

Interactive System インタラクティブ システム特論 (9)

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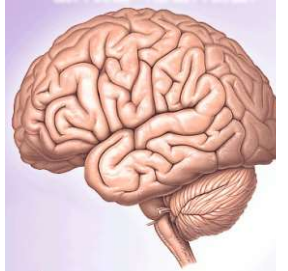
インタラクティブシステム特論
最終課題について: Web参照
最終課題提出翌週にGoogle classroomで評価
方法を連絡します。

Please see the web for final
presentation-style report.
Evaluation method is notified via google
classroom



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. 力覚、力覚インタフェース／Haptic Interface
8. 移動感覚インタフェース／Locomotion Interface



TODAY's TOPIC

1. 移動感覚のメカニズム Locomotive perception mechanism
2. 歩行感覚提示 How to present Walking sensation?
3. 搭乗感覚提示 How to present Riding sensation?
4. 巨大化を避ける試み Why are they so HUGE?



移動感覚：最後 & 最大の難問

Locomotion: The last & the most difficult



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



[https://en.wikipedia.org/wiki/Ready_Player_One_\(film\)](https://en.wikipedia.org/wiki/Ready_Player_One_(film))



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

視覚・聴覚・触覚...これまで学んだことで理想的なVR世界が作れるか
⇒飛んだり跳ねたり出来ない！

We can not make the “matrix” world by simple visual, auditory and tactile display. Something is missing.



移動感覚？／Locomotion?

複合感覚／Combined sensation

- 歩行／Walking

- 触覚／Tactile sensation
- 力覚／Force sensation
- 加速度／Acceleration
(前庭器官／vestibular)
- 速度／Velocity
(視覚的オプティカルフロー／Visual stimuli, or “optical flow”)



