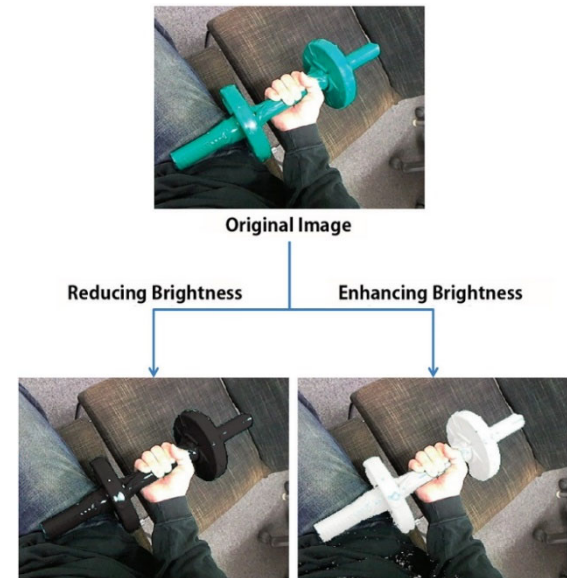
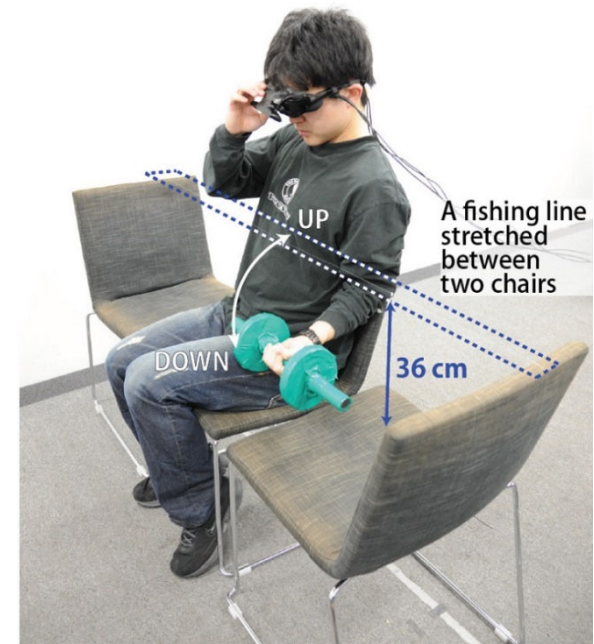
同じ重量なら小さいものをより重く感じる (家でやりましょう)
If two objects are the same weight, smaller one felt heavier.



明度 ⇒ 重さ知覚



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



Ban et al.: Augmented Endurance: Controlling Fatigue while Handling Objects by Affecting Weight Perception using Augmented Reality, CHI2013.

視覚によるハプティック錯覚 (2) : シュードハプティクス Vision Induced Haptics(2): Pseudo-Haptics



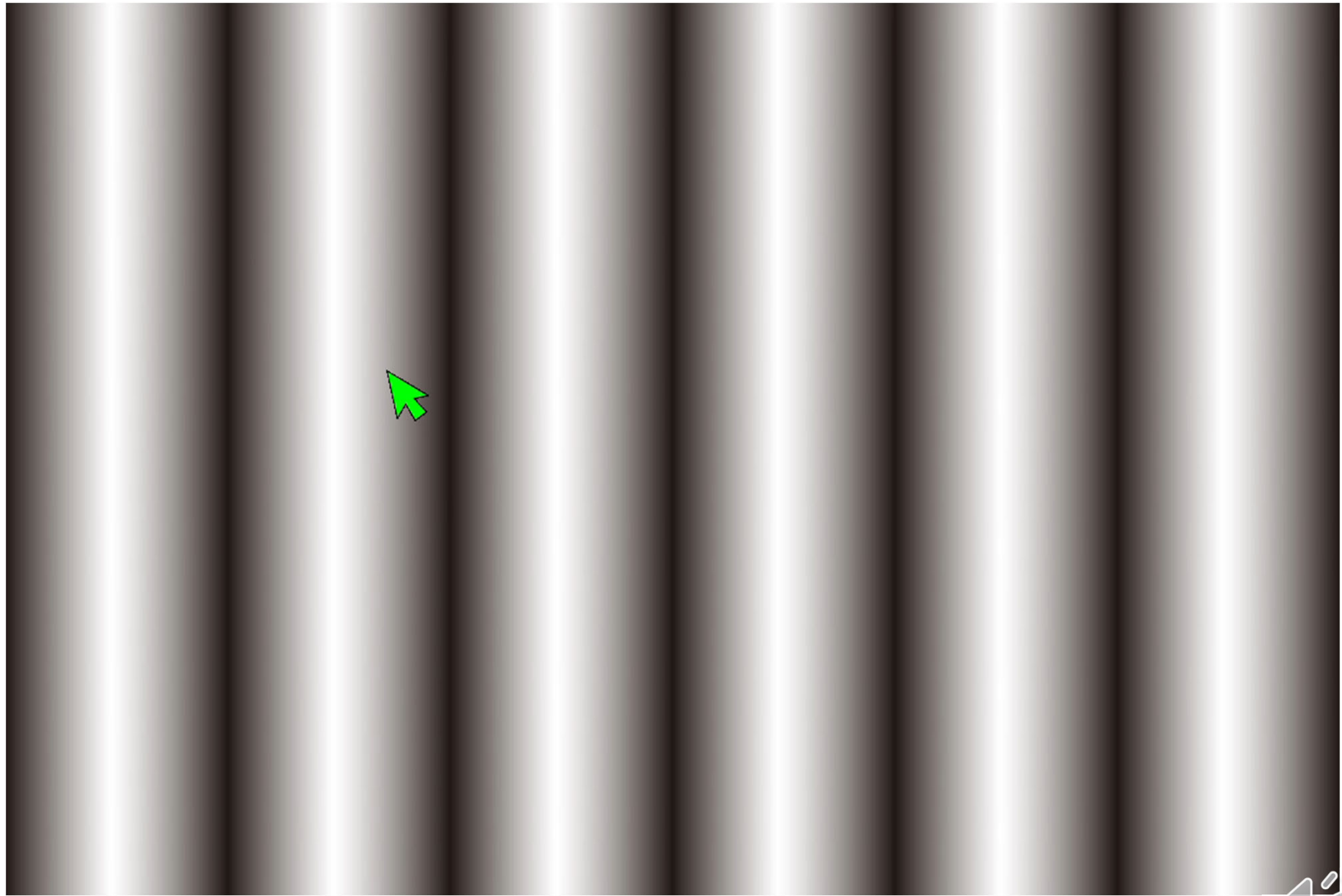
視覚的な動きによって、触覚的な抵抗感を感じる。マウスカーソルの動きを遅くしたときのブレーキ感。

Visual motion induces haptic resistance. (ex) Braking feeling when mouse cursor is suddenly slowed down.

http://www.irisa.fr/bunraku/GENS/alecuyer/projets_textures.html



PseudoHaptics

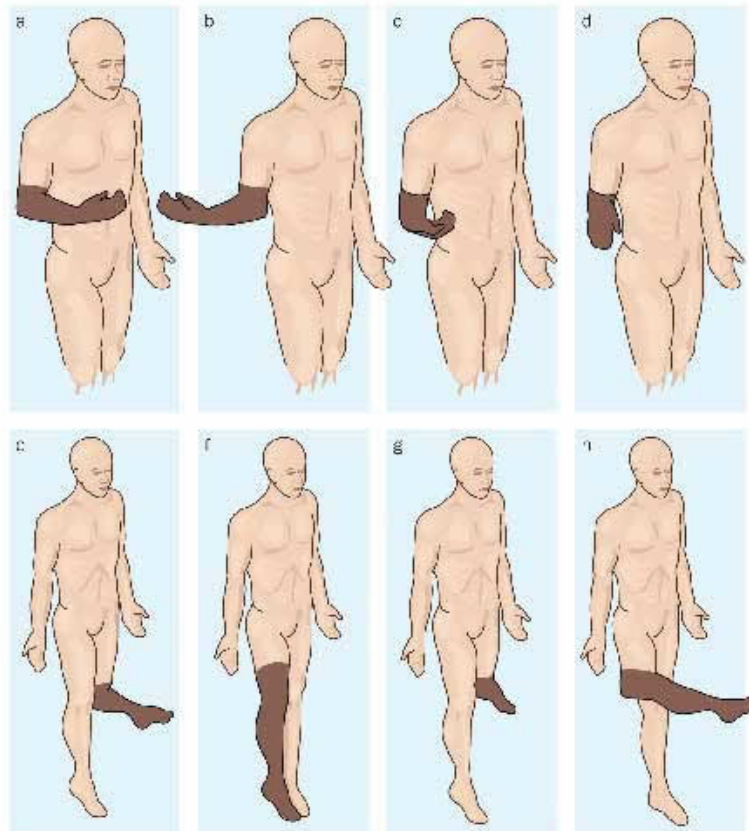
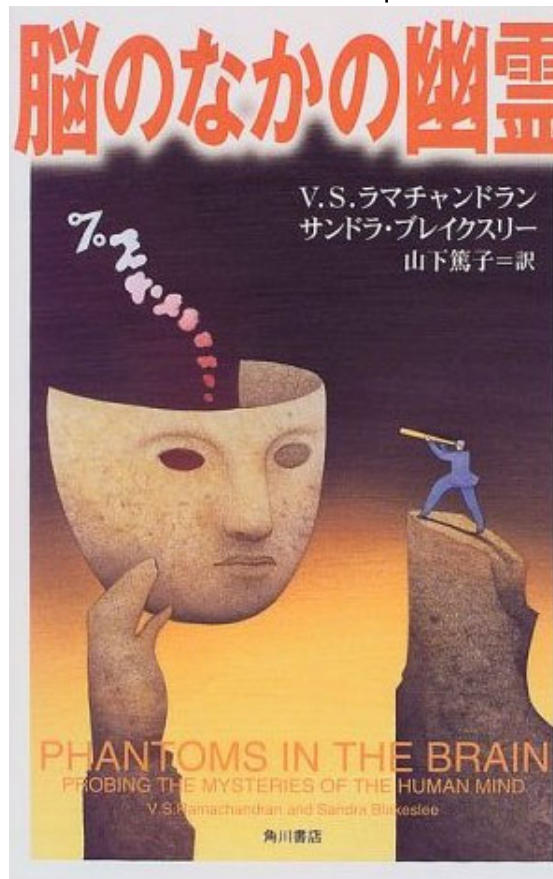


<https://github.com/HiroyukiKajimoto/PseudoHaptics>

(家でやりましょう)



視覚によるハプティック錯覚 (4) : ミラーボックスによる幻肢痛緩和 Reduction of phantom pain by mirror box

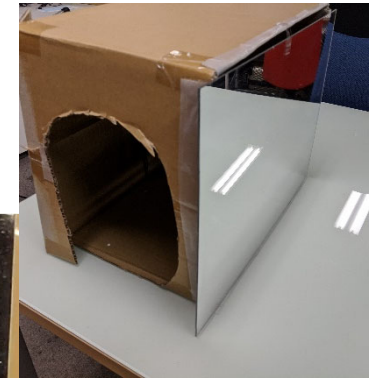


<https://www.amazon.co.jp/dp/4042982115>

幻肢痛：手足を失った後に、切断部位は問題ないのに激しい痛みを感じる現象。
ひとつの仮説：失った手足の脳内座標(ボディマップ)が狂い、体内に「食い込む」
ことで脳内で痛みシグナルが発生。姿勢をもとに戻せないために痛みを生じ続ける。

Phantom pain: After one's hand/arm/leg was removed, pain seems to occur from the removed site. One hypo.: Removed limb's body map in the brain comes wrong, and the brain generates pain signal.

ミラーボックスセラピー Mirror box therapy

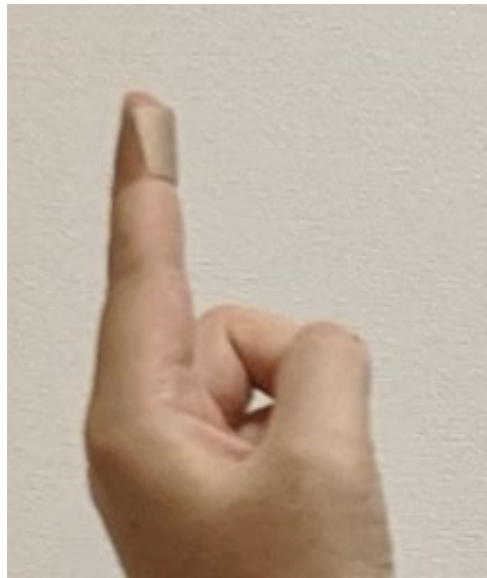


ミラーボックスを使い、両手を使っていることをイメージさせることで、脳内で無いはずの手を動かすことができる。これにより幻肢痛を劇的に低減できる。
Using mirror box, patients can “move” their lost limb in their brain, so that the phantom pain is dramatically reduced.



視覚による痛みの低減

Pain is reduced by visually making it small



反転させた双眼鏡を使って痛みの患部を観察すると痛みが減る。

Observing the pain region with reverted binocular, the pain is reduced.

- Moseley GL, Parsons TJ, Spence C. s. *Curr Biol.* 2008;18(22):R1047-R1048.
- Mancini F, Longo MR, Kammers MP, Haggard P. Visual distortion of body size modulates pain perception. *Psychol Sci.* 2011;22(3):325-330.



視覚+触覚によるハプティック錯覚：Rubber Hand Illusion



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

見えていない実際の手に触覚的な刺激を与え、同時にゴムの手に視覚的な刺激を与える。しばらくするとゴムの手が自分の手であるように感じる

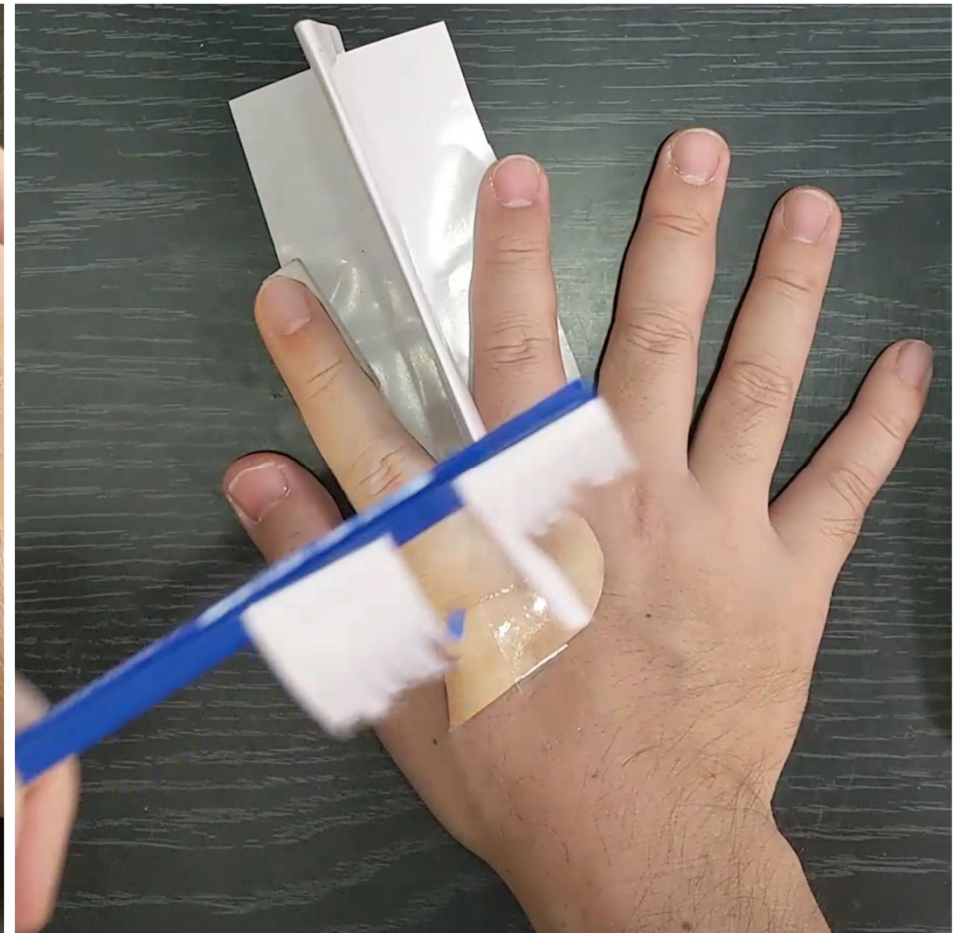
Watching a rubber hand being stroked synchronously with one's own unseen hand causes the rubber hand to be attributed to one's own body, to "feel like it's my hand."

Botvinick, M., & Cohen, J.: Rubber hands "feel" touch that eyes see, *Nature*, 391, 756 (1998)

Armstrong, K. C., & Ramachandran, V. S.: Projecting sensations to external objects: evidence from skin conductance response, *Proc R Soc Lond B Biol Sci*, 270, 1499-1506 (2003)



指バージョン：Rubber Hand Illusion (finger version)

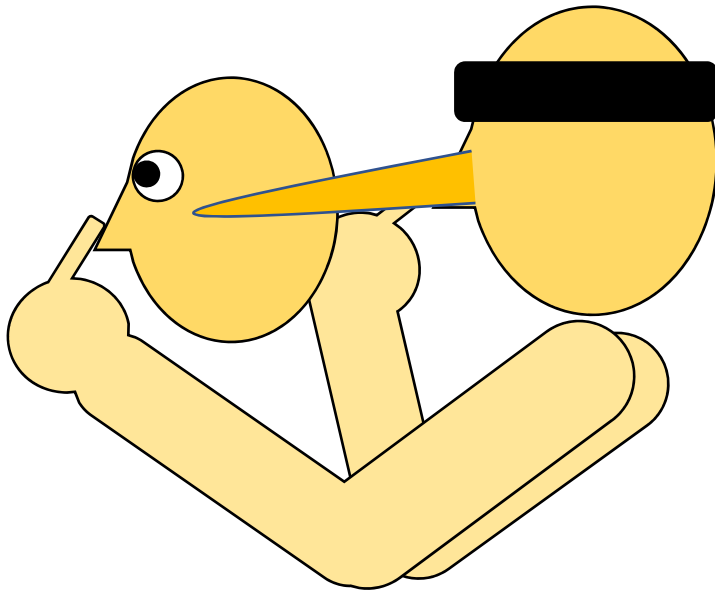


自分の手の写真を印刷すれば簡単にできます (家でやってみましょう)

You can try the rubber hand illusion using your finger. Take a photo of your hand and make a simple setup as shown.



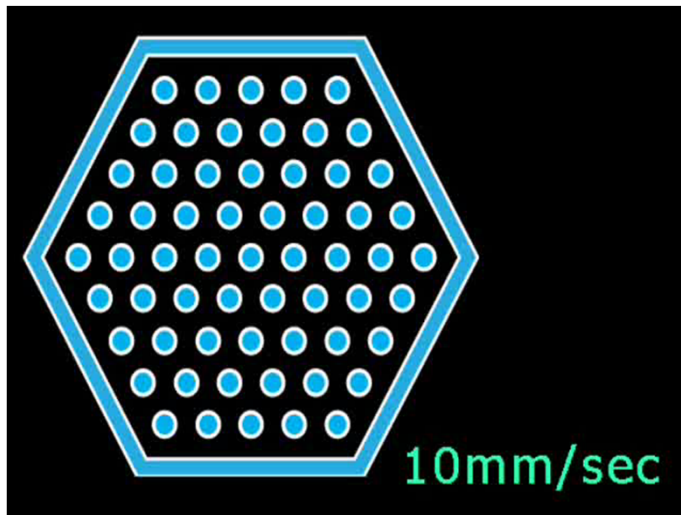
皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : ピノキオ錯覚 Pinocchio Illusion



自分の前の人の鼻を撫でつつ、自分の鼻も撫でると、1分程度で半分程度の人が自分の鼻が伸びたように感じる。



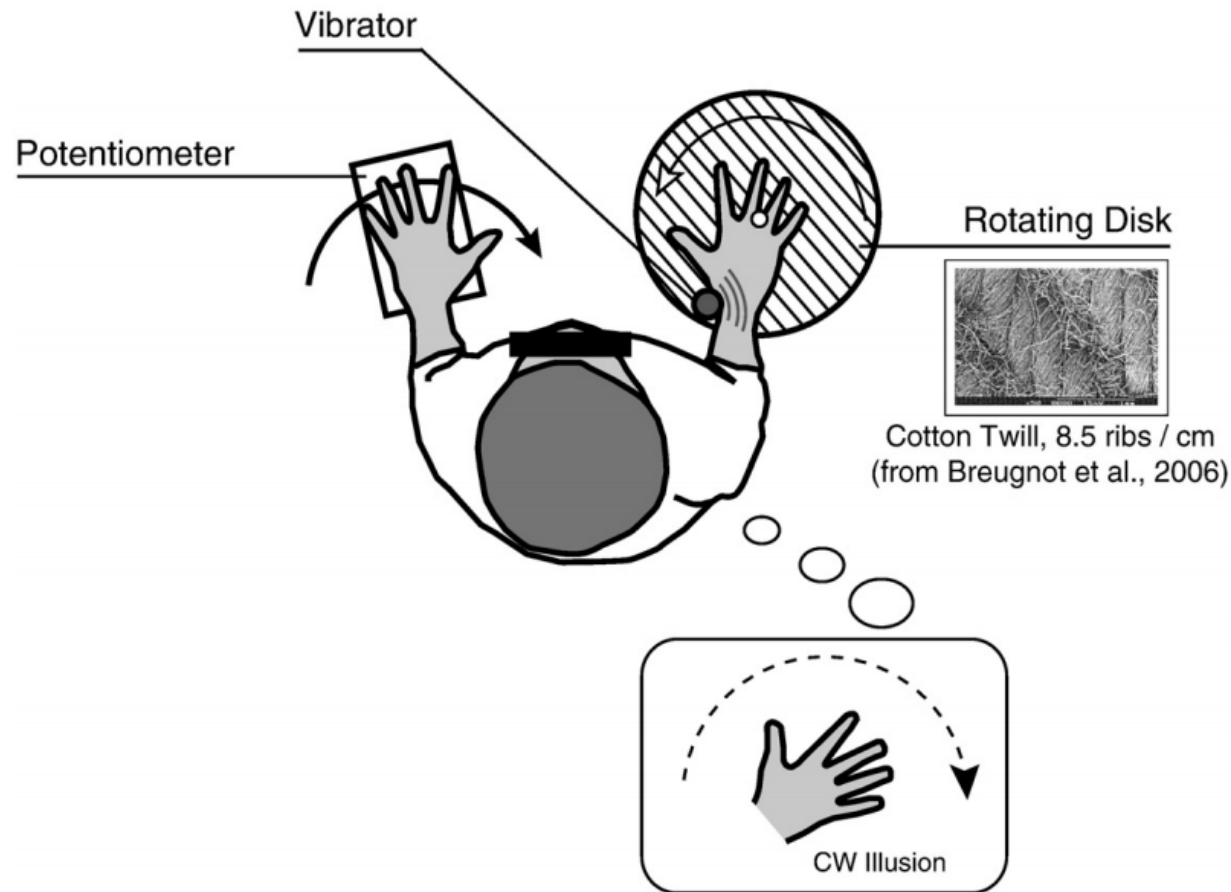
皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 動きの錯覚 Illusion of motion