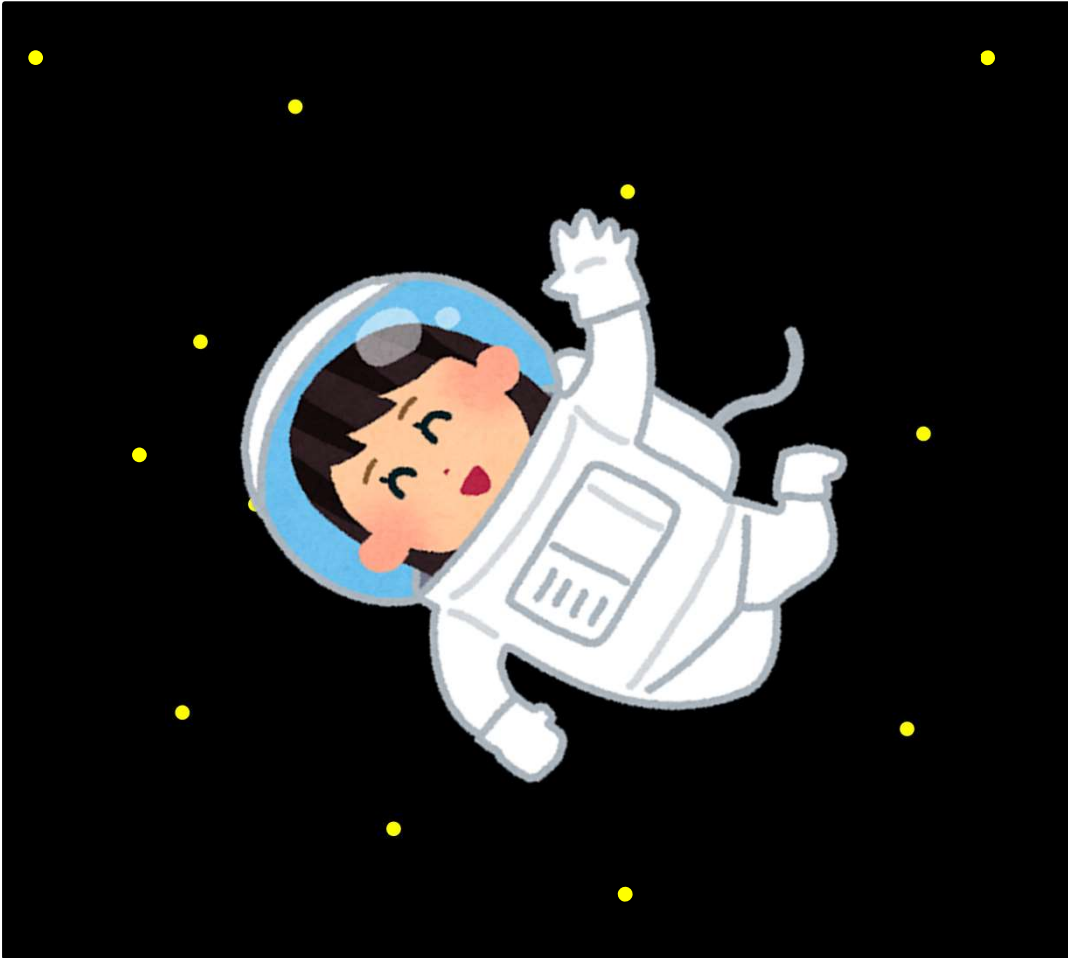
- 運転／Riding

- 加速度／Acceleration
- 速度／Velocity



速度は体内器官だけでは検出できない

Velocity cannot be measured by internal sense



2018@SanFrancisco

一定速度の状況は、速度0の状況と、物理的に区別がつかない。

よって、視覚的手がかり(オプティカルフロー)が大きな手がかり。

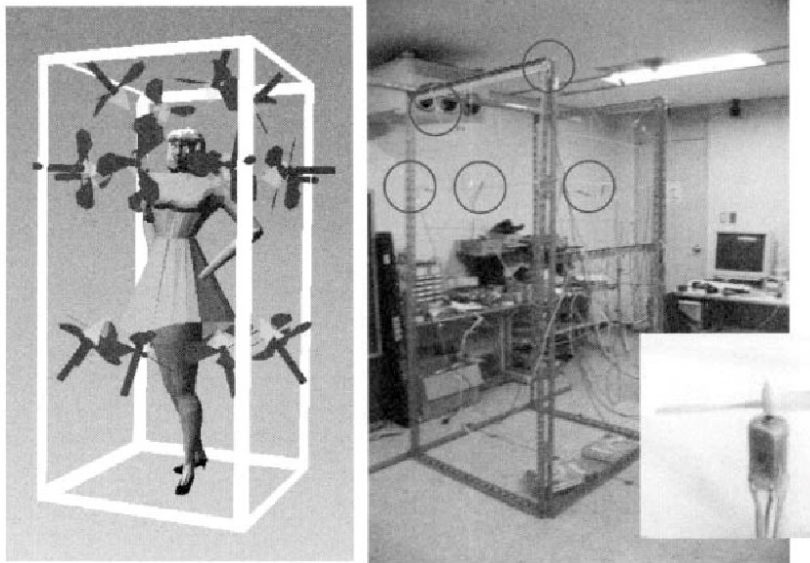
Constant speed situation is physically equivalent to speed=0 situation.

Therefore, Optical flow is the only cue.



風感覚による速度感

Wind can present velocity directly



T. Moon and G. Kim: Design and Evaluation of a Wind Display for Virtual Reality (2004)

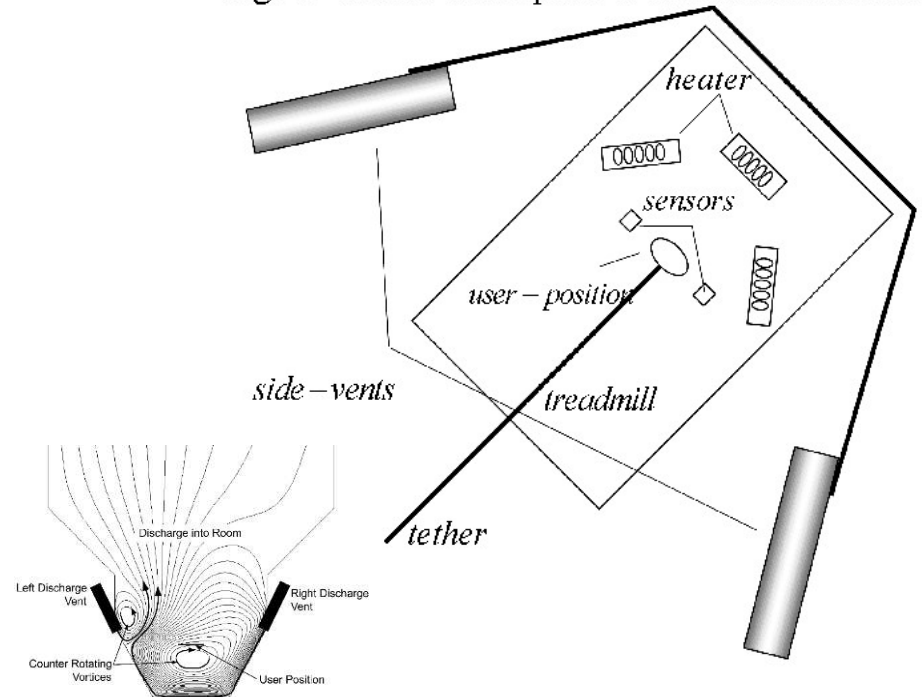
<https://dl.acm.org/doi/10.1145/1077534.1077558>



Cardin et al. Head Mounted Wind(2007)



Fig. 1. Sarcos Treadport Locomotion Interface.



Output Feedback Control of Wind Display in a Virtual Environment

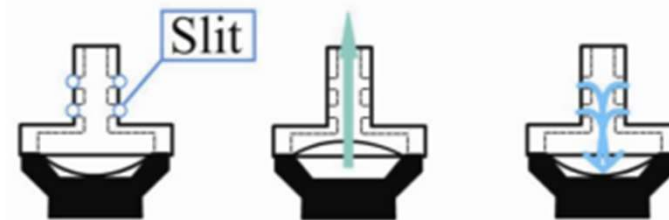
S. Kulkarni, M. Minor, M. W. Deaver, E. Pardyjak (2007)

<https://www.semanticscholar.org/paper/Output-Feedback-Control-of-Wind-Display-in-a-Kulkarni-Minor/5387f11f1a5843d2f2b33d77f0eb69f67784de96>

風感覚いろいろ / Several other wind displays



Sawada et al, BYUBYU-View: A Wind Communication Interface (2007)
https://www.youtube.com/watch?v=C6Q2RsT_MHQ



Kojima et al: A Novel Wearable Device to Present Localized Sensation of Wind(2009)
<https://dl.acm.org/doi/10.1145/1690388.1690399>
スピーカーを使った高速応答の風提示を「耳」に対して



We attached the wearable airflow displays

Jaeyeon Lee, Geehyuk Lee Designing a Non-contact Wearable Tactile Display Using Airflows (UIST2016)
https://www.youtube.com/watch?v=QdSK_K3Spew&t=30s

LRAir: High Energy Synthetic Jets

We developed a prototype actuator in order to showcase the capabilities of this class of device.

Our contributions include:


- A design and model optimizing the acoustic resonances in the system
- Small signal validation of this model
- Large signal measurements quantifying thrust and flow velocity
- Psychophysical measurements showing the low power capabilities of these jets.



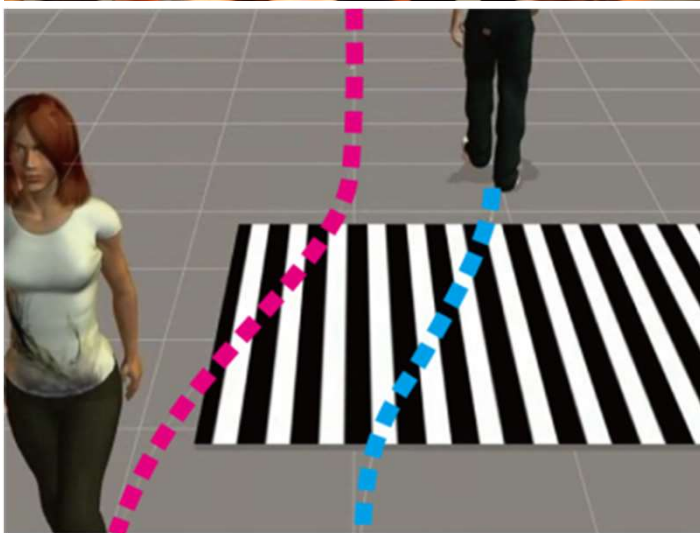
C. Shultz, C. Harrison, LRAir: Non-contact Haptics Using Synthetic Jets, HS2022
<https://www.youtube.com/watch?v=ecQ1dIAIT-k&list=PLXRBbyxY9IBXFYvTJMEuTnTQsH3M5aSBp&index=4>

視覚性自己運動知覚 (Vection)



- 運動しているような視覚的の手がかり(オプティカルフロー)から、観察者自身が運動しているように知覚(ex ホームで電車の動きを見る、SF映画のワープ場面) 
- From moving visual cues (optical flow), the observers themselves perceives as if they are in motion.

(参考:再)レンチキュラレンズを用いた歩行誘導 ／Walk Navigation by Lenticular Lens



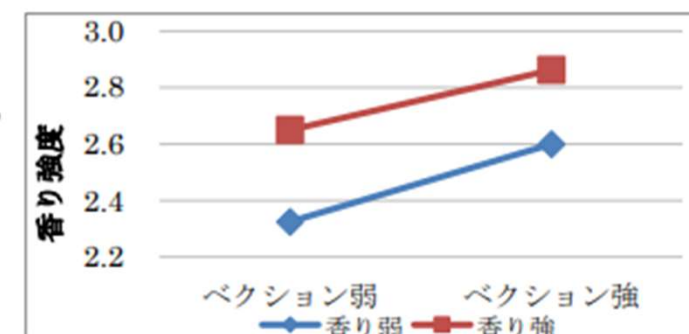
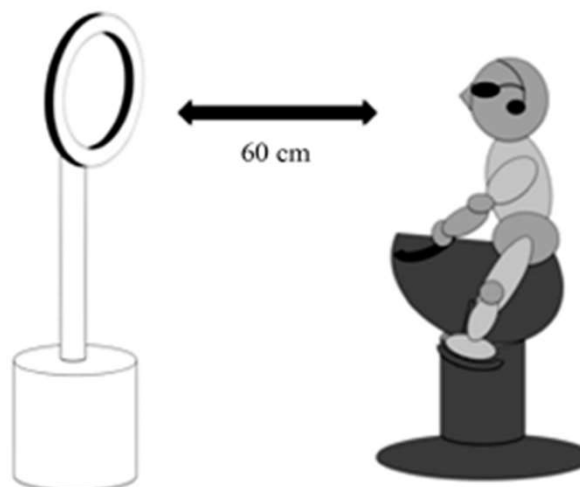
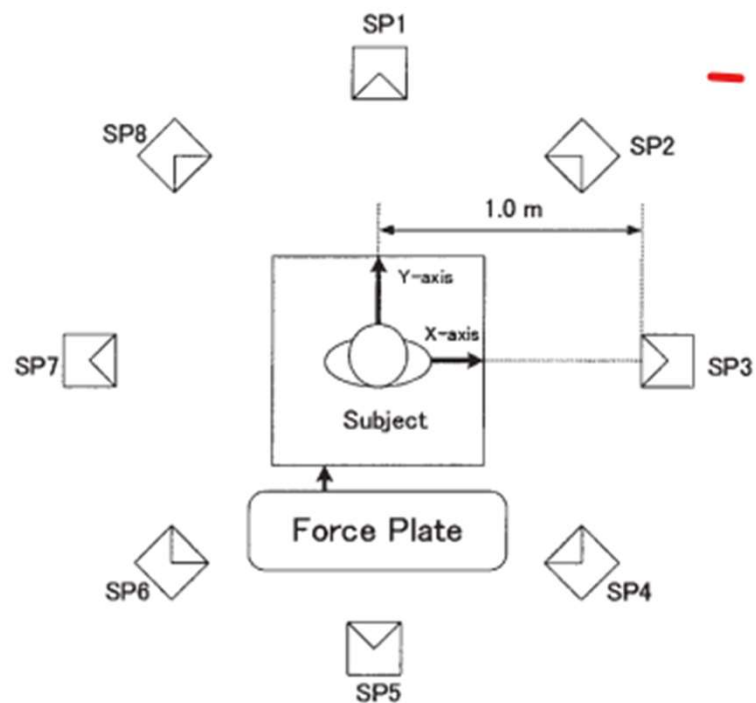
<https://www.youtube.com/watch?v=7FOZ5HIQ500>