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



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 動きの錯覚 Illusion of motion

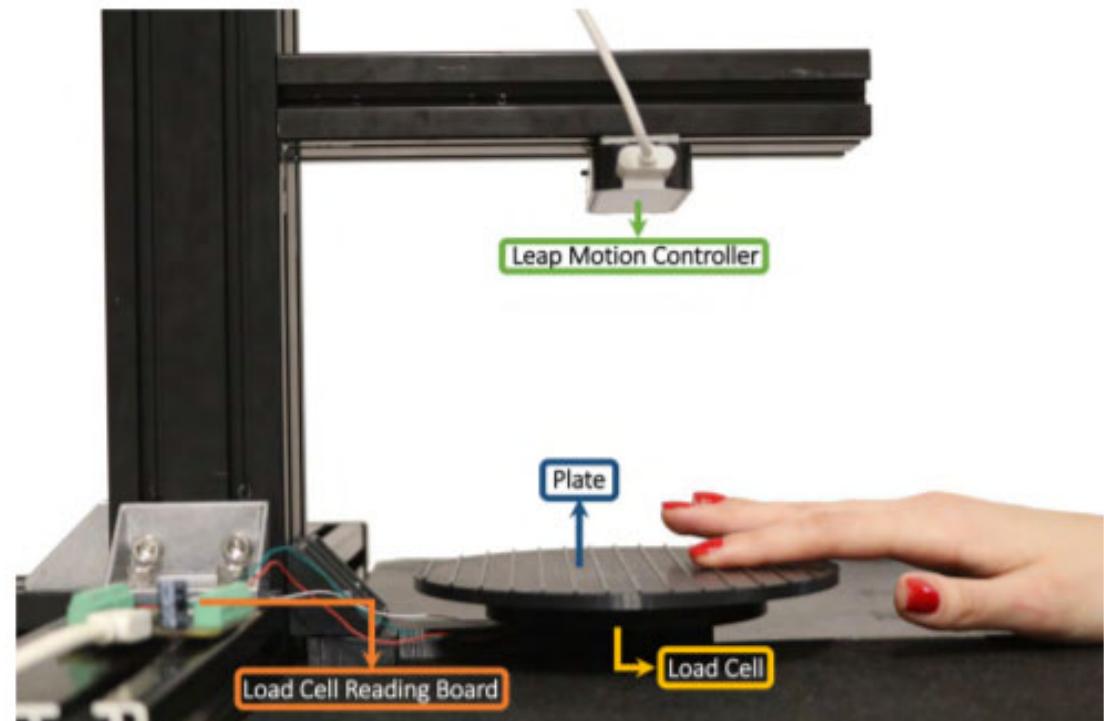
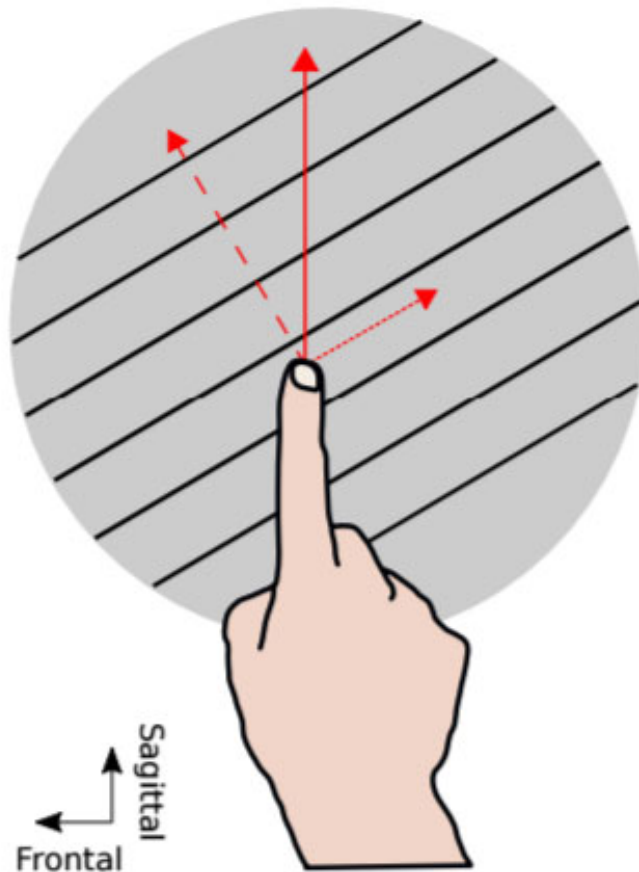


- 手のひらへの回転状触刺激＋振動による筋活動⇒手首が「回転し続ける」錯覚。

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



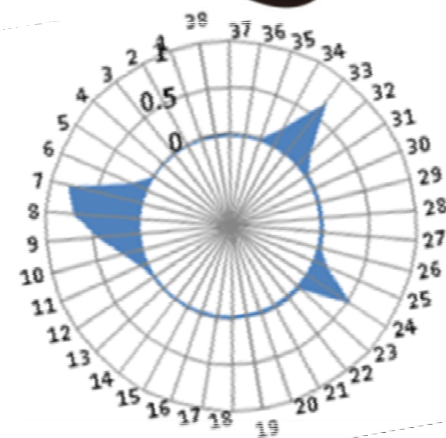
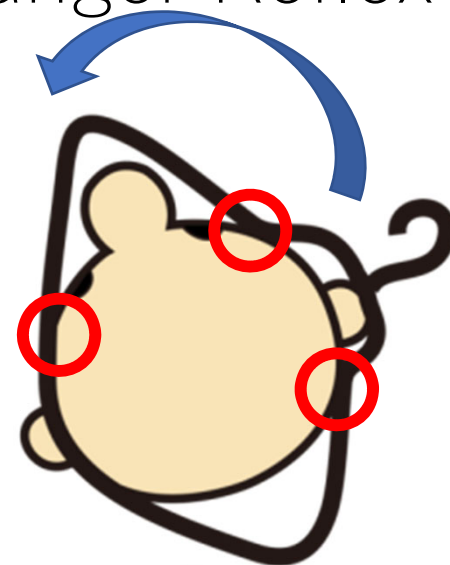
[WorldHaptics2017] Haptic Feedback of Membrane Puncture with an MR-Compatible Instrumented Needle and Electroactive Polymer Display* | Supplemental Material
Jung Hwa Bae, Amy Kyungwon Han, Christopher J. Ploch, Bruce L. Daniel, Mark R. Cutkosky



- シマシマの凸凹は皮膚上での触覚の運動を引き起こす。これが実際の指の運動と一致しない場合、指の動きの方向の誤認が生じ、結果的に動きの方向も変化。指先版Redirected Walking。



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : ハンガー反射／Hanger Reflex



- 側頭部圧迫によって外力を知覚
- 頭部の回旋をも誘発 (家でやってみましょう)
- Front temporal pressure induces “rotational” force perception.
- Rotation itself is induced.

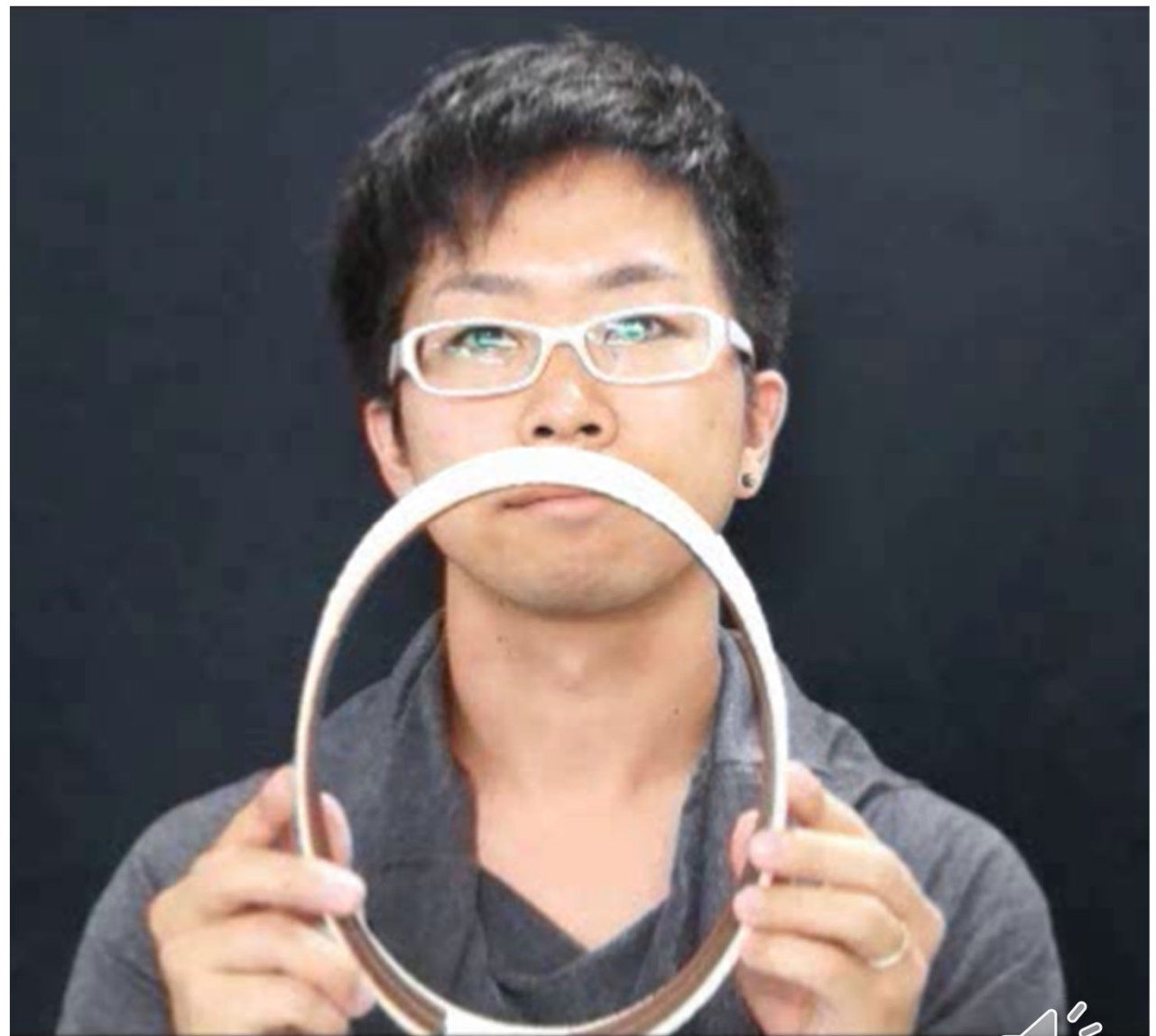
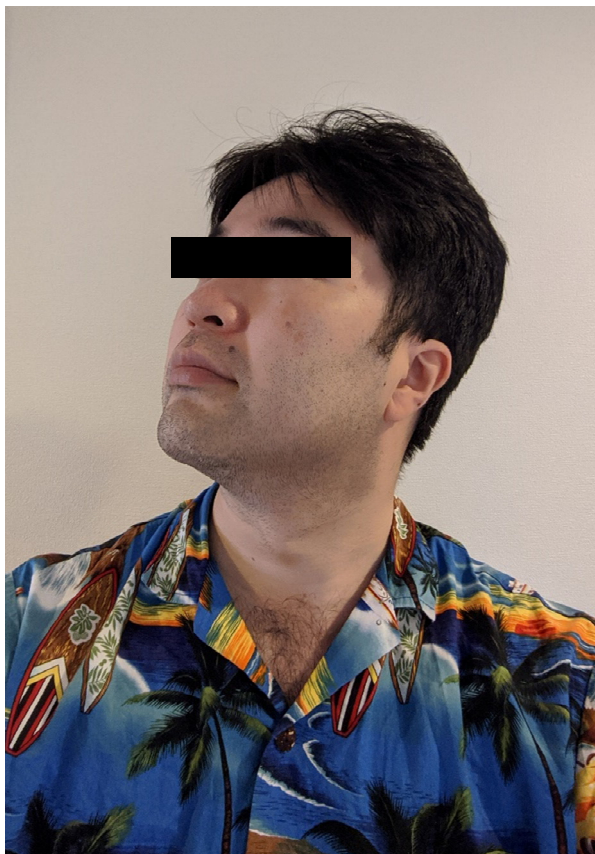


ハンガー反射

To clarify the details of the HR,
we measured pressure distribution
on the head when the reflex took place,



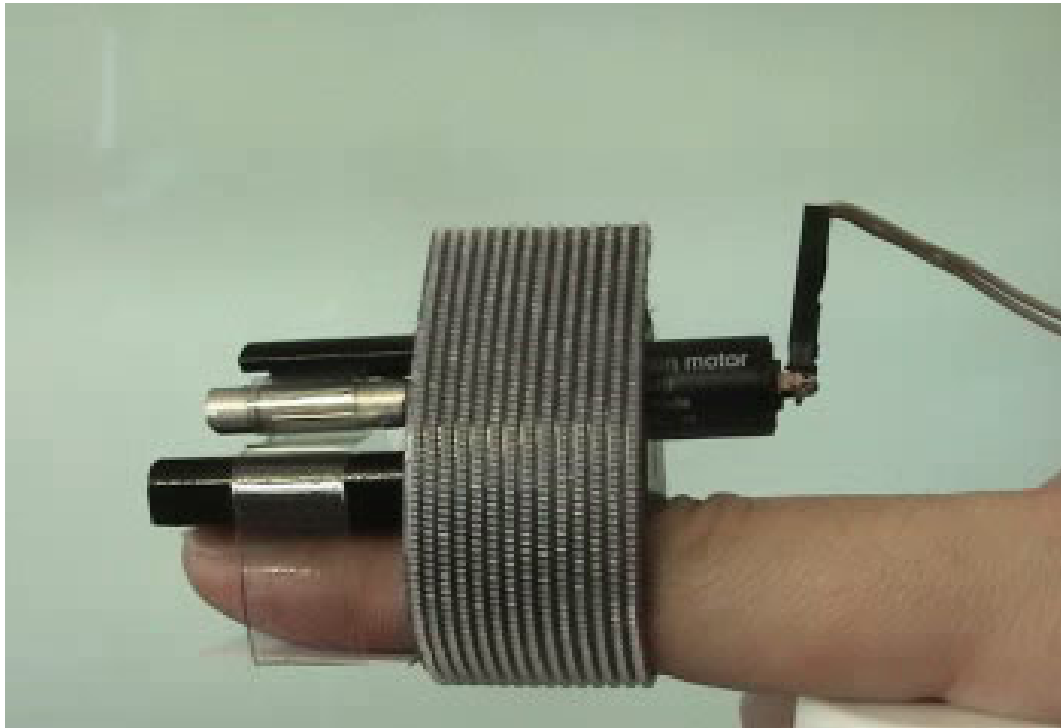
(参考)痙性斜頸への応用



T. Asahi et al. : Pilot Study of a Device to Induce the Hanger Reflex in Patients with Cervical Dystonia, *Neurologia medico-chirurgica*, Vol.58, No.5, pp.206-211, 2018



皮膚感覚によるハプティック錯覚 Cutaneous Induced Haptics : 皮膚圧迫による外力錯覚 Illusory external force by pressure

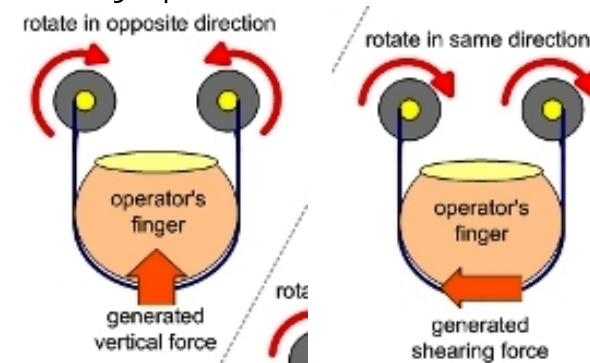


<http://reality.ei.tuat.ac.jp/>

A pseudo-force-feedback device by fingertip tightening for multi-finger object manipulation

G Inaba, EuroHaptics2016

稲葉、藤田：指先圧迫による擬似反力提示装置の提案と試作, 日本VR学会論文誌, 2007.



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

Minamizawa, Haptic Interface for Middle Phalanx Using Dual Motors, EuroHaptics, 2006.

Minamizawa: Wearable Haptic Display to Present Gravity Sensation - Preliminary Observations and Device Design", WorldHaptics 2007

- 皮膚の圧迫により、本来は外力がない状況で外力を感じる
- Simple pressure sensation is perceived as external force.



TODAY's TOPIC

1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface



力覚ディスプレイの形態 Grounded and Wearable Haptic Display



CAVE automatic virtual environment (Wikipedia)

https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment



Head Mounted Display (wikipedia)

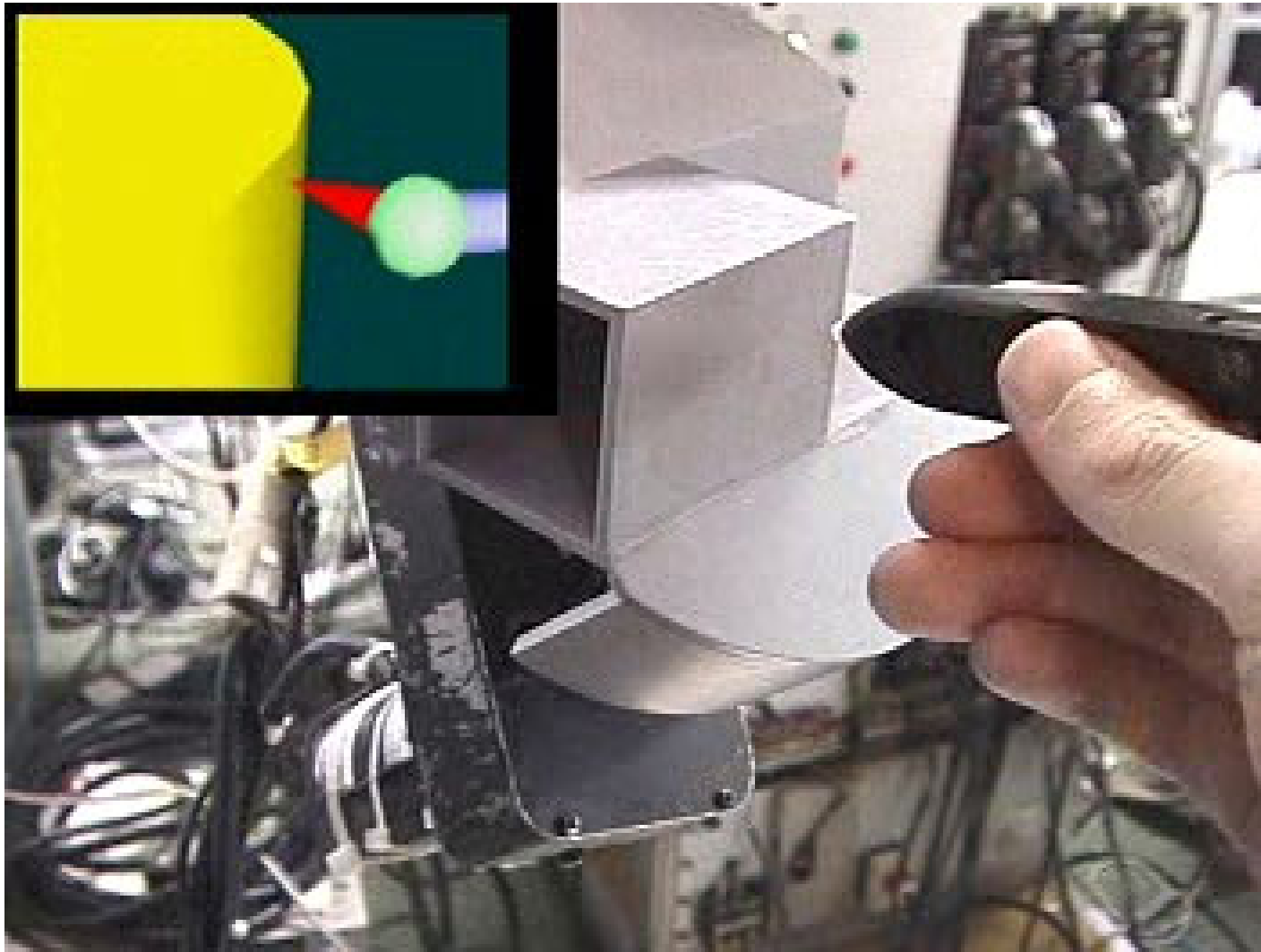
https://en.wikipedia.org/wiki/Head-mounted_display

視聴覚のディスプレイと同様、環境型と非環境型に分類可能？

Like visual and auditory displays, there are environmental type and non-environmental type.



環境型 ÷ 遭遇型 / Environment type ~ Encounter type
Active Environment Display (Tachi et al., 1994)

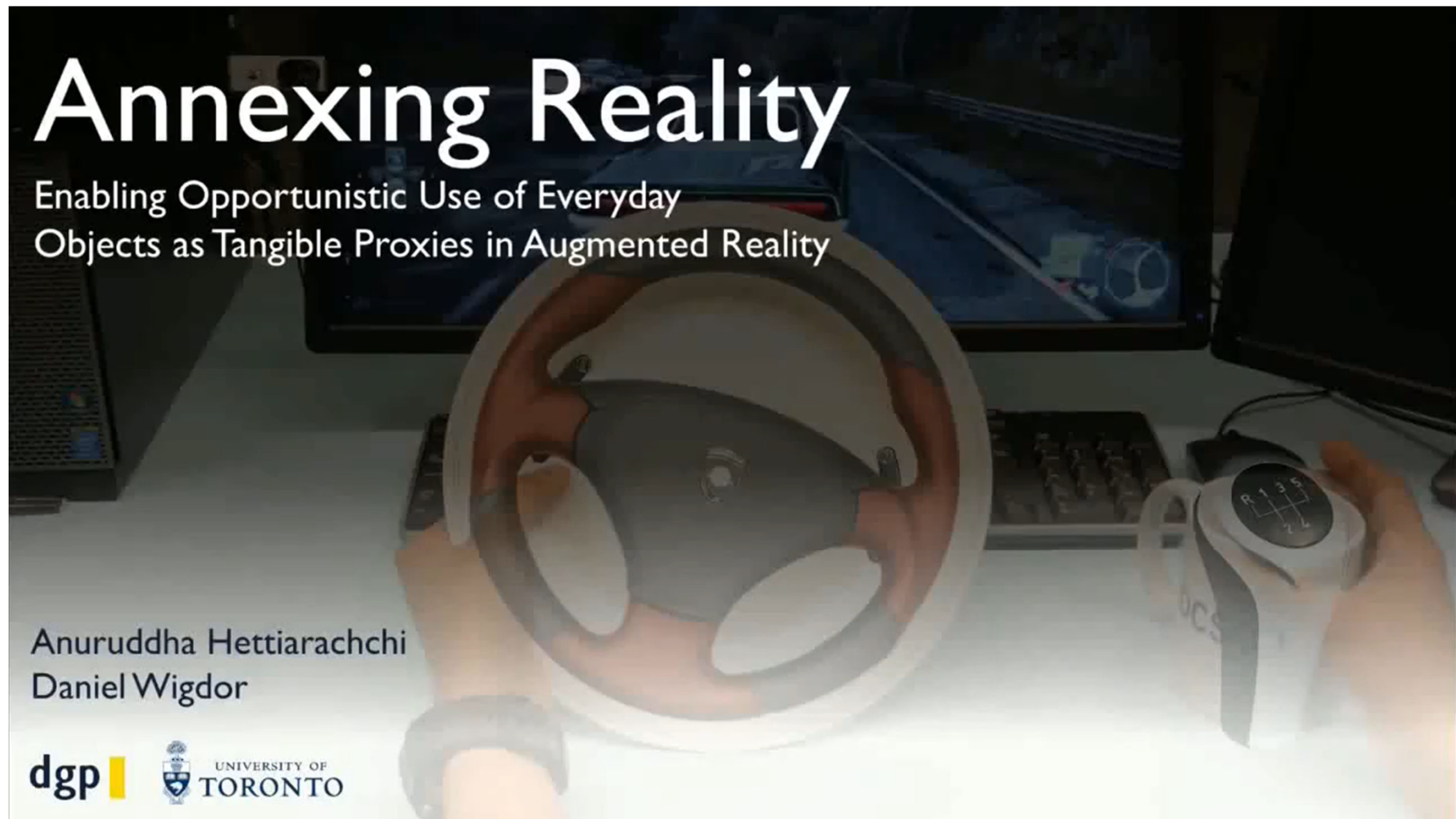


<http://tachilab.org/modules/projects/aed.html>

S. Tachi, T. Maeda, R. Hirata and H. Hoshino: A Construction Method of Virtual Haptic Space, Proceedings of the 4th International Conference on Artificial Reality and Tele-Existence (ICAT '94), pp.131-138, Tokyo, Japan (1994.7)



(CHI2016) Annexing Reality: Enabling Opportunistic Use of Everyday Objects as Tangible Proxies in Augmented Reality, Anuruddha Lakmal Hettiarachchi, Daniel Wigdor

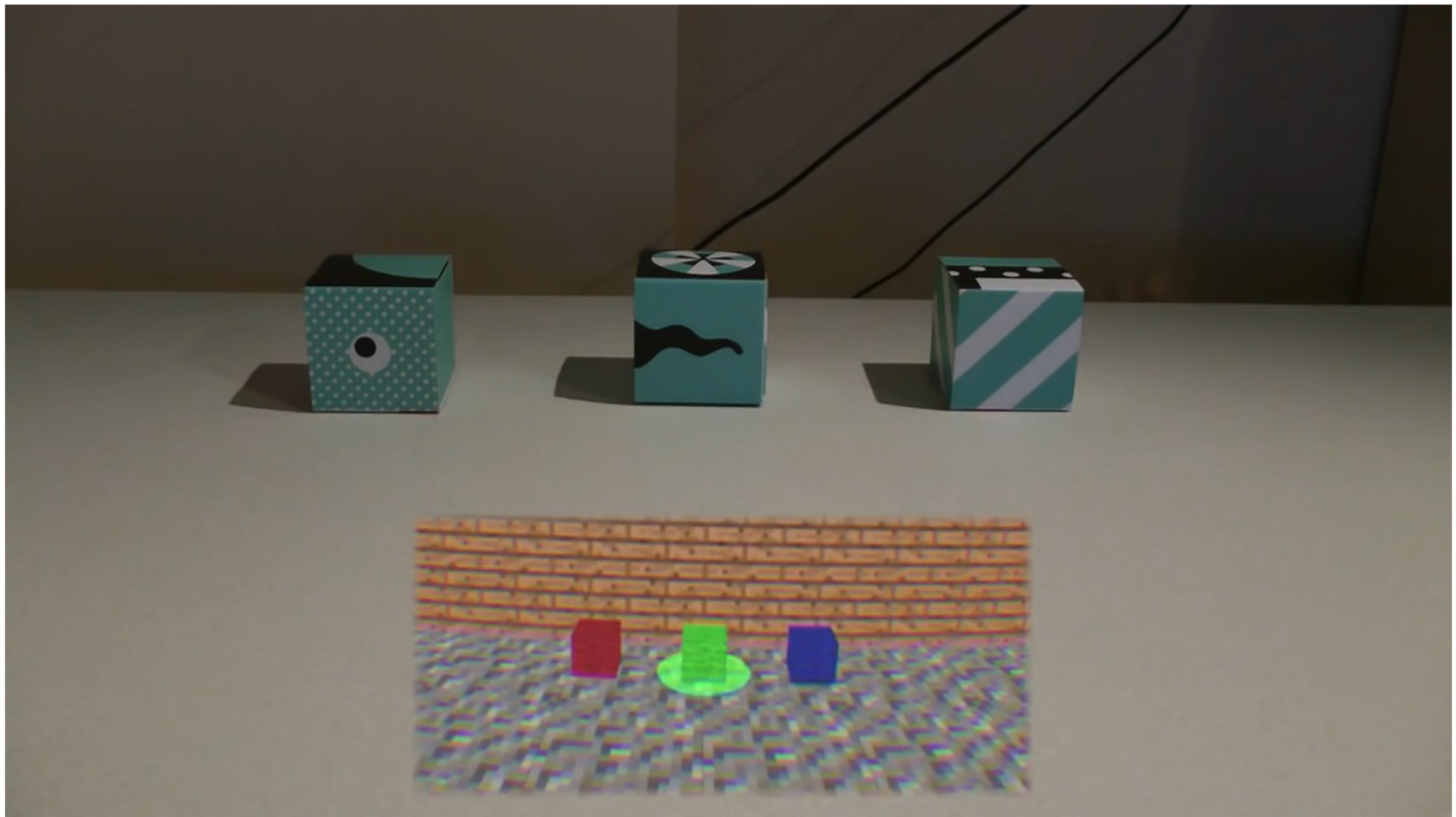


<https://www.youtube.com/watch?v=xL3WJQuyZil>

現実空間の物体をVR空間の物体として触らせることで触覚を提示



(CHI2016) Haptic Retargeting: Dynamic Repurposing of Passive Haptics for Enhanced Virtual Reality Experiences, Mahdi Azmandian, Mark Hancock, Hrvoje Benko, Eyal Ofek, Andrew D. Wilson



https://www.youtube.com/watch?v=v-5u0z4zA_8

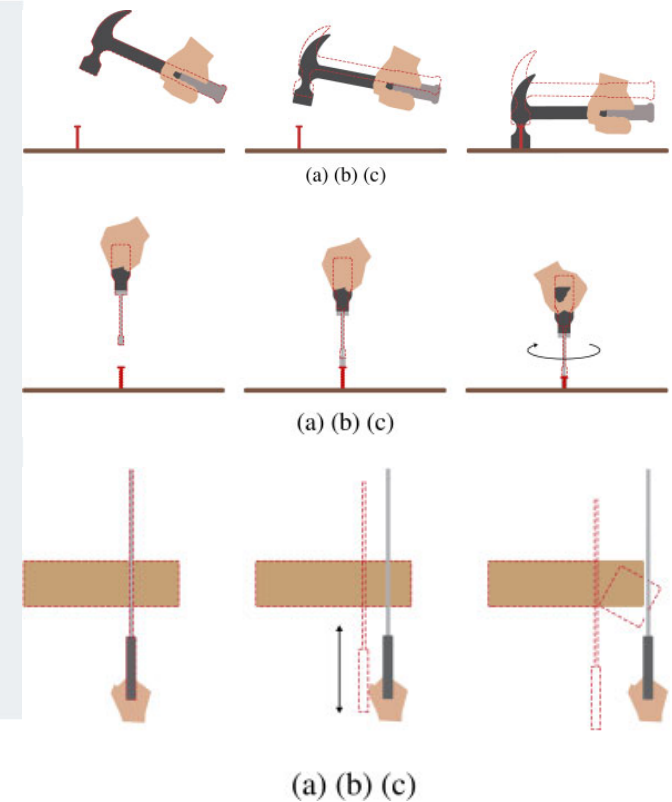
HMDによる視覚誘導によって、現実の物体を異なる場所で触っているように感じさせる。



(CHI2020) Knock on Wood: Combining Redirected Touching and Physical Props for Tool-Based Interaction in Virtual Reality, Patrick L. Strandholt; Oana A. Dogaru; Niels C. Nilsson; Rolf Nordahl; Stefania Serafin



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



- 実物を使ったHapticsで、視覚的なずらしのテクニックを使う。釘が沈んでいく。
- Use visual shifting techniques in haptics with real objects, the nails are sinking.



(CHI2019)HapTwist: Creating Interactive Haptic Proxies in Virtual Reality Using Low-cost Twistable Artefacts, Kening Zhu, Taizhou Chen, Feng Han, Yi-Shiun Wu

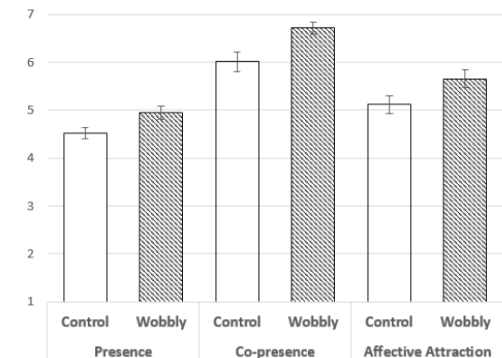
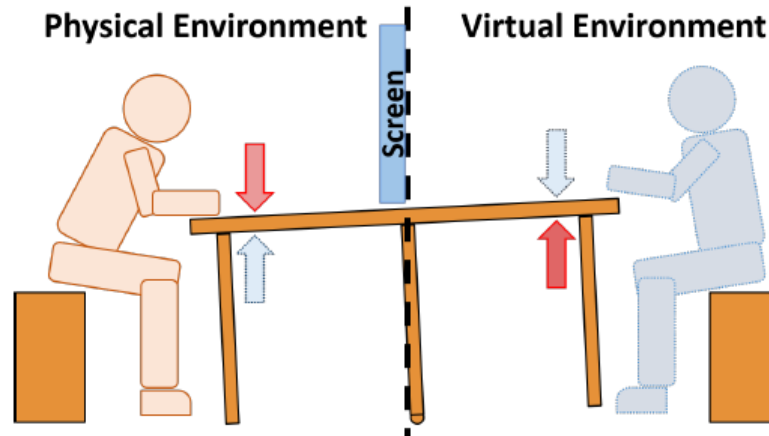


<https://www.youtube.com/watch?v=h9xpVDwVvMA>

- パツとVR空間用のTangibleデバイスを作る環境.



(IEEEVR2016) The Wobbly Table: Increased Social Presence via Subtle Incidental Movement of a Real-Virtual Table, Myungho Lee, Kangsoo Kimy, Salam Daherz, Andrew Raij

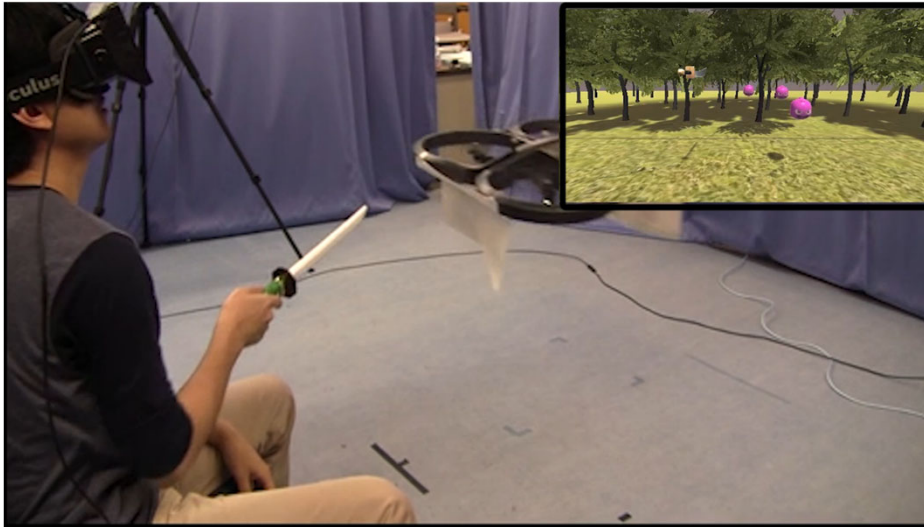


対面VR環境で机に微細なガタつきを設ける。VR側にもこのガタつきが反映される。VR内のVirtual Humanはこのガタつきに微かに応答する（机の下を覗きこむなど）。すると臨場感，空間共有感などが強調される。現実のものを使ったちょっとしたHapticsが現実感を底上げする好例。

In the face-to-face VR environment, the desk wobbles, and this is reflected in the VR. The sense of presence and the sense of shared space are emphasized.



Drone based haptics (encounter-type).



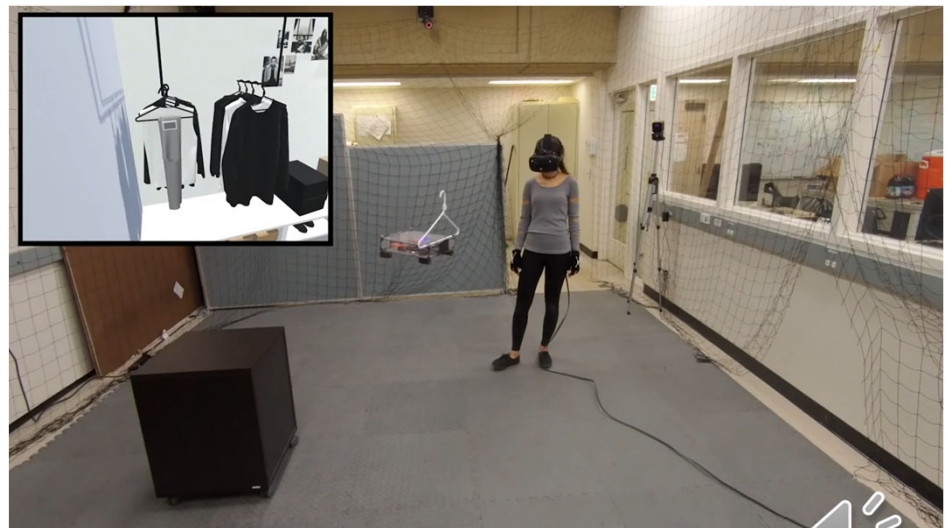
<https://www.youtube.com/watch?v=7MRCRywAQpA>
(SUI2016) A Non-grounded and Encountered-type Haptic Display Using a Drone, Yamaguchi et al.



<https://dl.acm.org/doi/abs/10.1145/3027063.3050426>
(CHI2017) Tactile Drones - Providing Immersive Tactile Feedback in Virtual Reality through Quadcopters, Knierim et al.



<https://dl.acm.org/doi/abs/10.1145/3282894.3282898>
(MUM2018) VRHapticDrones: Providing Haptics in Virtual Reality through Quadcopters, Hoppe et al.



<https://www.youtube.com/watch?v=JJV6fbCqm6g>
(CHI2019) Beyond The Force: Using Quadcopters to Appropriately
Objects and the Environment for Haptics in Virtual Reality, Abtahi et al.

(CHI2020) Haptic-go-round: A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences, Hsin-Yu Huang;Chih-Wei Ning;Po-Yao Wang;Jen-Hao Cheng;Lung-Pan Cheng



Haptic-go-round

A Surrounding Platform for Encounter-type Haptics in Virtual Reality Experiences

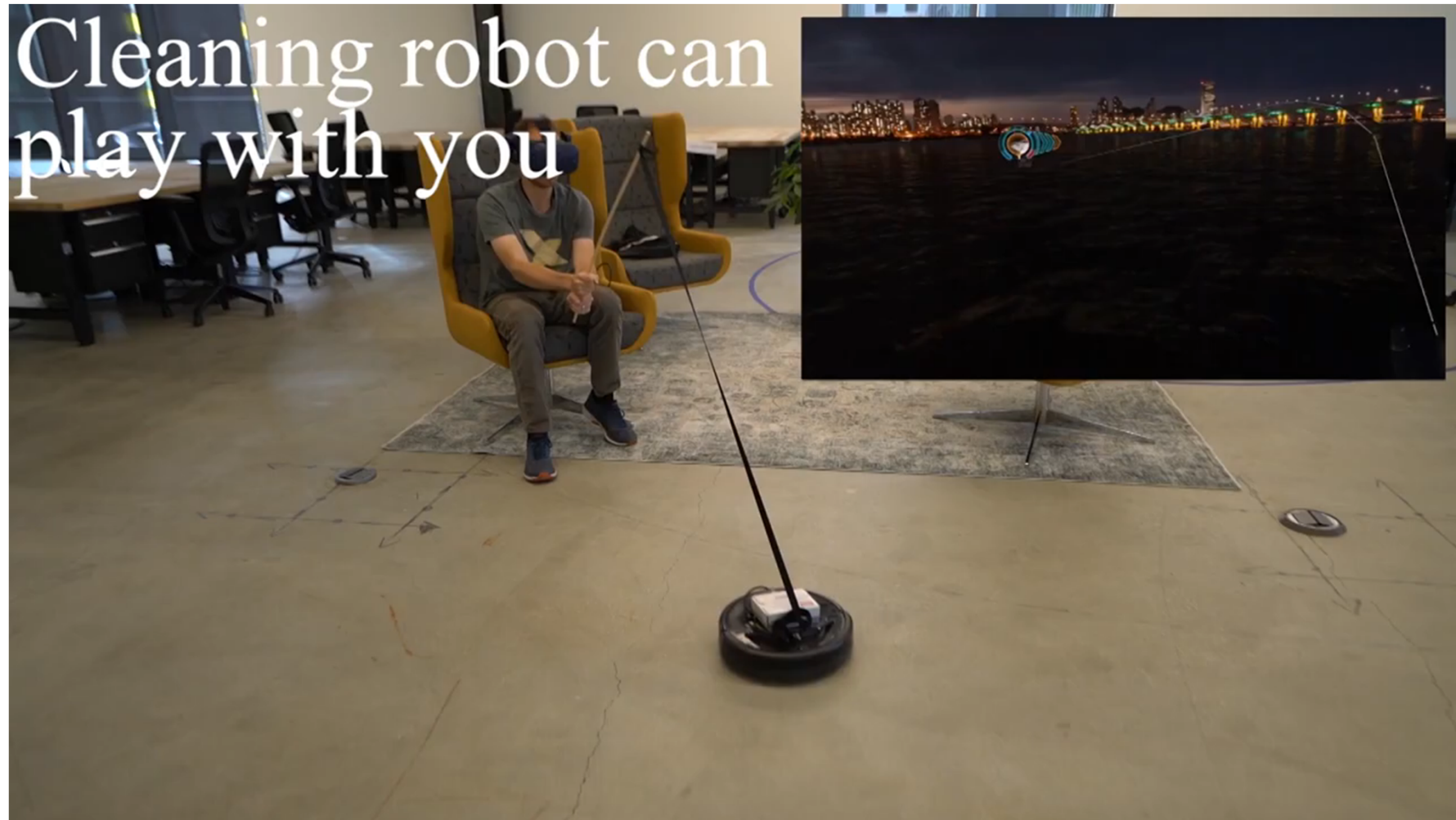
Hsin-Yu Huang*, Chih-Wei Ning*, Po-Yao Wang,
Jen-Hao Cheng, Lung-Pan Cheng

*Both authors contributed equally to this work

- <https://www.youtube.com/watch?v=AvB4rxwzbmE>
- Haptics用のデバイスが周りに多数配置されている。



(CHI2020) MoveVR: Enabling Multiform Force Feedback in Virtual Reality using Household Cleaning Robot, Yuntao Wang;Zichao (Tyson) Chen;Hanchuan Li;Zhengyi Cao;Huiyi Luo;Tengxiang Zhang;Ke Ou;John Raiti;Chun Yu;Shwetak Patel;Yuanchun Shi



- <https://www.youtube.com/watch?v=JeipEtvHxeY>
- 家用掃除ロボットをハプティックデバイスとして利用する



(再) 力覚ディスプレイの形態 Grounded and Wearable Haptic Display



CAVE automatic virtual environment (Wikipedia)

https://en.wikipedia.org/wiki/Cave_automatic_virtual_environment



Head Mounted Display (wikipedia)

https://en.wikipedia.org/wiki/Head-mounted_display

視聴覚のディスプレイと同様、環境型と非環境型に分類可能。

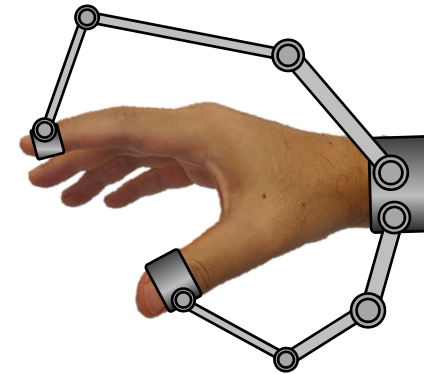
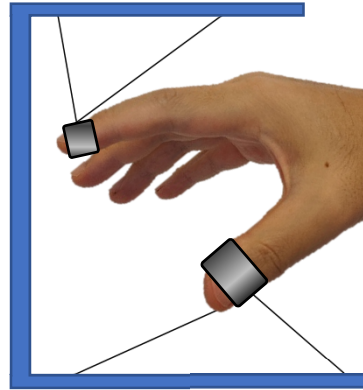
Like visual and auditory displays, there are environmental type and non-environmental type.



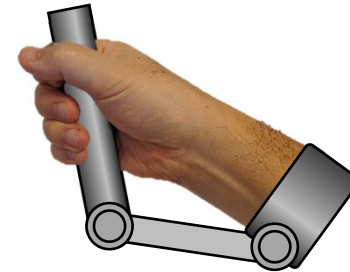
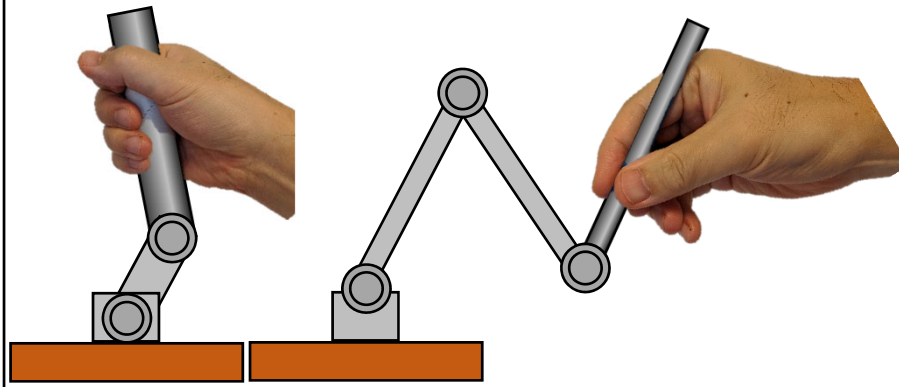
非環境型の力覚ディスプレイの形態

Configurations of non-environmental haptic displays

装着
Wear



把持
Hold



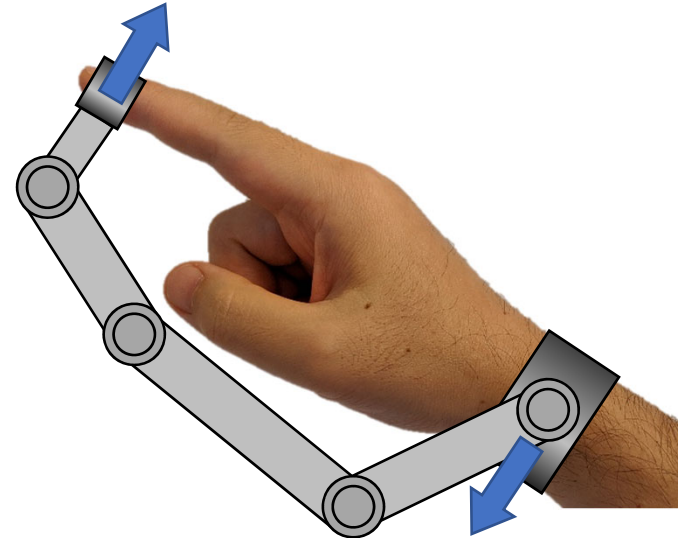
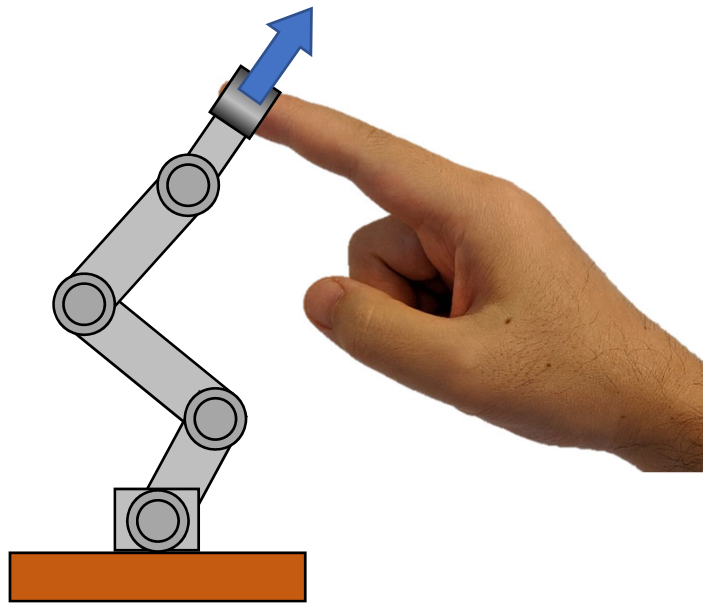
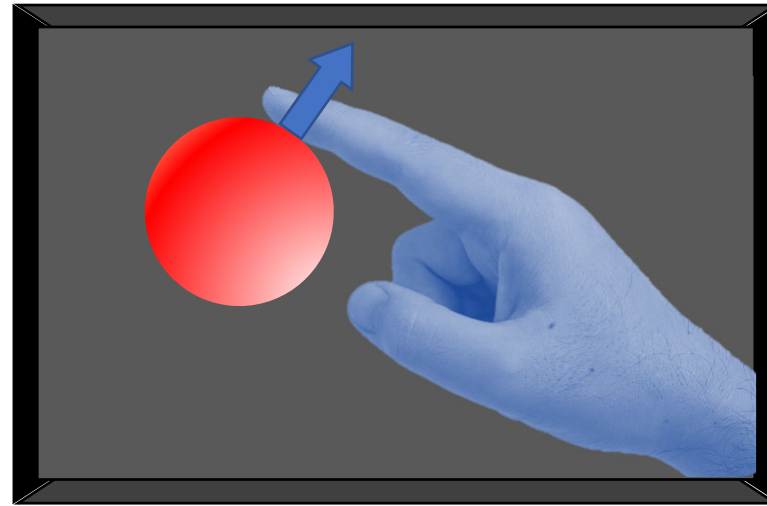
環境接地 Environment Grounded

身体接地 Body Grounded

- 装着型か、把持型か／Wear or Hold
 - 装着型：手の振る舞いの再現 Wear type presents “hand, finger” behavior.
 - 把持型：ツールの振る舞いの再現 Hold type presents “tool” behavior.
- 環境接地か、身体接地か／How it is grounded
 - 環境接地：外界に対して力を発揮 Force is applied from environment.
 - 身体接地：別の身体部位との間に力を発揮 Force is exerted in between body parts.



接地はなぜ重要か Why grounding matters?



環境に接地すると所望の力のみ提示可能。身体に接地すると作用反作用で他の力が発生する。
When grounded to the environment, the desired force can be presented. When grounded to the body, the action-reaction generates other forces.