M. Furukawa, et al. "Vection Field" for Pedestrian Traffic Control", Augmented Human2011.

- 場が歩行者を誘導する**ベクション場**の形成.
- **レンチキュラレンズ**を用い, 視覚刺激を床面へ広範囲呈示.
- 受動素子 ⇒ **歩行者の動きに同期した刺激**を**完全無電源**で実現.



他の感覚によるベクシオン Vection by other modalities



- 聴覚性ベクシオン: 前後方向の移動

- The effects of linearly moving sound images on self-motion perception, Sakamoto et al. *Acoustical Science & Technology* (2004)

- Seno, T., Hasuo, E., Ito, H., & Nakajima, Y. (2012). Perceptually plausible sounds facilitate visually induced self-motion perception (vection). *Perception*, 41, 577-593.

- 風による皮膚感覚性ベクシオン:

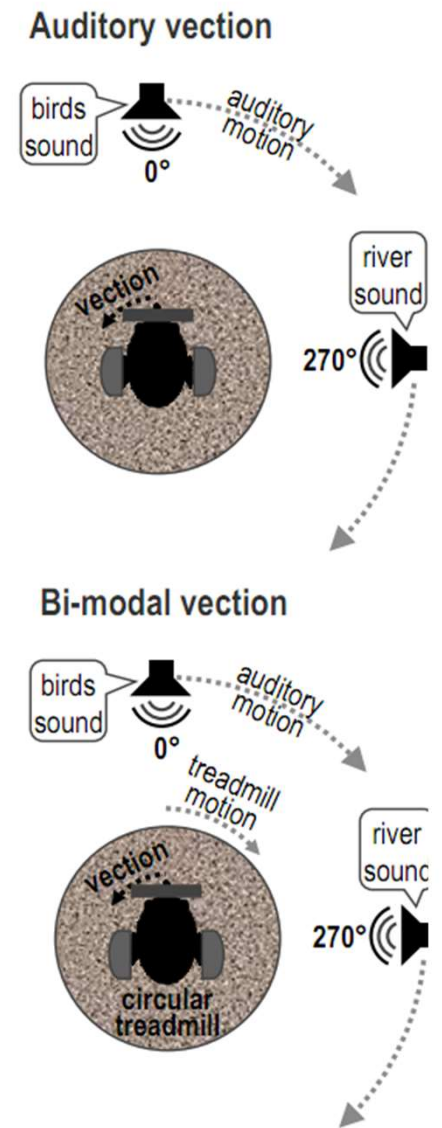
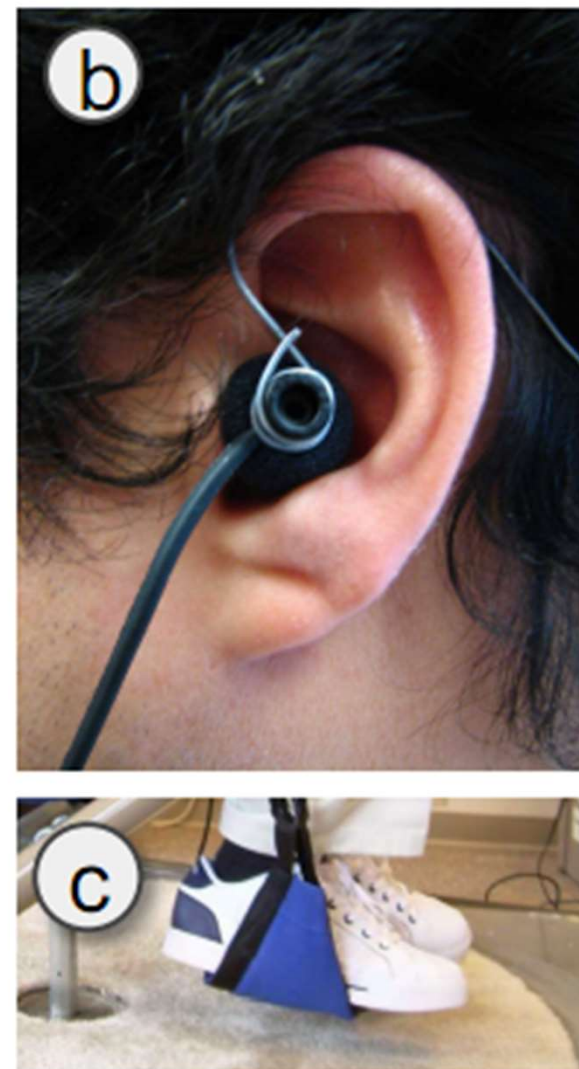
- Self-Motion Perception Induced by Cutaneous Sensation Caused by Constant Wind.; *Psychology*, Seno et al. (2014)