CyberGrasp/CyberForce



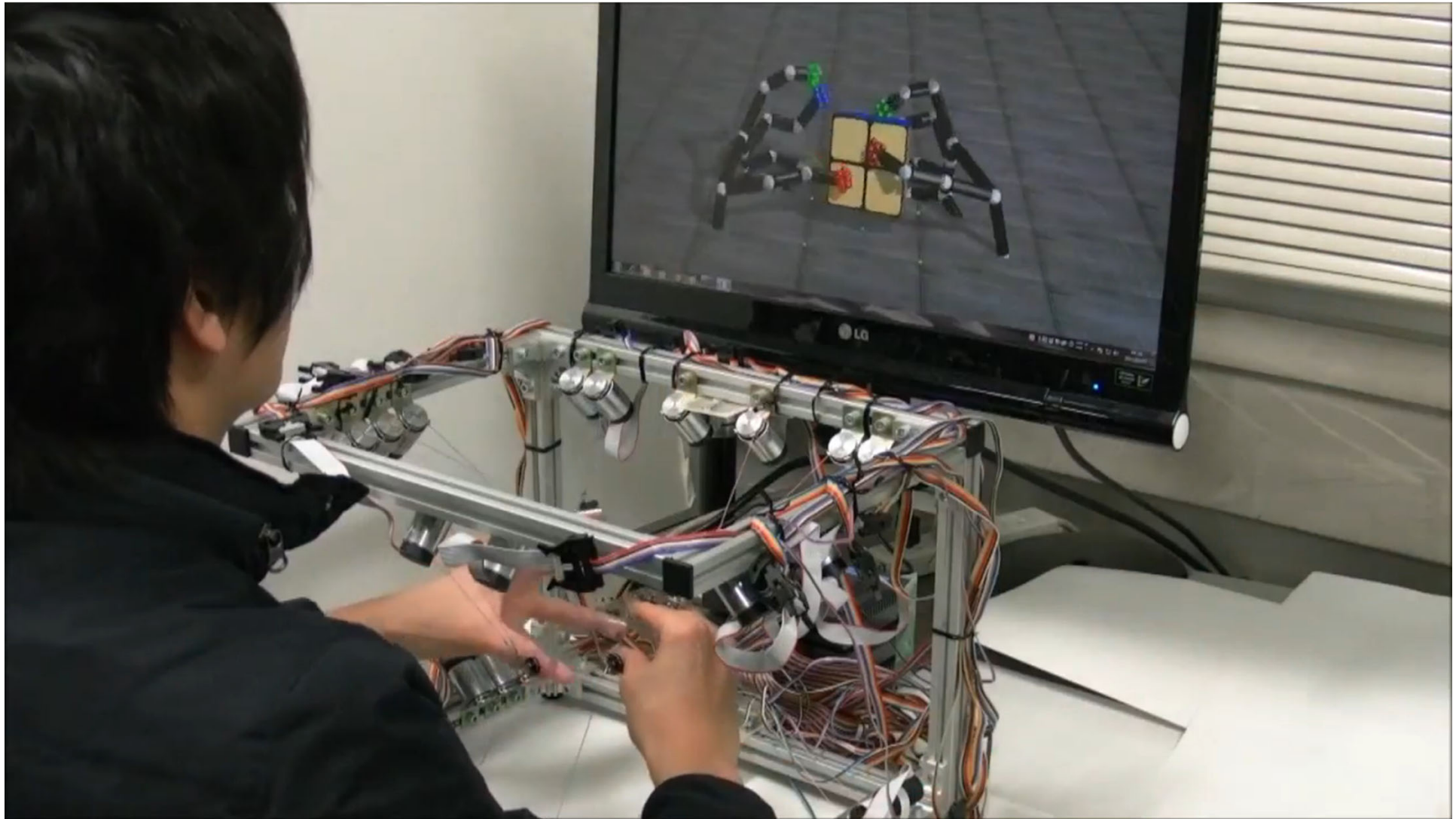
<http://www.youtube.com/watch?v=Td7QcAgCtWE&feature=fvw>

装着型。腕全体は環境接地、各指は身体接地。

Wear type. The whole arm is environmental grounded, whereas each finger is body grounded.



SPIDAR-8

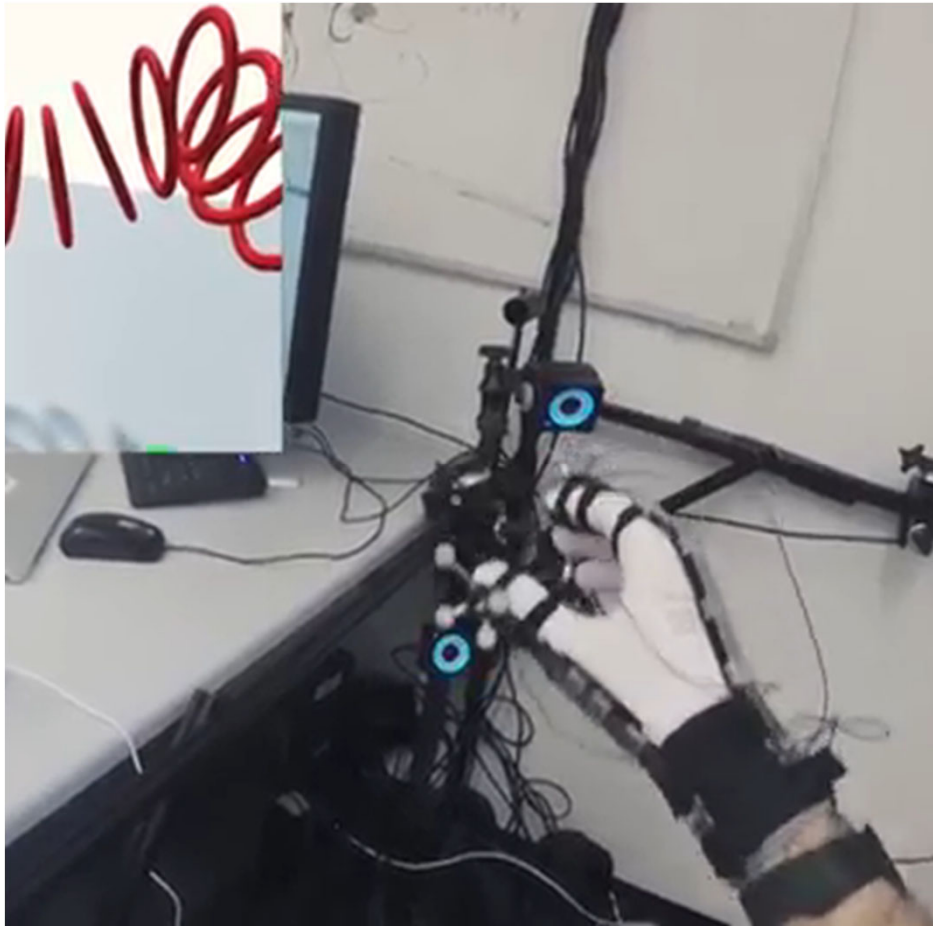


- Wear type. Environment grounded.
- (left) 4 finger, (right) 4 finger
- One finger is pulled by 3 wires

<https://www.youtube.com/watch?v=ZUb4-g8J93k>

Somsak WALAIRACHT, Yasuharu KOIKE, Makoto SATO. A New Haptic Display for Both-Hands-Operation: SPIDAR-8, ISPACS'99

手首、手の甲を接地部位とする
Grounded to wrist, back of the hand, or palm



<https://www.youtube.com/watch?v=fgRaw9k-Eu8>

(CHI2018) DextrES: Wearable Haptic Feedback for Grasping in VR via a Thin Form-Factor Electrostatic Brake, Hinchet et al.

静電気力によるブレーキで力覚提示グローブ。手首部分に接地

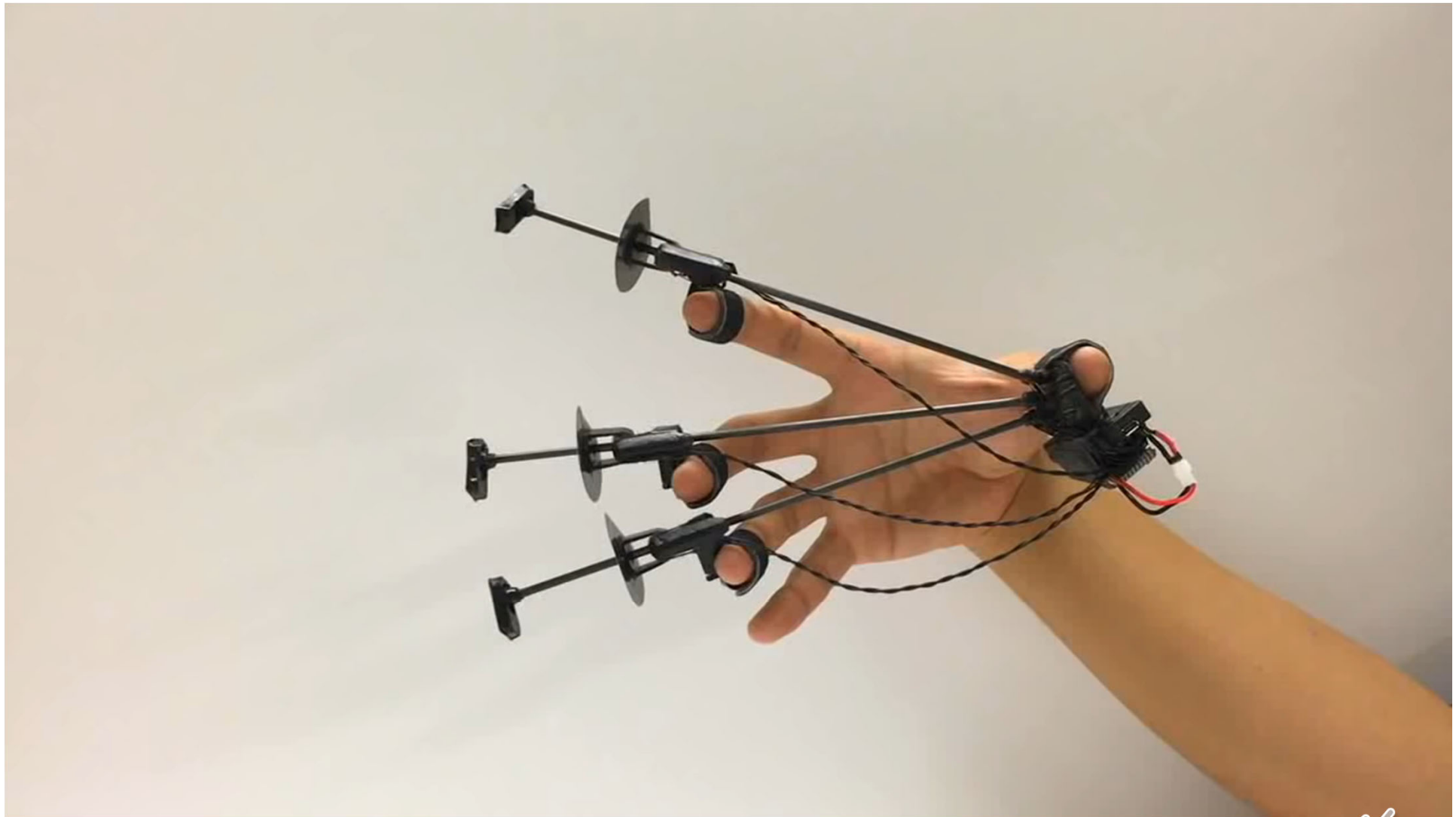


<https://www.youtube.com/watch?v=yt1QNW08mqg>

(CHI2018) CLAW: A Multifunctional Handheld Haptic Controller for Grasping, Touching, and Triggering in Virtual Reality, Choi et al.

二本指の間の力覚で幅広いウェアラブル力覚を提供。手掌部にハンドルとして接地。

指同士で接地する Mutual grounding to fingers

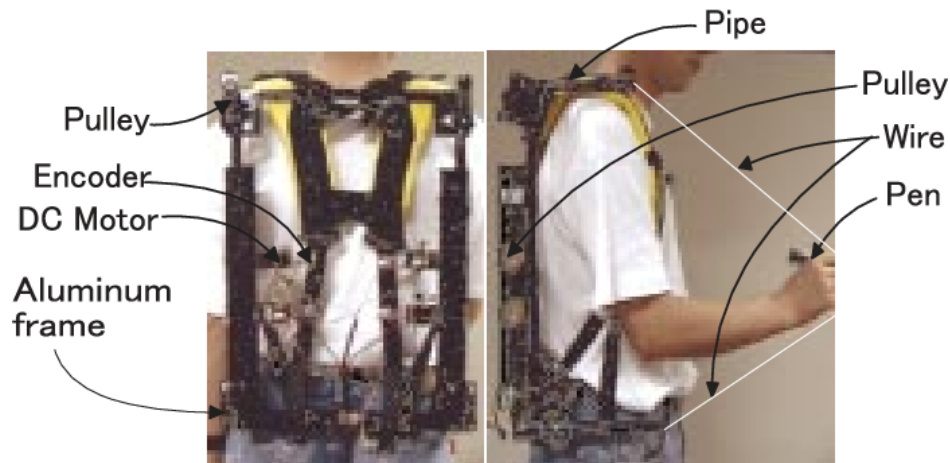


<https://www.youtube.com/watch?v=kgE7JwIUuX4>

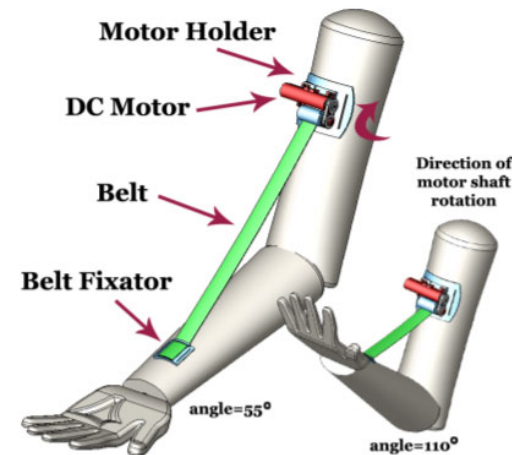
Choi, I., Hawkes, E. W., Christensen, D. L., Ploch, C. J., and Follmer, S. Wolverine: A wearable haptic interface for grasping in virtual reality. In Intelligent Robots and Systems (IROS), 2016



Grounded to the other body parts (String or belt based)



(IEEEVR2001) HapticGEAR: The development of a wearable force display system for immersive projection displays. Hirose et al.



(AH2010) ExoInterfaces: novel exoskeleton haptic interfaces for virtual reality, augmented sport and rehabilitation, Tsetserukou et al.

HapticSphere: Physical Support to Enable Precision Touch Interaction in Mobile Mixed-Reality

Chiu-Hsuan Wang, Chen-Yuan Hsieh,
Neng-Hao Yu¹, Andrea Bianchi², Liwei Chan

Industrial Design, NTUST, Taiwan¹
Industrial Design, KAIST, Korea²
Computer Science, NCTU, Taiwan



<https://www.youtube.com/watch?v=VAvPfq4rrNc>

(IEEEVR2019) HapticSphere: Physical Support To Enable Precision Touch Interaction in Mobile Mixed-Reality, Wang et al.

WIREALITY

Enabling Complex Tangible Geometries in
Virtual Reality with Worn Multi-String Haptics

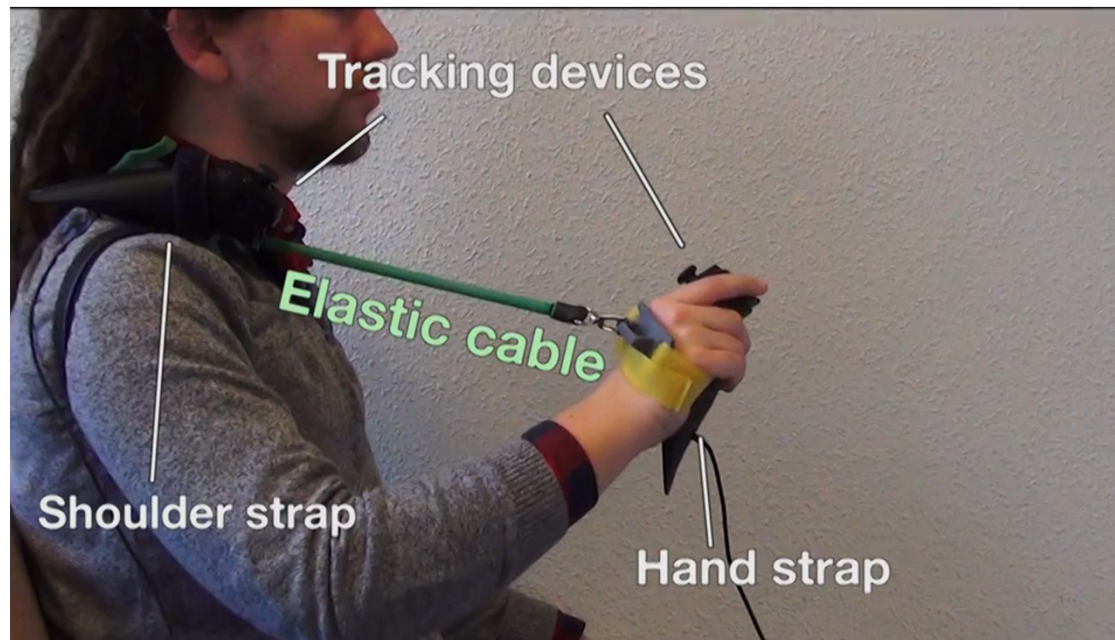
Cathy Fang Yang Zhang Matthew Dworman Chris Harrison



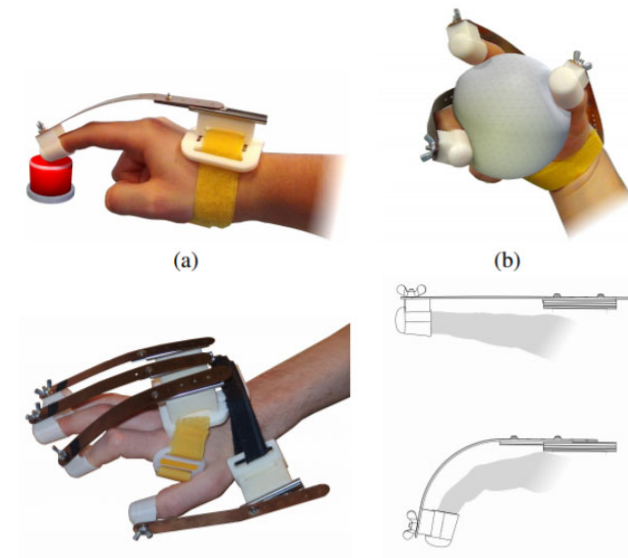
<https://www.youtube.com/watch?v=-0mZJaTVQKQ>

(CHI2020) Wireality: Enabling Complex Tangible Geometries in Virtual Reality with Worn Multi-String Haptics, Fang et al.

パッシブ弾性要素 + 身体接地 Passive elastic elements + body grounded



https://www.youtube.com/watch?v=ub7pz5_TXX8
(IEEEVR2015) Elastic-Arm: Human-Scale Passive Haptic Feedback for Augmenting Interaction and Perception in VR, Merwan Achibet et al.



(3DUI2017) FlexiFingers: Multi-finger Interaction in VR Combining Passive Haptics and Pseudo-Haptics
Merwan Achibet et al.

- 手・指に対してパッシブな弾性力を提示することで、VR空間での力覚の納得感を高める。
- A passive elastic plate enhances realism of force perception in VR space.





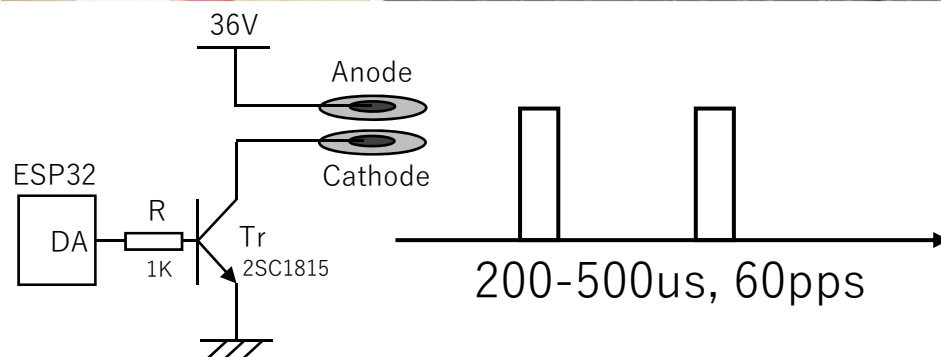
稲見, 川上: 仮想体感装置, 特開平7-20978

IVRC1993

<https://www.youtube.com/watch?v=9QVd45N1j00>

- 拮抗筋の電気刺激で抵抗力を提示。軽量。ただし刺激場所での触覚も生じる。
- 接地部位は身体。機能的電気刺激の分野では古くから利用
- Antagonist Muscle is electricall stimulated. Light weight, but strong tactile sensation also. Grounded to joint. Used in the field of Functional Electrical Stimulation (FES).



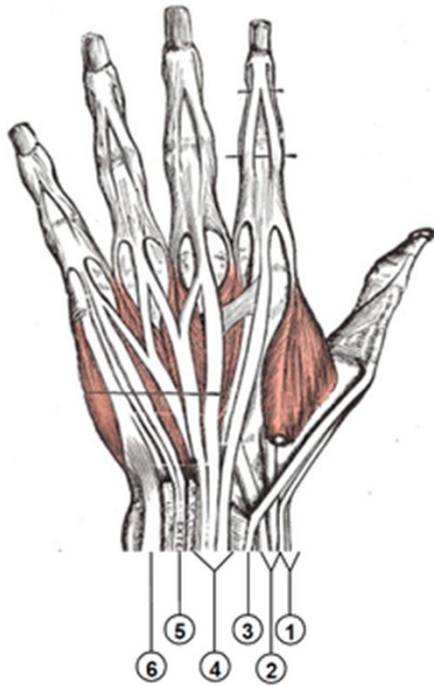


(この回路は安全ではないので非推奨です。
必要なら問い合わせてください。)

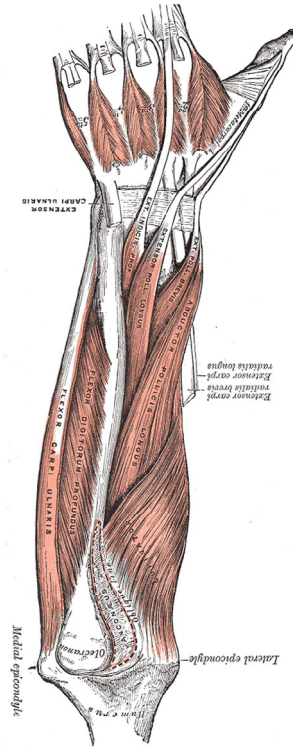
This circuit is not safe and not recommended.



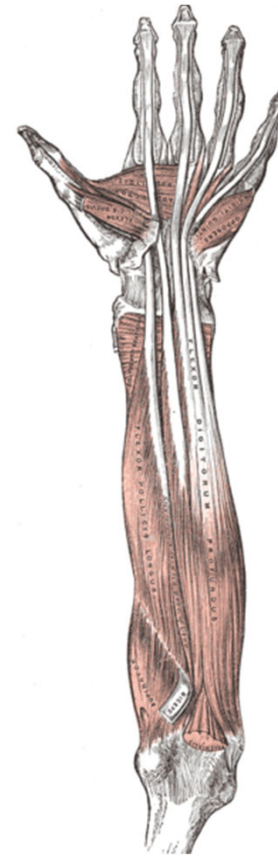
(参考) 指を動かす筋肉／Muscles for fingers



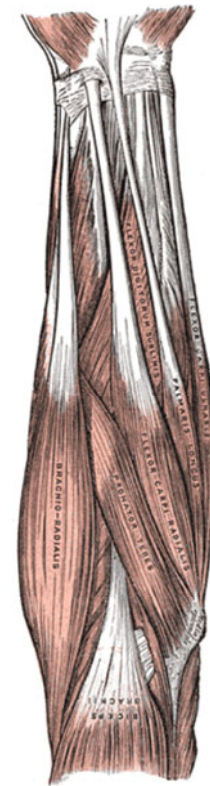
https://en.wikipedia.org/wiki/Muscles_of_the_hand



Deep muscles of the posterior forearm (背側)



Deep muscles of the anterior forearm (腹側)



Superficial muscles of the forearm

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

- 非常に多くの筋が担当。多くが前腕に存在。
- 手外筋：前腕中にあり大まかな動きを担当 Extrinsic hand muscles: Large & coarse finger motion
- 手内筋：掌中にあり細かな動きを担当 Intrinsic hand muscles: Small & fine finger motion.

EMS for HCI



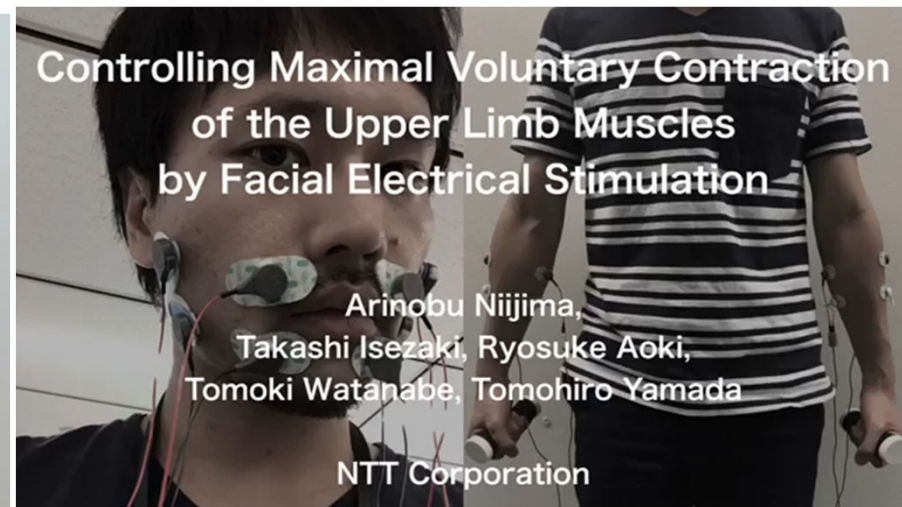
<https://www.youtube.com/watch?v=9XBoZyfB8hY>
(CHI2011) PossessedHand: Techniques for controlling human hands using electrical muscles stimuli, Tamaki et al.