- 嗅覚とベクシオンの相互作用。ベクシオンは嗅覚に影響を与える:

- HMD提示によるベクシオン刺激と嗅覚刺激の知覚的相互作用に関する検討、有賀他、日本VR学会論文誌(2019)



聴覚によるベクシオン Vection by sound field



ベクシオンは音源の移動でも生じる

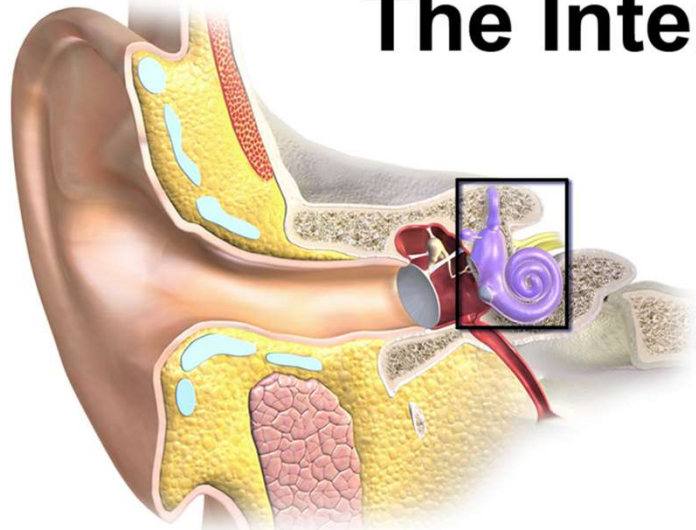
特に回転する床を用意し、被験者が足で能動的に回転させると強い効果

(CHI2011) Bernhard E et al, Spatialized Sound Enhances Biomechanically-Induced Self-Motion Illusion (Vection)



内耳の前庭器官 Vestibular System

The Internal Ear



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

三半規管
Semicircular ducts

Anterior
Lateral
Posterior

Cristae within ampullae

卵形囊(らんけいのう)
Utricle

Vestibulocochlear nerve

Sacculle
球形囊(きゅうけいのう)

卵円窓 / Oval Window
(中耳からの入力)