<https://www.youtube.com/watch?v=KMxIfj7zhlw>
(CHI2015) Proprioceptive Interaction, Lopes et al.



<https://www.youtube.com/watch?v=qHRn05Kmwew>
(CHI2018) Adding Force Feedback to Mixed Reality Experiences and Games using Electrical Muscle Stimulation, Lopes et al.

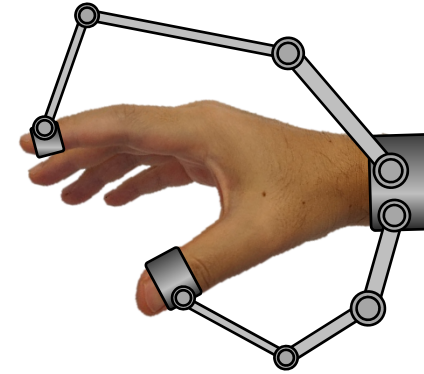
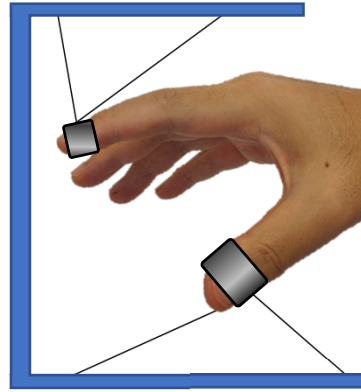


<https://www.youtube.com/watch?v=R1DDTgT5X04>
(CHI2018) Controlling Maximal Voluntary Contraction of the Upper Limb Muscles by Facial Electrical Stimulation, Nijima et al.

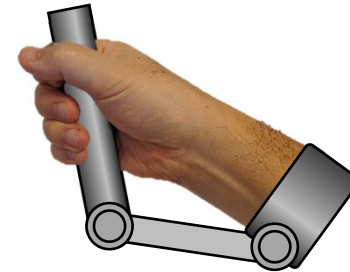
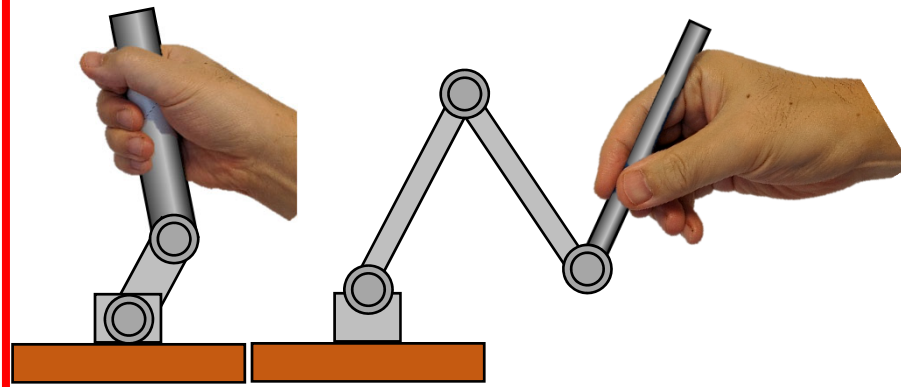
非環境型の力覚ディスプレイの形態

Configurations of non-environmental haptic displays

装着
Wear



把持
Hold



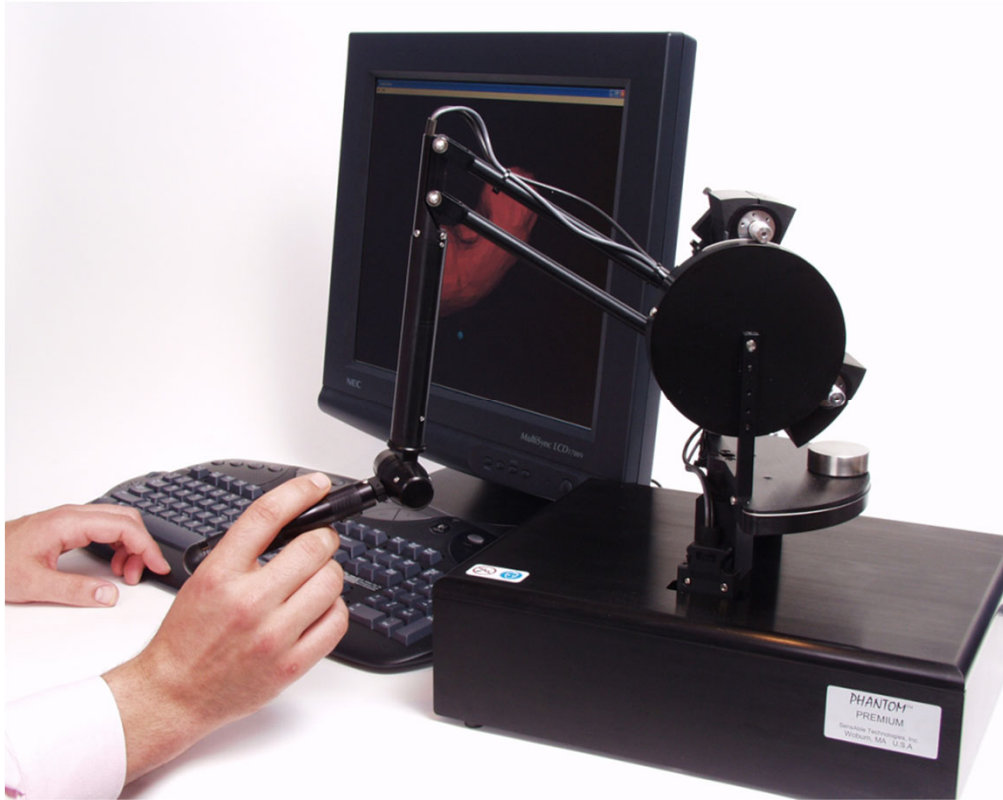
環境接地 Environment Grounded

身体接地 Body Grounded

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 - 装着型：手の振る舞いの再現 Wear type presents “hand, finger” behavior.
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 - 身体接地：別の身体部位との間に力を発揮 Force is exerted in between body parts.



PHANToM (SensAble)



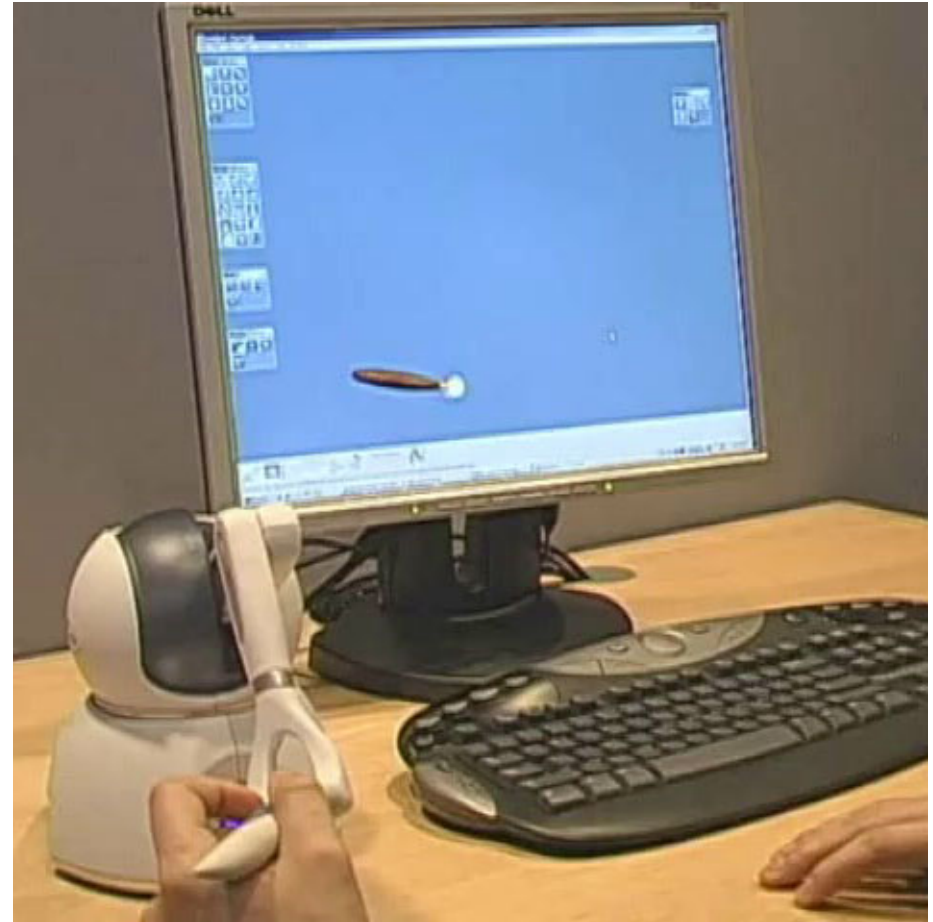
https://en.wikipedia.org/wiki/Thomas_Massie

- 最も有名なハプティックデバイス。6自由度をサポート
- 指サックタイプも開発されたが多くはペングリップタイプ
- Most Famous Haptic Interface with 6DOF
- Fingerstall type was developed, but most are pen-grip type

Massie T. H., Salisbury J. K., "The PHANTOM Haptic Interface: A Device for Probing Virtual Objects," Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 1994.



PHANToM, PHANToM Omni (SensAble)



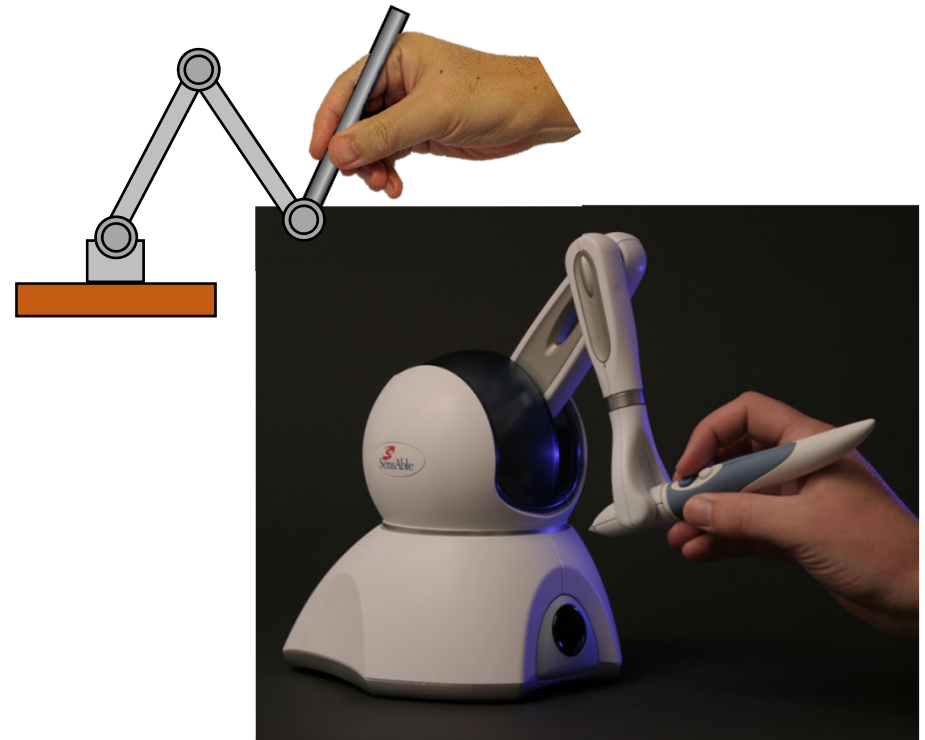
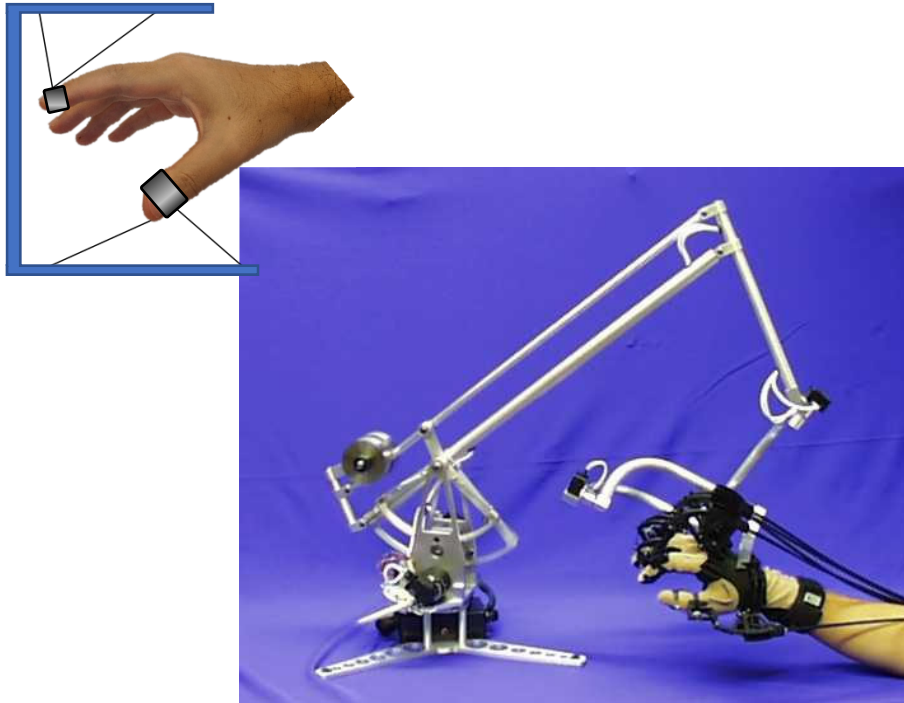
<http://www.youtube.com/watch?v=u9jdhUvOmMw&feature=related>

<http://www.youtube.com/watch?v=REA97hRX0WQ>



装着型と把持型の小さくて大きな違い

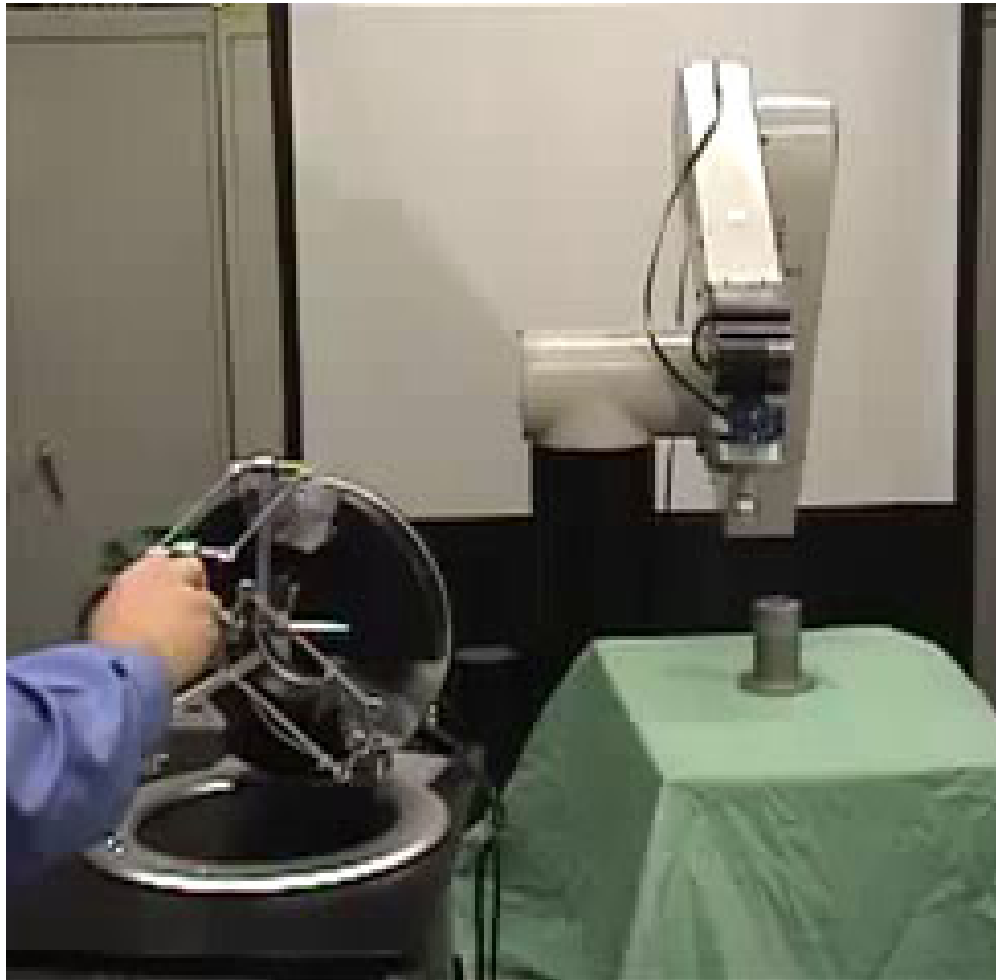
Small but significant difference between wear type and grip type



- 装着型／Wear type :
 - 指ごとにサポートする必要 Each finger must be supported
 - VR世界を手で直接触るには必須/ Direct touch in VR is possible
- 把持型／Grip type :
 - 「ペン」等の類推の利く **道具** に対して力提示（道具再現型）．指への力提示は間接的 Force is presented to “Tool”, and presentation to hand is indirect.
 - 多くの応用で現実的解/Practical solution for many applications

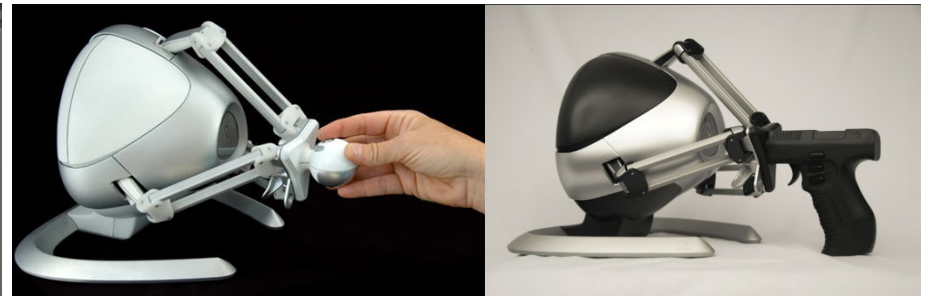


パラレルリンクタイプ Parallel link type



<http://www.youtube.com/watch?v=Oh7saN3hl68>

Omega (force dimension)



<http://www.youtube.com/watch?v=mW70eIK9Yrs>

Falcon (Novint)



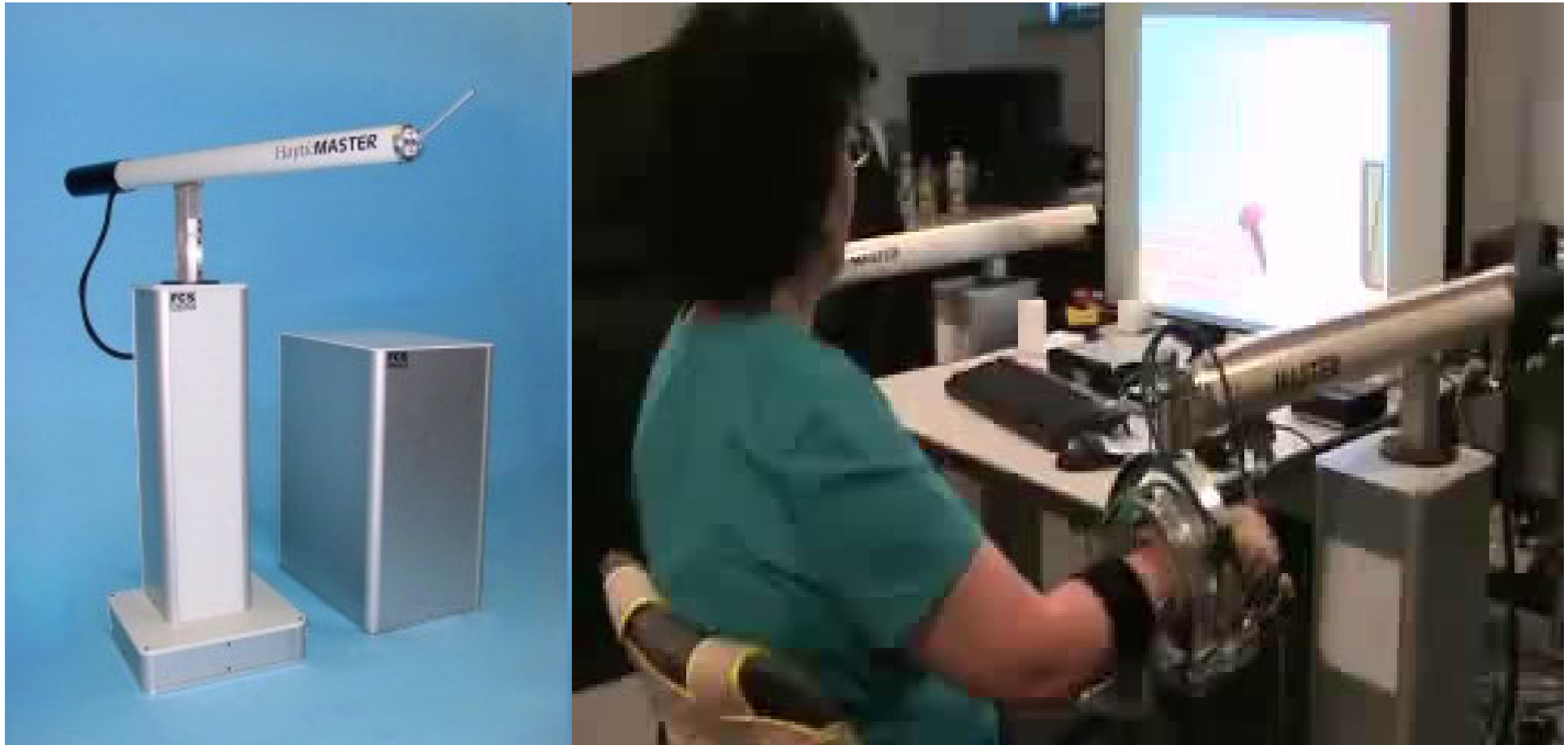
把持型SPIDAR



<https://www.youtube.com/watch?v=ZUb4-g8J93k>



HapticMaster (MOOG FCS)



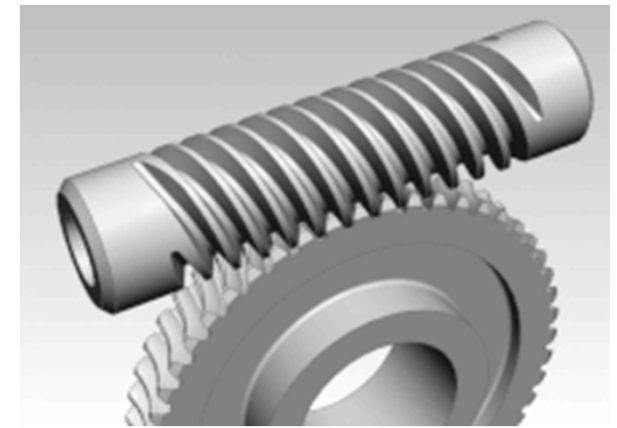
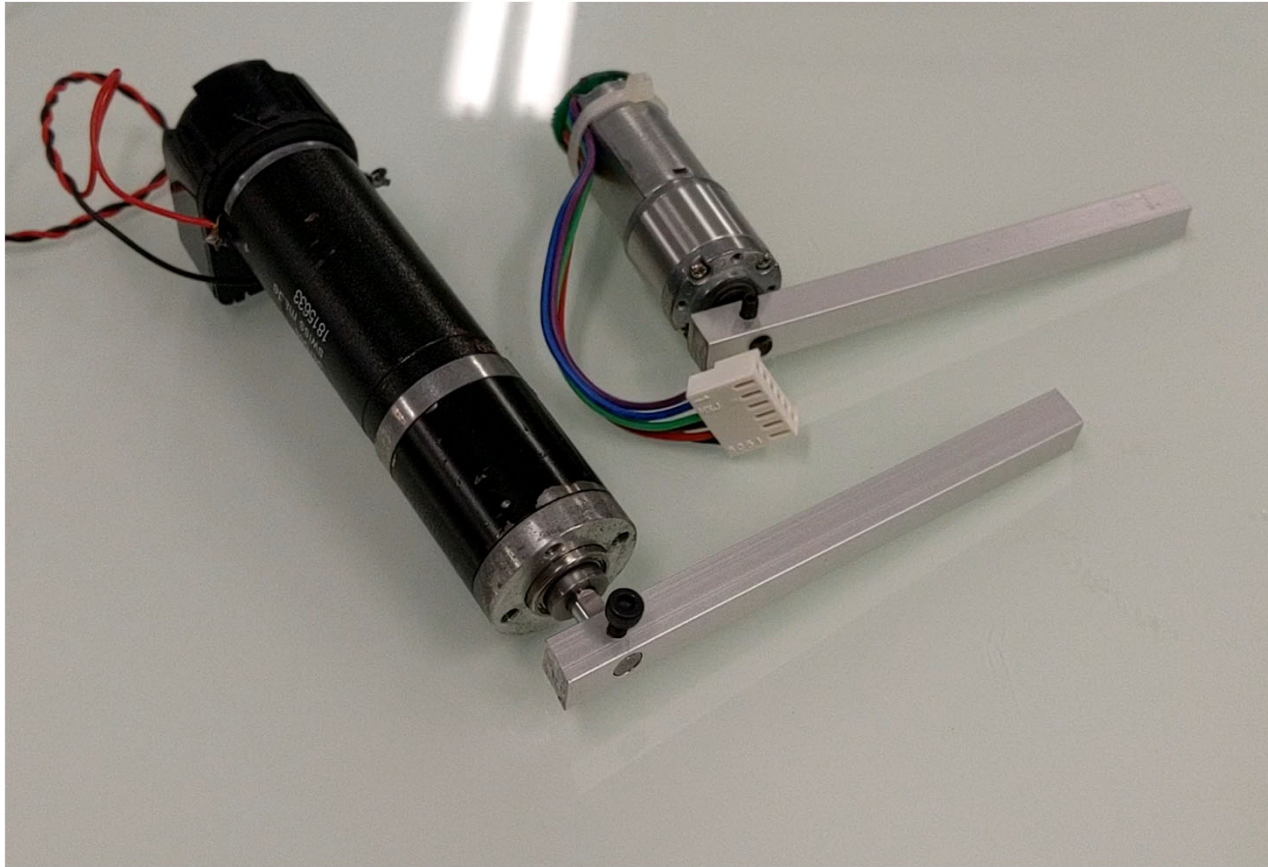
<http://www.youtube.com/watch?v=tgGEcE1VS6I>

- 産業用ロボット的なバックドライバビリティのない剛構造＋力センサ
- Rigid structure without back-drivability, like industrial robot. With force sensor



Van der Linde R.Q., Lammertse P., Frederiksen E., Ruiter B(2002) The HapticMaster, a new high-performance haptic interface

軽く作るかしっかりつくるか？ Make it **light**, or make it **rigid**?



- バックドライバビリティ / back-drivability = 出力軸を直接動かせるかどうか
Whether output shaft can be moved directly
- 通常の歯車 / Ordinary gear : バックドライバビリティ有. ただしギア比が大きいほど減少 (1:50程度) Back-drivable, but reduced if gear ratio is higher.
- ウォームギア / Worm gear : バックドライバビリティ無 Not back-drivable.

出力軸を直接触るため、バックドライバブルかどうかで制御が変わる。

As Human handles output shaft directly, control method is closely related to back-drivability

軽く作るかしっかりつくるか? Make it **light**, or make it **rigid**?



- 「軽い」装置：
 - ワイヤ駆動等. 低ギア比.
 - バックドライバビリティ有)

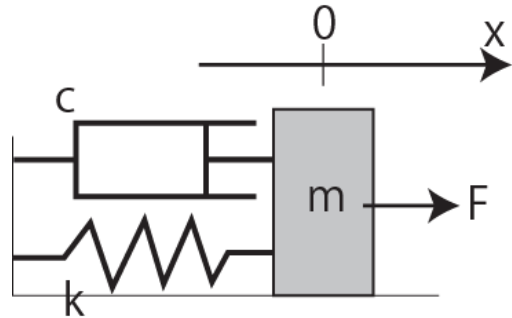


- 「固い」装置：
 - 産業用ロボットなど.
 - 高ギア比. ユーザは動かせない.
 - ハンドル先端の力センサに応答.



「軽い」装置の制御方法

How to control “light” haptic interface?



$$m\ddot{x} = f - c\dot{x} - kx$$



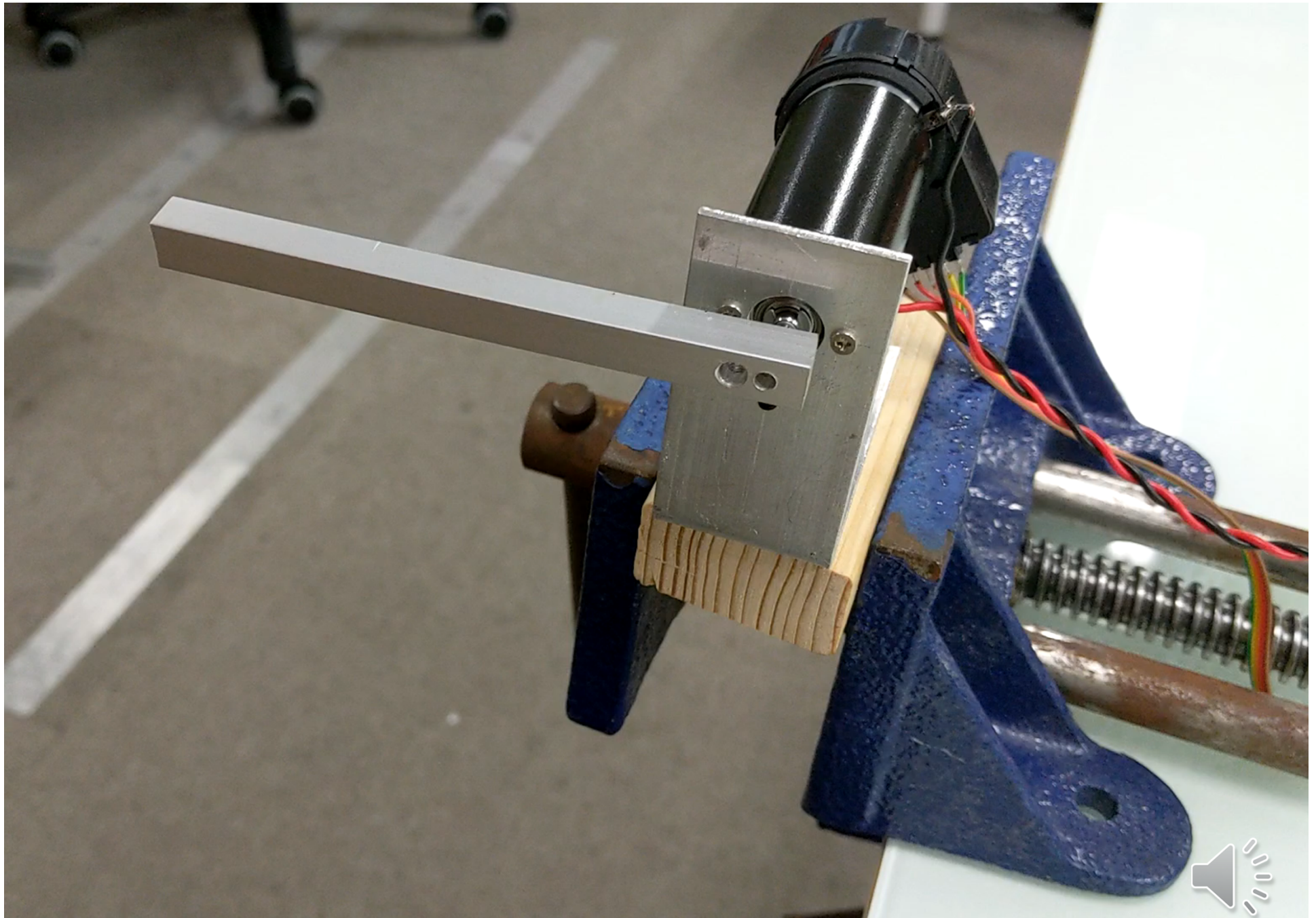
インピーダンス型のシミュレート手法

- 手先の位置を計測.
- 位置や速度に応じた力を出力.
- 手先が壁にめり込むところから開始するから，力覚ディスプレイは操作者の力だけで動かせる必要＝バックドライバビリティ有

Impedance based method

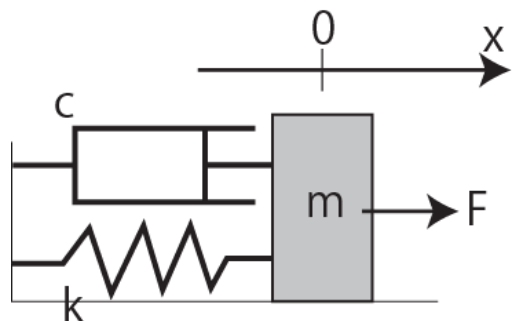
- Measure grip position.
- Output force according to the position and velocity.
- As in the first step, position must be changed by the user, the haptic interface must be back-drivable.





「堅い」装置の制御方法

How to control “rigid” haptic interface?



$$m\ddot{x} = f - c\dot{x} - kx$$



アドミッタンス型のシミュレート手法

- 操縦者の力を計測
- その力に基づき、手先がどう動くか計算。その軌道を出力.
- 手先に力センサ必須だが、バックドライバビリティは不要，産業用ロボット等の固い装置を利用可能

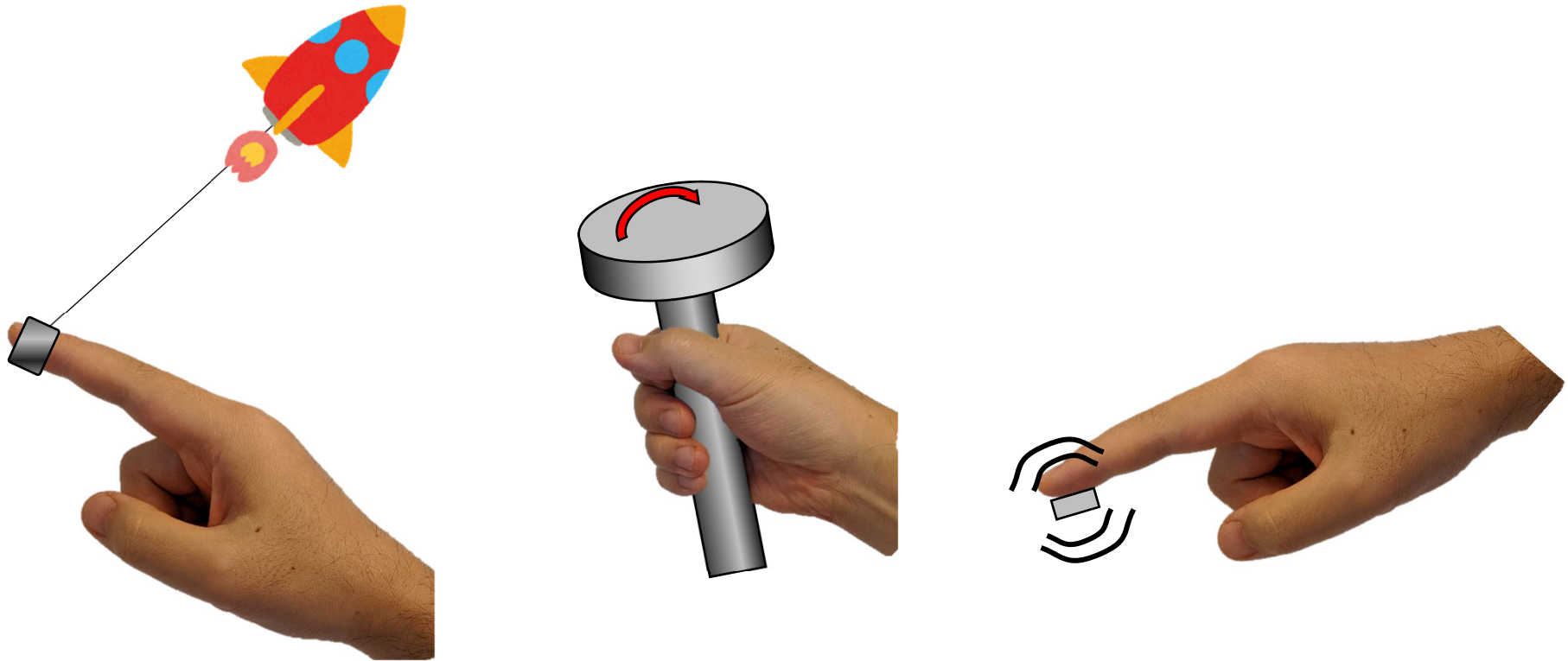
Admittance based method

- Measure operator's force
- Calculate world's behavior according to the force, and change position of the grip.
- Force sensor is necessary, but back-drivability is not. Rigid robot can be used such as industrial robot.



非接地の力覚提示装置は可能か

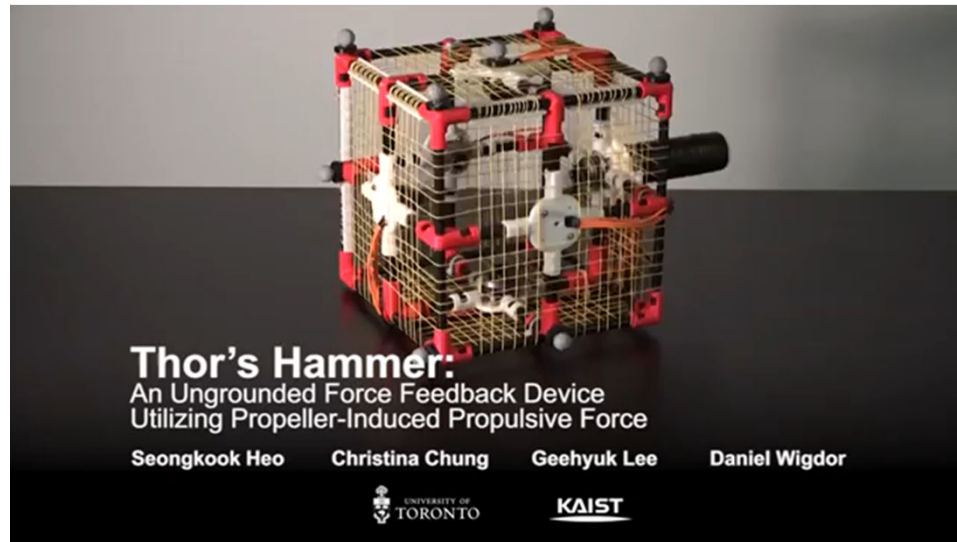
Is non-grounded haptic display possible?



- なんとか力を出す。 Somehow exert physical force.
- 何らかのトルクを出す。 Exert torque.
- 皮膚感覚や錯覚を利用。 Substitute with cutaneous cue or use illusion.



風を利用した力覚提示 Haptic display using wind



<https://www.youtube.com/watch?v=Y3hs2RUM4ZQ>

(CHI2018) Thor's Hammer: An Ungrounded Force Feedback Device Utilizing Propeller-Induced Propulsive Force, Seongkook Heo, Christina Chung, Geehyuk Lee, Daniel Wigdor

プロペラによる力覚提示



https://www.youtube.com/watch?v=Qh3SDRaOR_4

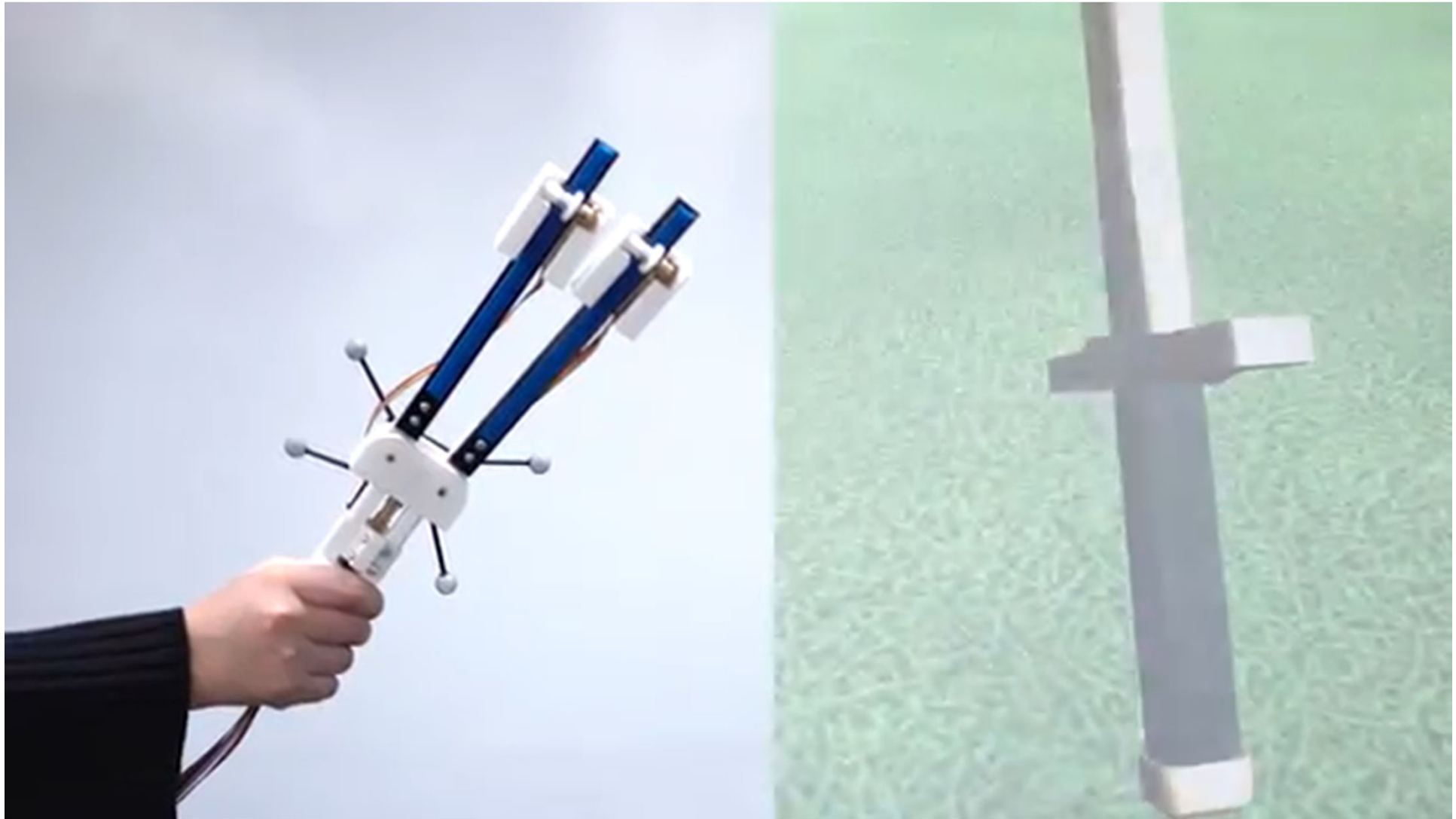
(Siggraph2018) LevioPole: Mid-Air Haptic Interactions Using Multirotor, Tomoya Sasaki Richard Sahala Hartanto Kao-Hua Liu Keitarou Tsuchiya Atsushi Hiyama Masahiko Inami

ドローンによる力覚提示



(SIGGRAPH2018 Emerging Technologies) Transcalibur: Weight Moving VR Controller for Dynamic Rendering of 2D Shape Using Haptic Shape Illusion

Jotaro Shigeyama Takeru Hashimoto Shigeo Yoshida Taiju Aoki Takuji Narumi Tomohiro Tanikawa Michitaka Hirose



<https://www.youtube.com/watch?v=TJA7psWM8sY>

- 重心位置を変化させる + ビジュアルの組み合わせで様々な武器を再現。
- 力を出すのではなく特性を変えることによるパッシブな力覚提示の例。

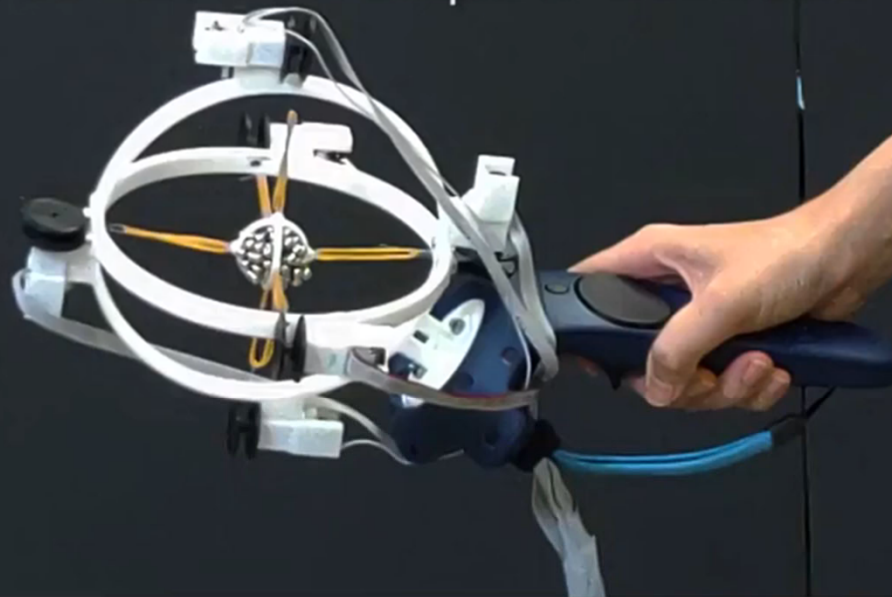


(CHI2020) ElastOscillation: 3D Multilevel Force Feedback for Damped Oscillation on VR Controllers, Hsin-Ruey Tsai;Ching-Wen Hung;Tzu-Chun Wu;Bing-Yu Chen

ElastOscillation:

3D Multilevel Force Feedback for Damped Oscillation on VR Controllers

Hsin-Ruey Tsai, Ching-Wen Hung,
Tzu-Chun Wu, Bing-Yu Chen
National Chengchi University
National Taiwan University



國立政治大學
National Chengchi University



國立臺灣大學
National Taiwan University

- <https://www.youtube.com/watch?v=VoMLVFoWFwo>
- ゴム紐 + おもりで、張力を変えることで特性を変える



(CHI2019) Drag: on - A Virtual Reality Controller Providing Haptic Feedback Based on Drag and Weight Shift, André Zenner, Antonio Krüger