正円窓 / Round Window

Vestibular duct

Cochlear duct

Tympanic duct

蝸牛管

Cochlea

 Bony labyrinth

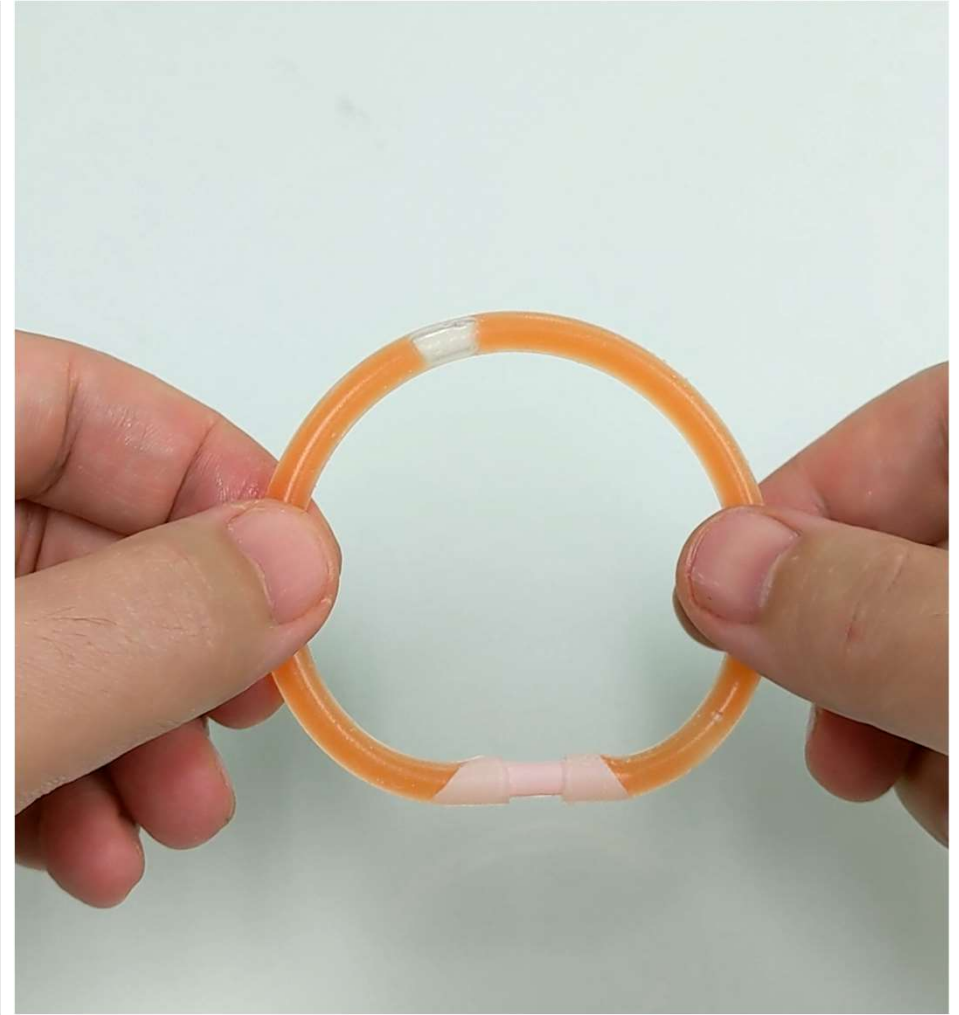
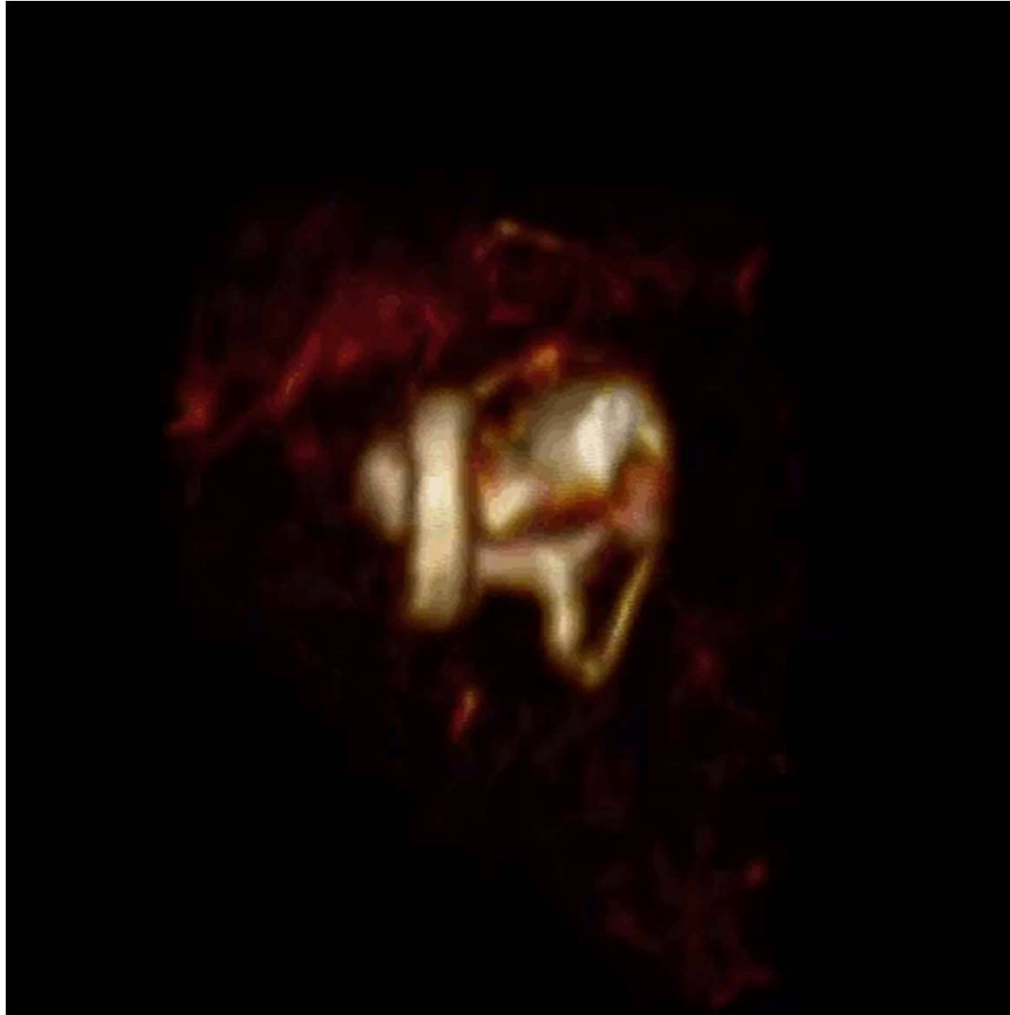
 Membranous labyrinth

Sensory Complex:

- Angular Acceleration
- Acceleration
- Sound



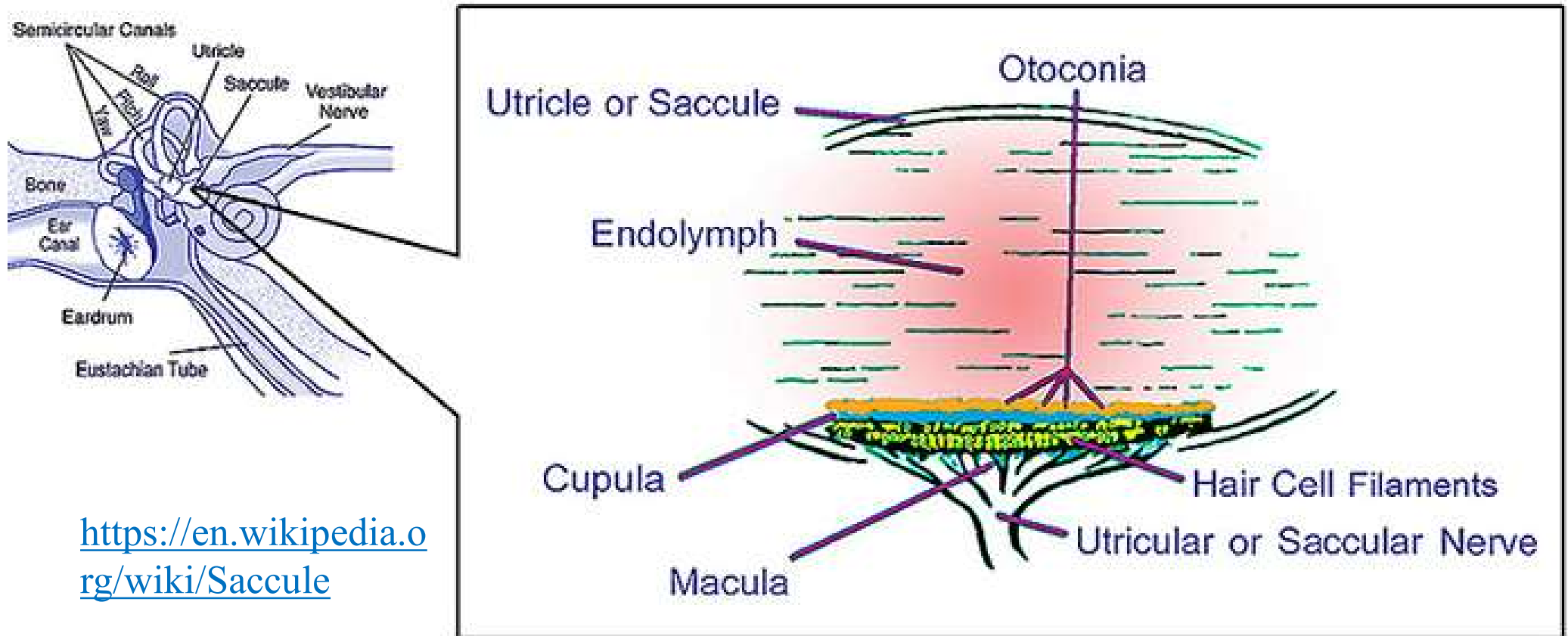
半規管／Semicircular Canal



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

- 3本のリンパ液に満たされた円周状パイプ。
Three round “pipe”, filled with liquid.
- 角加速度が生じたとき、パイプ内の液体が移動し、有毛細胞が活動
When **angular acceleration** is applied, liquid moves, and hair cell is activated.

耳石器 otolith (球形囊(ノウ)と卵形囊 Saccule & Utricle)



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

- リンパ液の満たされたドーム／Dome filled with liquid.
- 有毛細胞の上の砂(オモリ)が加速度により動き, 有毛細胞が活動
Acceleration is applied, weight on hair cells shift, activate hair cell.
- 並進加速度(重力)センサ／Accrleration, or “Gravity” sensor.
- 球形囊: 垂直加速度, 卵形囊: 水平加速度
Saccule: Vertical Accel. Utricle: Horizontal Accel.

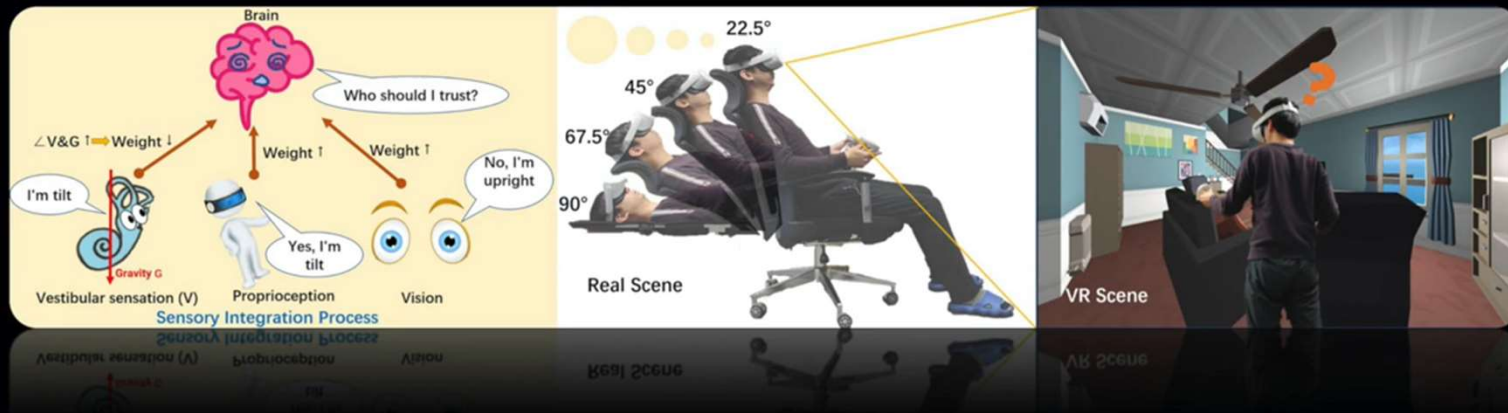


(UIST2022) Exploring Sensory Conflict Effect Due to Upright Redirection While Using VR in Reclining & Lying Positions