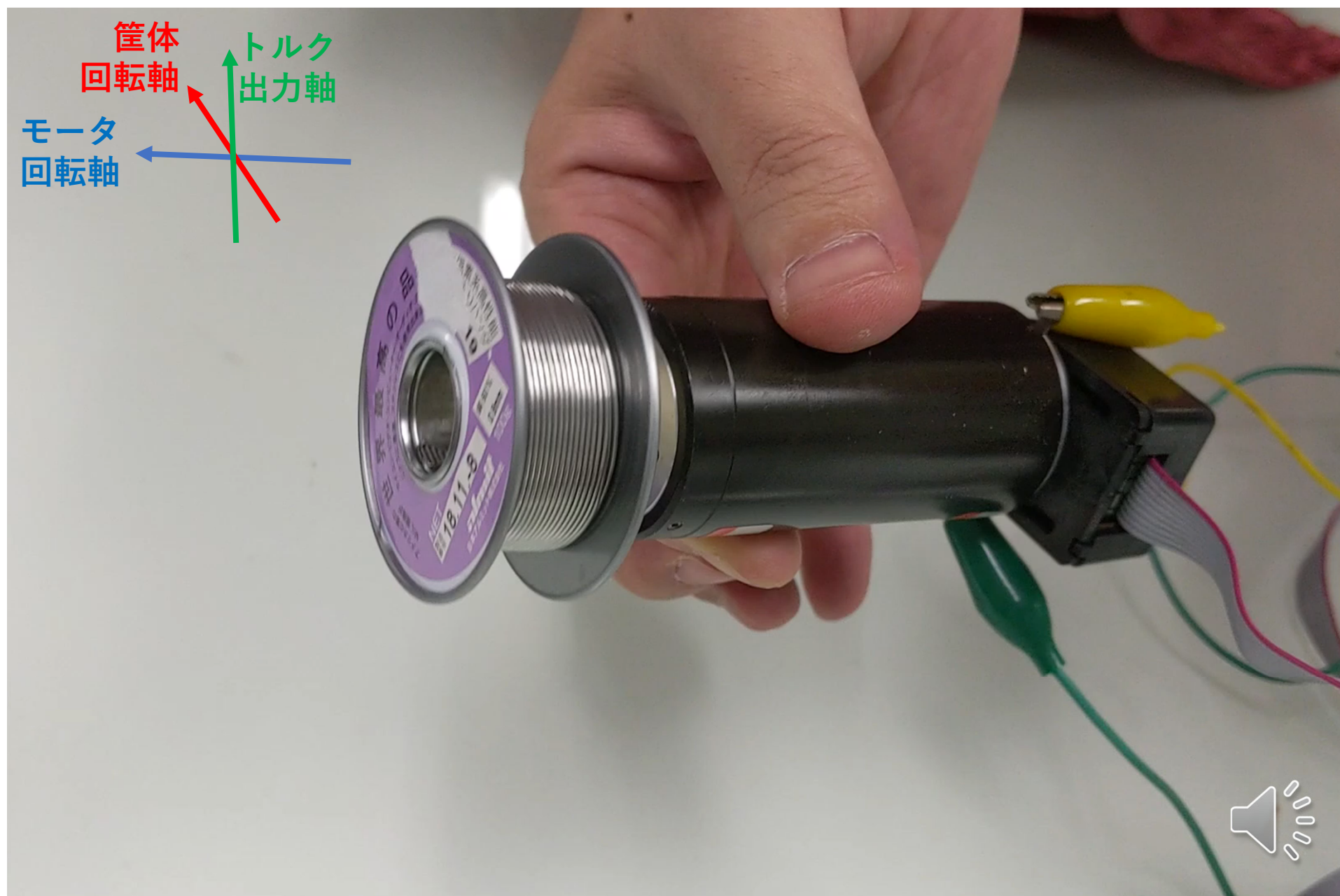


<https://www.youtube.com/watch?v=kiNHqsaoJxc>

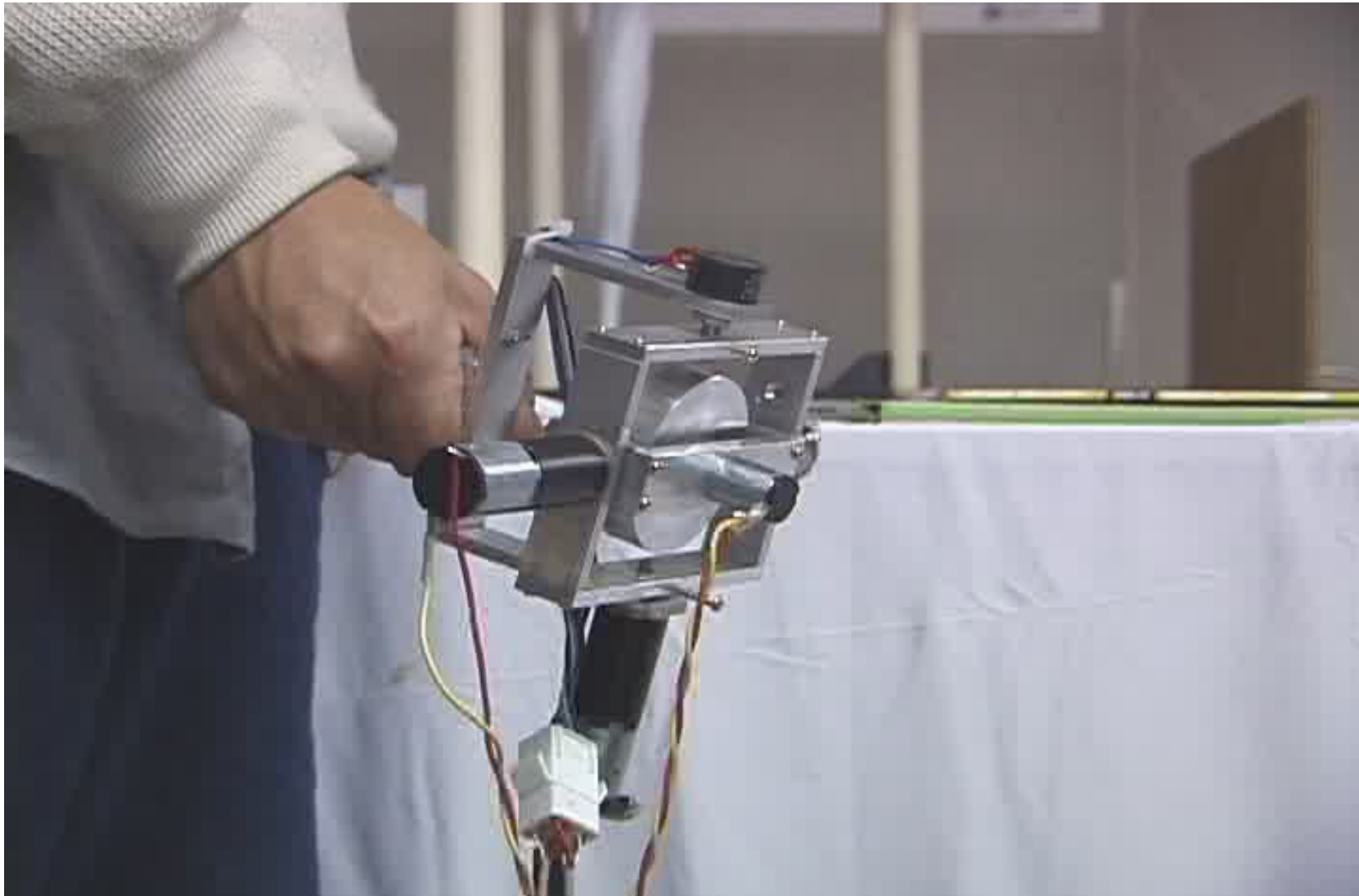


- VR環境中での色々な手で持つものを実現する．扇子を使うことで抵抗感を出す．

ジャイロ効果の利用/ Using gyro effect



ジャイロ効果の利用：定速回転→回転軸変動
Using gyro effect: Rotation axis is turned



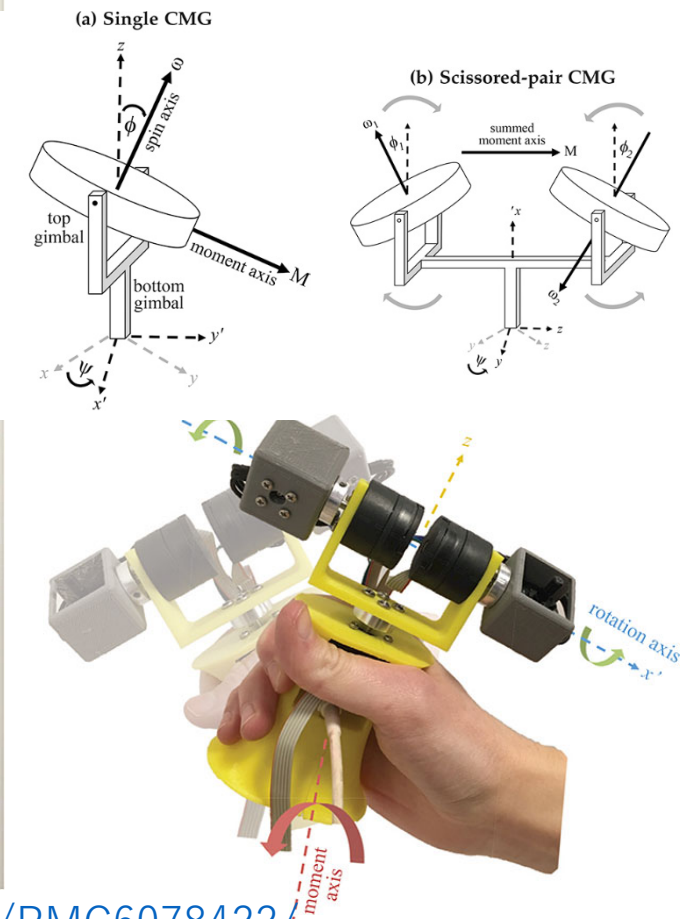
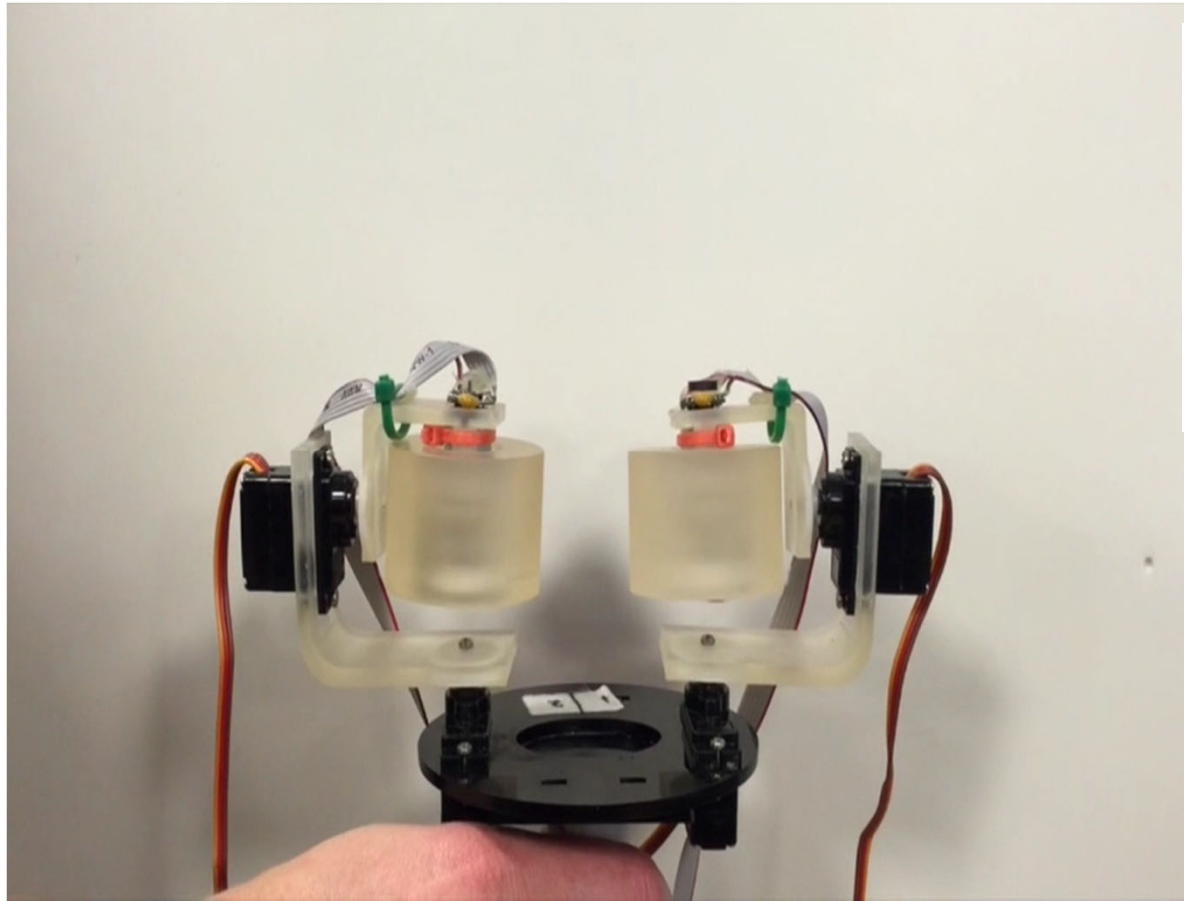
吉江 将之、矢野博明、岩田 洋夫 : ジャイロモーメントを用いた力覚呈示装置、
日本VR学会論文誌Vol.7 No.3 (2002)

http://intron.kz.tsukuba.ac.jp/gyro/gyro_j.html



(HapticsSympo2016) A Dual-Flywheel Ungrounded Haptic Feedback System Provides Single-Axis Moment Pulses for Clear Direction Signals

Julie M. Walker, Michael Raitor, Heather Culbertson, Philipp Stolka, Allison Okamura



<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078422/>

単一のジャイロでジャイロ効果によるトルク提示を行うと、回転軸が傾いていくため所望外の軸のトルクも発生してしまう。これを2つのフライホイールによってキャンセル。When a single gyro is used to provide torque by the gyroscopic effect, an undesired axis of torque is also generated. This is cancelled by the two flywheels.

(UIST2017) GyroVR: Simulating Inertia in Virtual Reality using Head Worn Flywheels,
Jan Gugenheimer, Dennis Wolf, Eythor R. Eiriksson, Pattie Maes, Enrico Rukzio



- ハードディスク回転+頭を振った際のジャイロ効果で抵抗感と感じさせる。
- 「HMDに組み込まれた触覚」のさきがけ的研究。

The hard disk is rotated and the gyroscopic effect generates torque, which is made to feel like resistance.



回転速度変化/ Change of rotation speed



<https://youtu.be/J8YvKlxFmTs?t=492>

Daijiro Koga et al., Virtual Chanbara, Siggraph2002

<http://www.siggraph.org/s2002/conference/etc/ch/virtual.html>



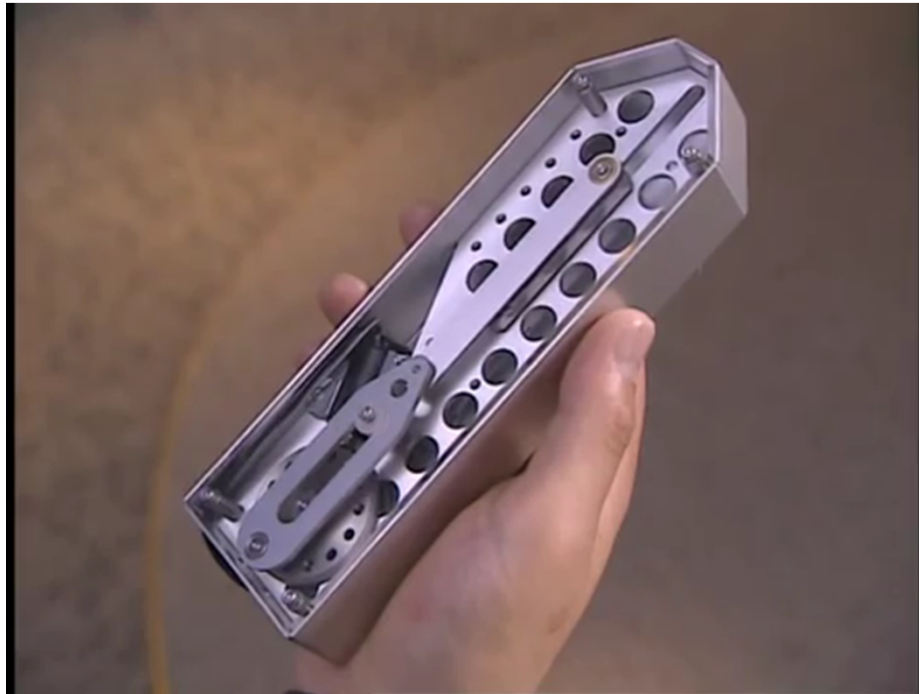
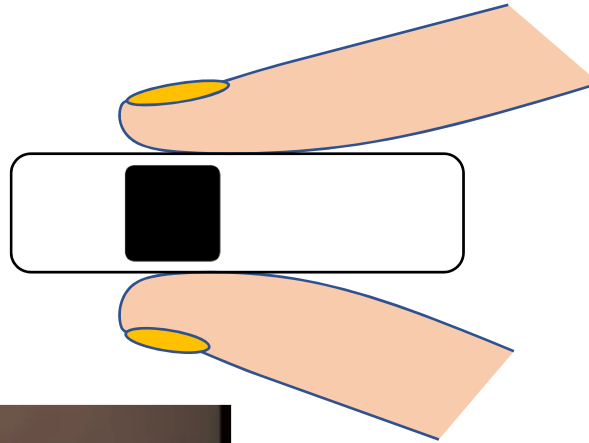
<http://staff.aist.go.jp/n-nakamura/HapticNavi/movie.html>

仲田他, 角運動量変化を利用した力覚提示デバイス, 日本バーチャルリアリティ会論文誌, 6-2, pp.115-120、2001

中村, 福井, "GyroCubeを用いた HapticCompassの提案", 感覚代行シンポジウム, 2002



偏加速度の利用／Using Asymmetric Acceleration



Buru-Navi (Amemiya et al. 2004～)

http://www.youtube.com/watch?v=Yj_WnNWV8F4

<http://www.kecl.ntt.co.jp/human/burunavi/>



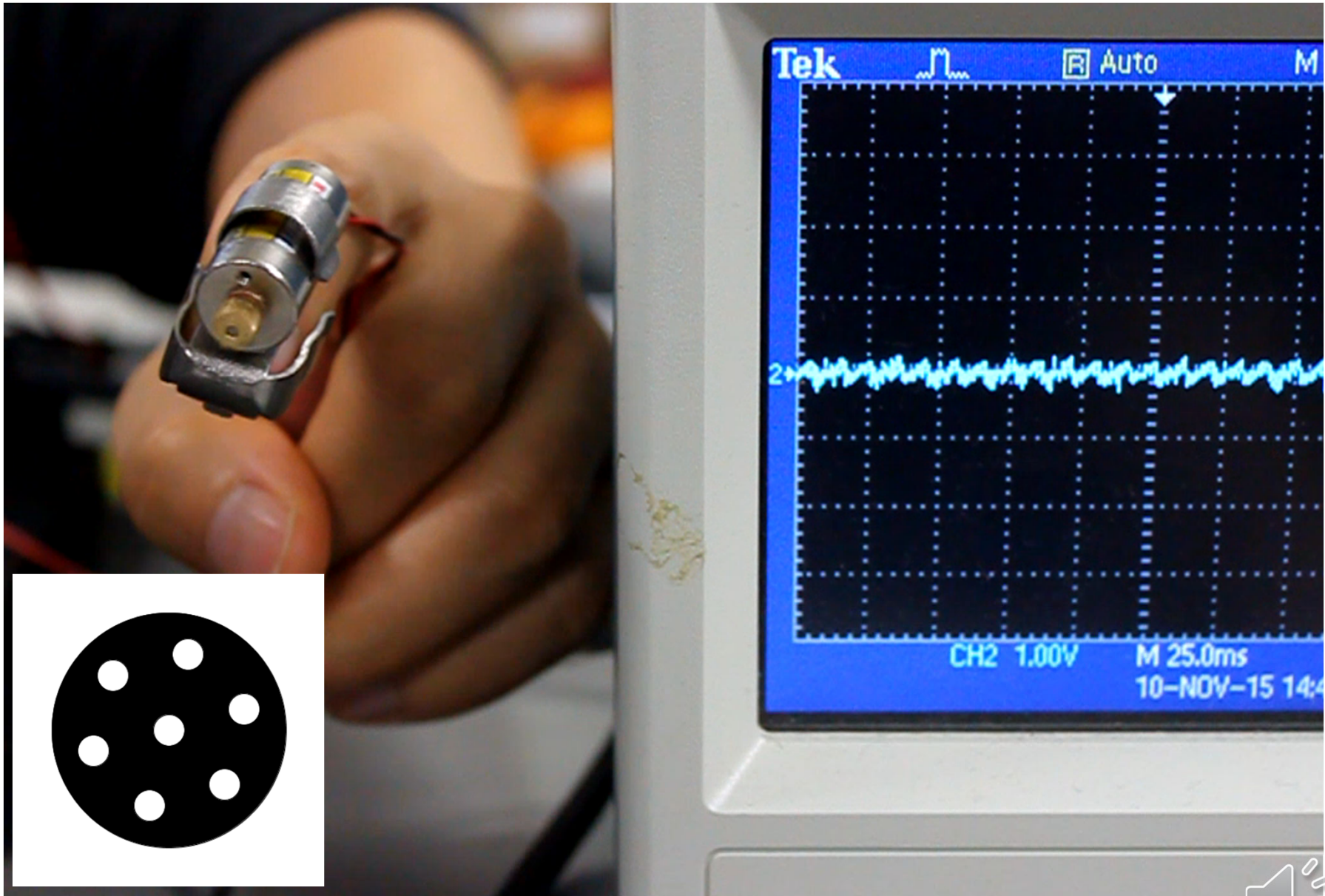
Traxtion (Amemiya et al. 2013～)

<https://vimeo.com/84665437>

<https://lab.rekimoto.org/projects/traxion/>



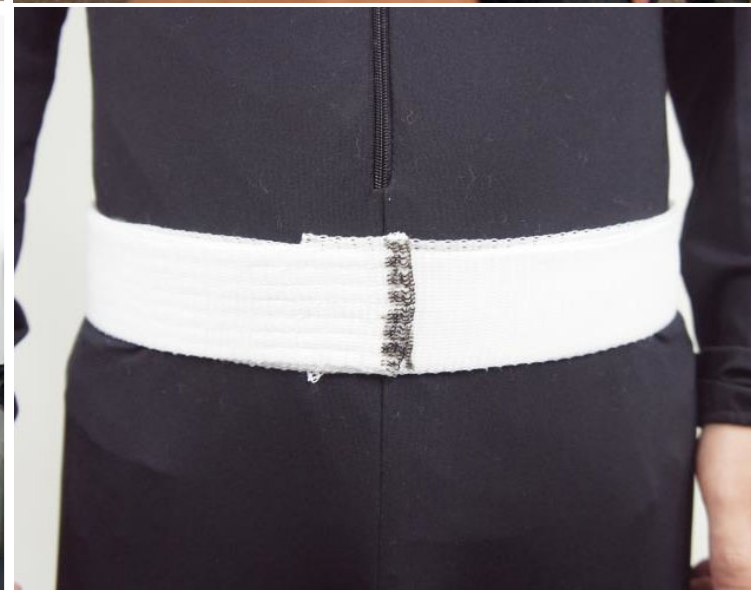
回転も偏加速度で提示可能：Illusory torque presentation



[V. Yem, R. Okazaki and H. Kajimoto, "Vibrotactile and Pseudo Force Presentation using Motor Rotational Acceleration." Proc. of IEEE HapticsSymposium 2016.](#)



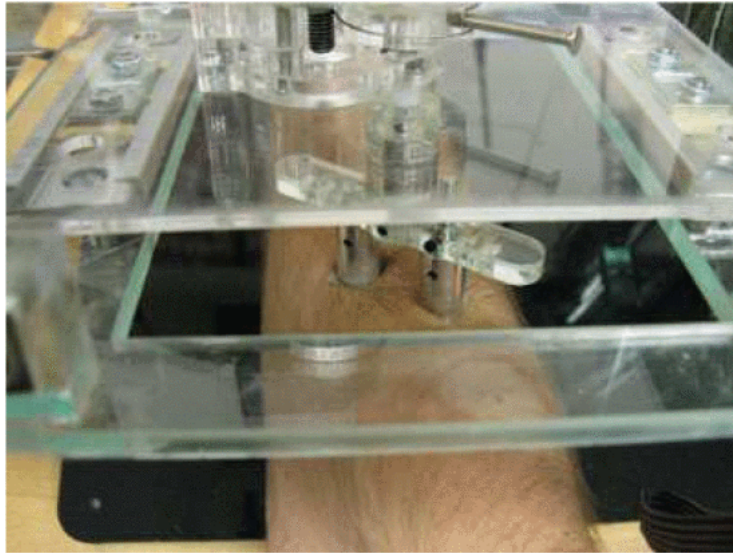
ハンガー反射の身体の他の部位への適用(前腕, 腰)



Nakamura et al., Application of Hanger Reflex to wrist and waist. IEEE VR 2014

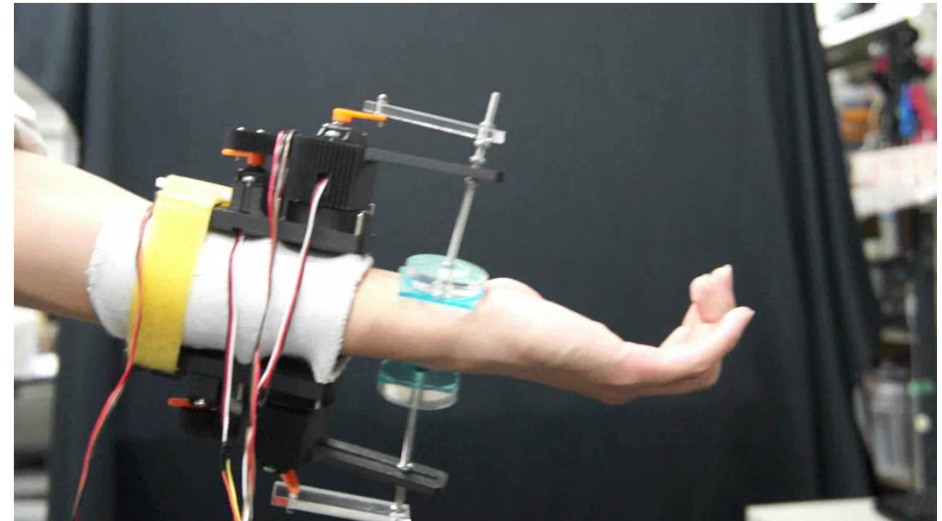


Several skin drag type displays (especially on the forearm)



<https://ieeexplore.ieee.org/document/5444675>

(HapticsSymposium2010) Skin nonlinearities and their effect on user perception for rotational skin stretch, Shull et al.



<https://dl.acm.org/doi/10.1145/2160125.2160141>

(AH2010) Transmission of forearm motion by tangential deformation of the skin. Kuniyasu et al.



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

(CHI2015) Skin Drag Displays: Dragging a Physical Tactor across the User's Skin Produces a Stronger Tactile Stimulus than Vibrotactile, Ion et al.



<https://www.youtube.com/watch?v=HsC4gcziDJ0>

(CHI2019) Springlets: Expressive, Flexible and Silent On-Skin Tactile Interfaces, Hamdan et al.

TODAY's TOPIC

1. 力覚関連のメカニズム Haptic Perception Mechanism
2. 力覚ディスプレイの分類 Classifying Haptic Displays
3. 力覚ディスプレイの応用 Application of Haptic Interface



(再) 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



力覚ディスプレイの応用分野の方向性

Elements of application for tactile display

- **Mobile**

- 市場が巨大。差別化要素としての触覚

- **Emotion, Affection, Communication**

- 力覚は皮膚感覚とともにコミュニケーションの要素となる

- **Navigation, Instruction**

- 力覚は身体座標に直接提示でき、皮膚感覚に比べ実際に正確に動かすこともできる。

- **Reality, Multimodal**

- 力覚は皮膚感覚とともに、存在感、現実感を上げることが出来る

- **The Whole Body**

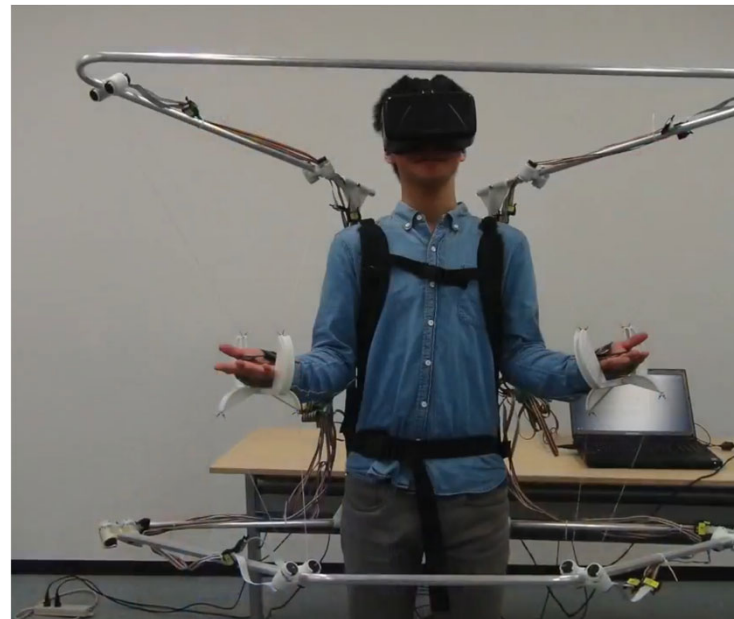
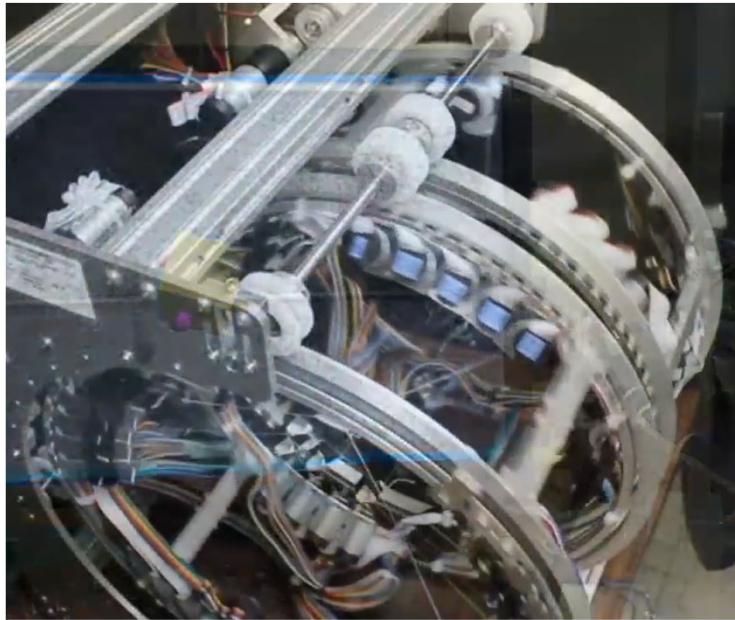
- 身体全体への力覚提示により、臨場感を生じる

- **Haptic AR**

- 力覚を現実世界で使うことでAR化する



全指・全身・モバイルSPIDAR



The Whole
Body

Navigation
Instruction

Mobile



<https://www.youtube.com/watch?v=ZUb4-g8J93k>

Remote mutual communication Robotic User Interface

Emotion, Affection, Communication



<http://files.tachilab.org/publications/intconf2000/Sekiguchi200412ICAT.pdf>
(ICAT2004) The Design of Internet-Based RobotPHONE, Sekiguchi et al.



https://www.youtube.com/watch?v=qygCh35_oBA
(CHI2012) PINOKY: a ring that animates your plush toys. Sugiura et al.



<https://www.youtube.com/watch?v=gVvFL-G2biE>
(AsiaHaptics2014) Force Control of Stuffed Toy Robot for Intention Expression, Kleawsirikul et al.



内視鏡手術シミュレータ Laparoscopic Surgery Simulator

Navigation,
Instruction



ロボット遠隔手術／Robotic Tele-Surgery: da Vinci



<https://www.youtube.com/watch?v=QksAVT0YMEo>



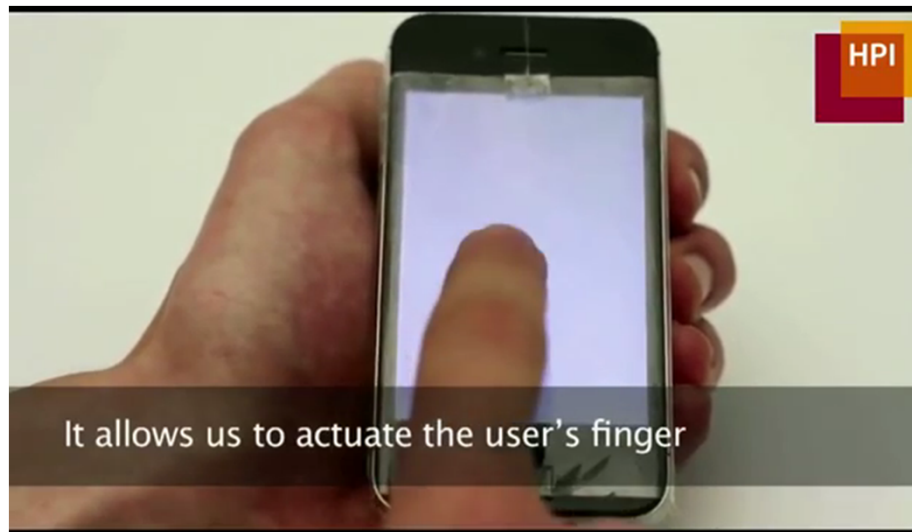
da Vinci: 製品としては力の提示なし。人の入力から振動を除く等のサポートはあり。
研究としては力覚提示各種あり。

daVinci: No force presentation. Low pass filtering of human input to eliminate vibration.

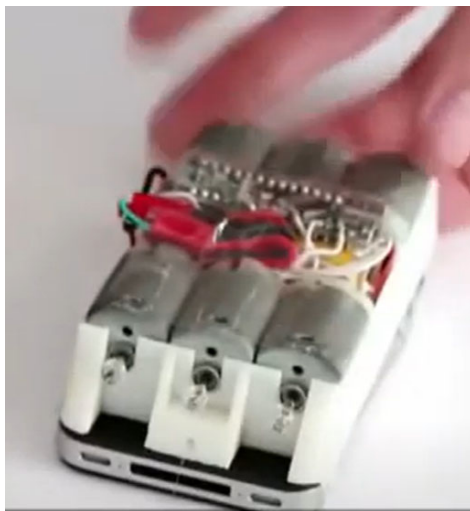


指を駆動して情報提示 Display by actuation

Navigation
Instruction
Mobile



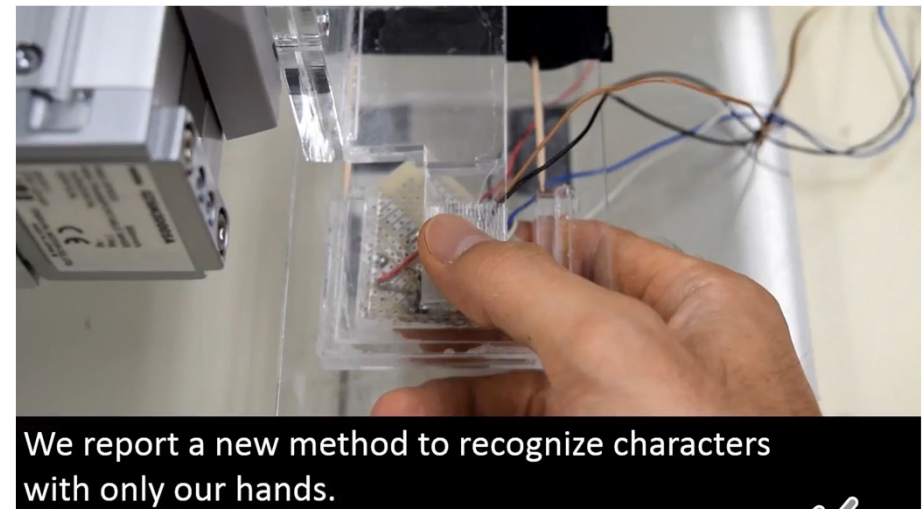
<https://www.youtube.com/watch?v=xxAO8dxP-zI>



A. Roudaut et al., "Gesture output: Eyes-free output using a force feedback touch surface", CHI2013



Hasegawa et al., Character Reading via Stylus Reproducing Normal Handwriting Motion, IEEE Trans. On Haptics, 2016.



We report a new method to recognize characters with only our hands.

<https://www.youtube.com/watch?v=Nu7n5EcZkMs>

Yoshida et al. Character Recognition by Flick Movements Presented on Fingers, AsiaHaptics2016.

ロボットトレーニング：ゴルフ Robot Golf Training

Navigation,
Instruction

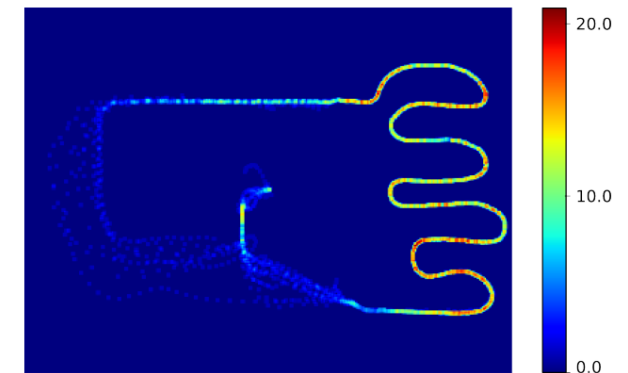
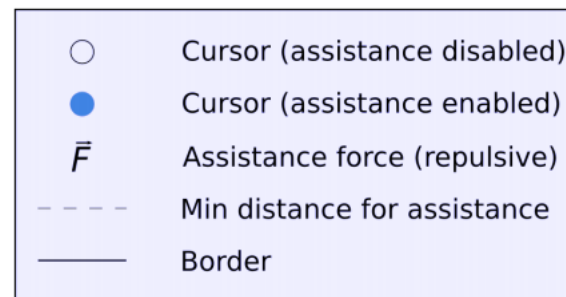
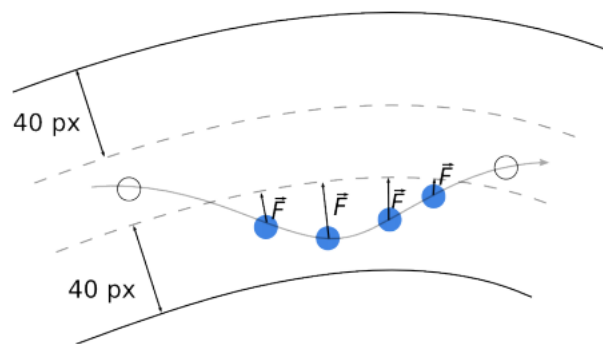
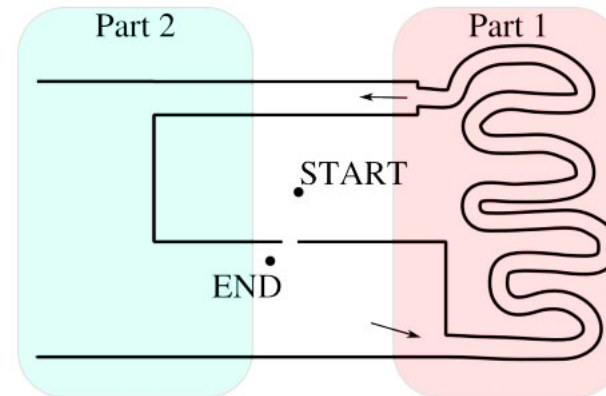


<http://robogolfpro.com/>



難易度の自動調整 Adjustment of difficulty

Navigation,
Instruction



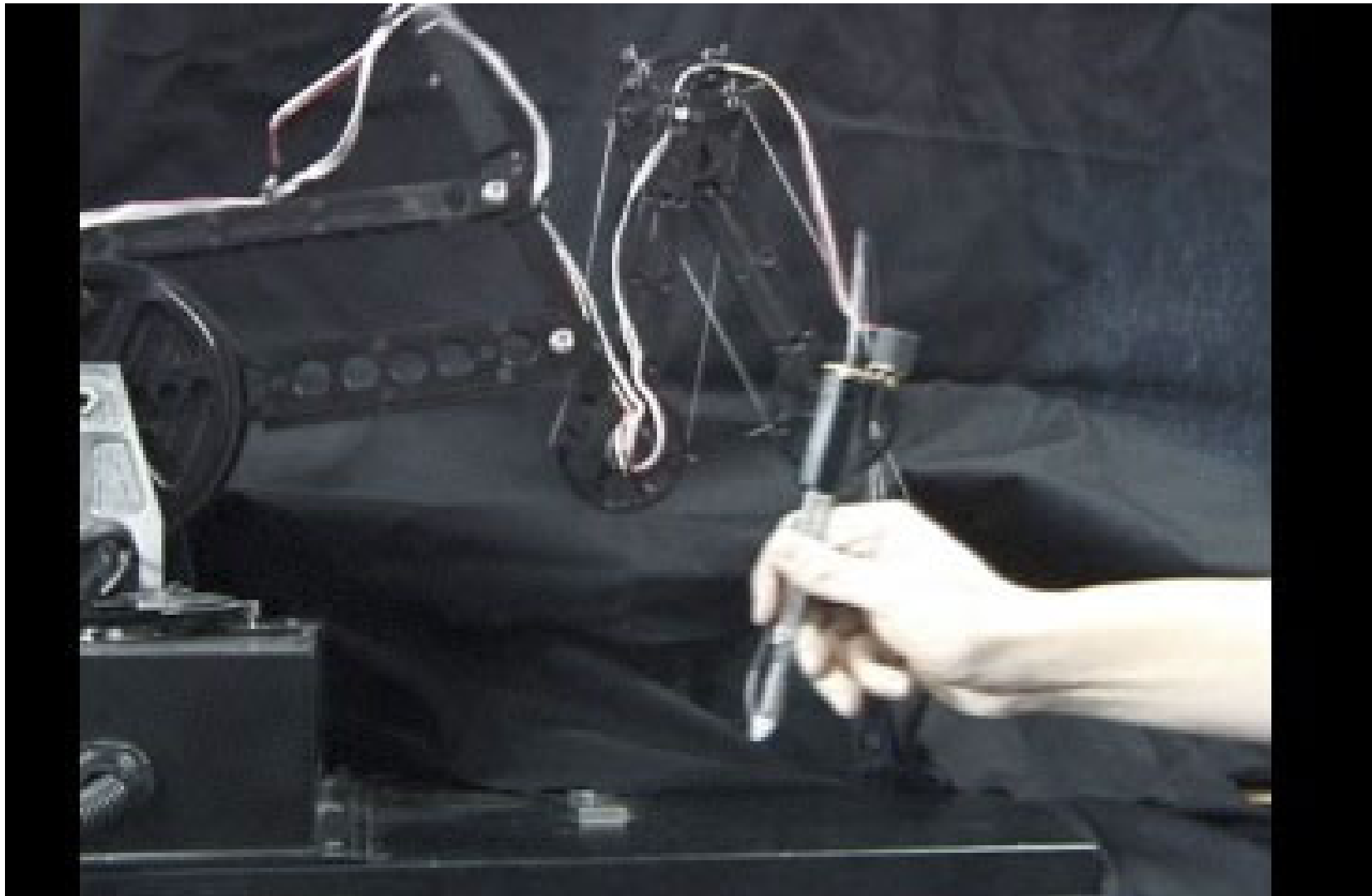
- 触覚ガイドの強さを、脳活動に応じて変化させる。
- 難しい所にさしかかると自動的に重くなる。



触れない物を触る

Haptic AR

Touching the non-touchable by sensory conversion



<https://youtu.be/GaOtiDuvngE>

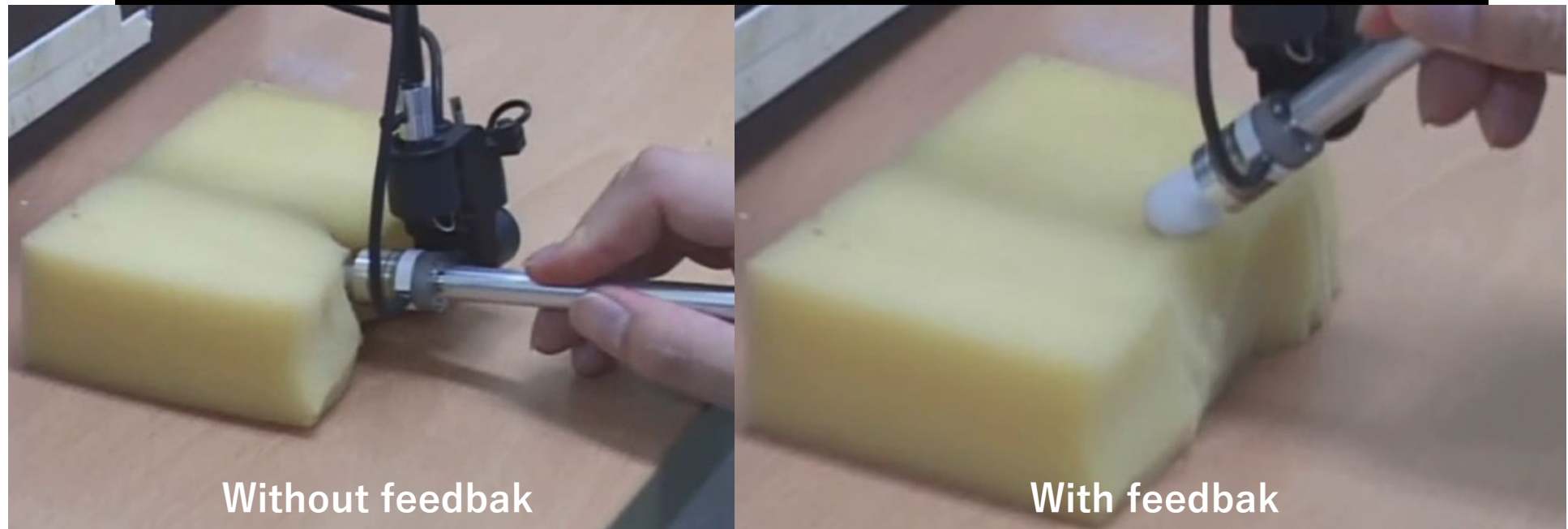
野嶋 琢也, 関口 大陸, 稲見 昌彦, 舘 暲: 力覚提示を利用した実時間実環境作業支援システムの提案, 日本バーチャルリアリティ学会論文誌, Vol.7, No.2, pp.193-200 (2002.5)



Haptic AR(2): カセンサと制御により柔らかさを劇的に変える

Stiffness Modulation by using force sensor and impedance control

Haptic AR

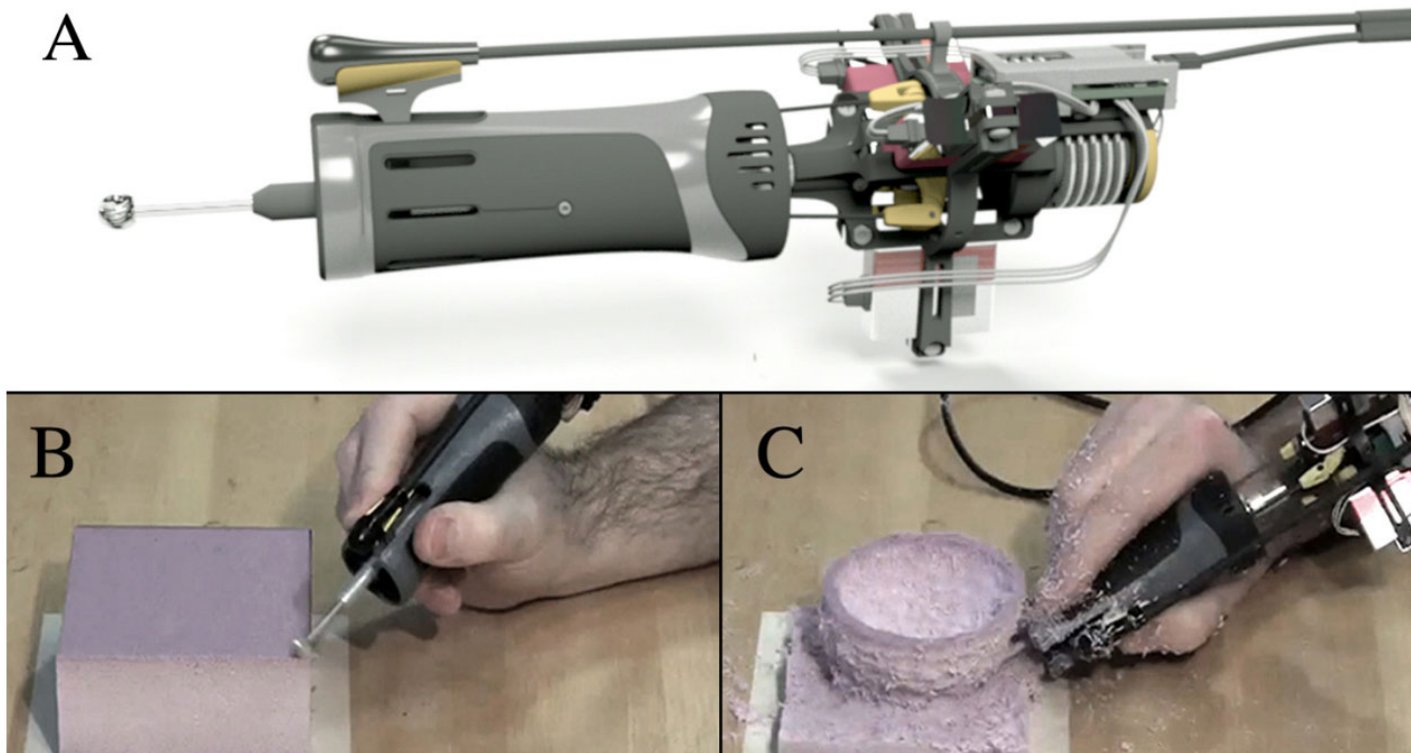


Stiffness Modulation for Haptic Augmented Stiffness Shifting: Improving the Perceived Hardness of a Virtual Surface, Gabjong Han, Seokhee Jeon, Seungmoon Choi, Haptics Symposium 2010



定規（自由度拘束）としてのHaptic AR Haptic AR as a ruler (reducing DoF)

Haptic AR



http://web.media.mit.edu/~amitz/Research/Entries/2011/11/15_FREE-D.html

Zoran et al.: FreeD – A Freehand Digital Sculpting Tool, CHI2013

運慶は今太い眉を一寸の高さに横へ彫り抜いて、鑿の歯を豎に返すや否や斜に、上から槌を打下した。堅い木を一刻に削って、厚い木屑が槌の声に応じて飛んだと思ったら、小鼻のおっ開びらいた怒り鼻の側面がたちまち浮き上がって来た。その刀の入れ方がいかにも無遠慮であった。そうして少しも疑念を挟みはさんでおらんように見えた。

「よくああ無造作に鑿を使って、思うような眉や鼻ができるものだ」と自分はいささか感心したから独言のように言った。するとさっきの若い男が、「なに、あれは眉や鼻を鑿で作るんじゃない。あの通りの眉や鼻が木の中に埋まっているのを、鑿と槌の力で掘り出すまでだ。まるで土の中から石を掘り出すようなものだからけっして間違ふはずはない」と云った。

自分はこの時始めて彫刻とはそんなものかと思ひ出した。はたしてそうなら誰にでもできる事だと思ひ出した。それで急に自分も仁王が彫ってみたくなったから見物をやめてさっそく家へ帰った。（夏目漱石「夢十夜」第六夜より抜粋）

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.拮抗筋構造の利点について説明せよ Explain merit of antagonistic muscle structure.
- 2.筋紡錘の役割について説明せよ Explain role of muscle spindle
- 3.ゴルジ腱器官の役割について説明せよ Explain role of Golgi tendon organ.
- 4.サイズー重さ錯覚について説明せよ Explain size-weight illusion.
- 5.シュードハプティクスについて説明せよ Explain pseudo-haptics illusion
- 6.ラバーバンドイリュージョンについて説明せよ Explain rubber-hand illusion
- 7.幻肢痛について説明せよ Explain phantom pain.
- 8.ハンガー反射について説明せよ Explain hanger reflex
- 9.遭遇型ハプティックデバイスについて説明せよ Explain encounter type haptic device.
- 10.装着型ハプティックデバイスについて説明せよ Explain wear type haptic device.
- 11.装着型と把持型のハプティックデバイスの違いについて説明せよ Explain difference between wear type and grip type haptic device.
- 12.バックドライバビリティについて説明せよ Explain back-drivability