Tianren Luo, Zhenxuan He, Chenyang Cai, Teng Han, Zhigeng Pan, Feng Tian

Exploring Sensory Conflict Effect Due to Upright Redirection While Using VR in Reclining & Lying Positions

Tianren Luo, Zhenxuan He, Chenyang Cai, Teng Han*, Zhigeng Pan, Feng Tian



<https://www.youtube.com/watch?v=bKAz3PO0gRQ&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=94>

VRでリクライニング姿勢で視点が上向きになっている場合の内部・外部の知覚への影響を調査。上向き姿勢は45度で最も強いSimulator Sicknessを生じる。

Investigated the effects on internal and external perception when the viewpoint is in a reclining posture in VR and the viewpoint is facing upward. The upward posture produces the strongest Simulator Sickness at 45 degrees.

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歩行感覚の再現

How to present “Walking” Sensation?

- 足踏み、パッシブ / Footstep, Passive
- 歩行制御 / Redirection
- トレッドミル / Treadmill
- 装着型 / Wearable
- 応用例 / Application



最近の詳細な分類は例えばこちら: Nilsson et al. Natural Walking in Virtual Reality, Computers in Entertainment 16(2):1-22 · April 2018


足踏み／Just Footstep



<https://youtu.be/J8YvKIXFmTs?t=702>
vRoad Runner, IVRC2002



<https://www.youtube.com/watch?v=AbvP2I1nh8s&t=86s>
Classic Game Room HD - WALK IT OUT! for Wii review

- The user make footstep on the (turn) table.
- (The table slowly rotates, so that the user's direction is returned.) 

はしごを登る Walk up the ladder

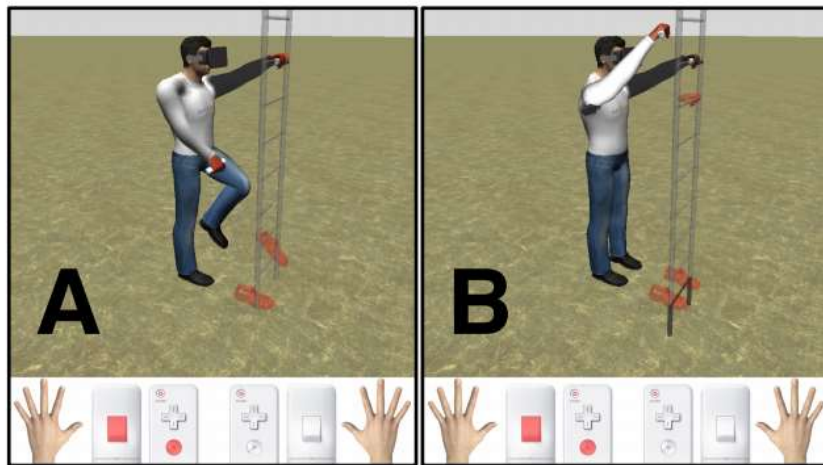


Figure 1: Users climb up with March-and-Reach by grabbing a virtual rung with two buttons, and then raising and lowering a foot to virtually step up on the next rung. The transparent red shapes represent the user's virtual hands and feet.

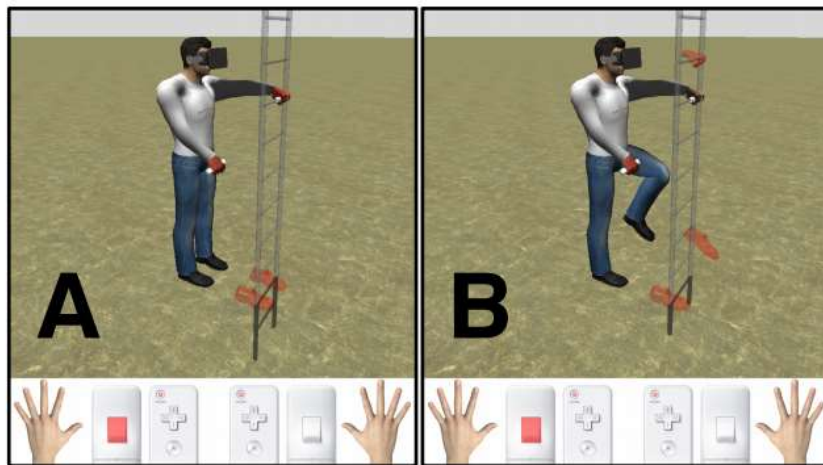
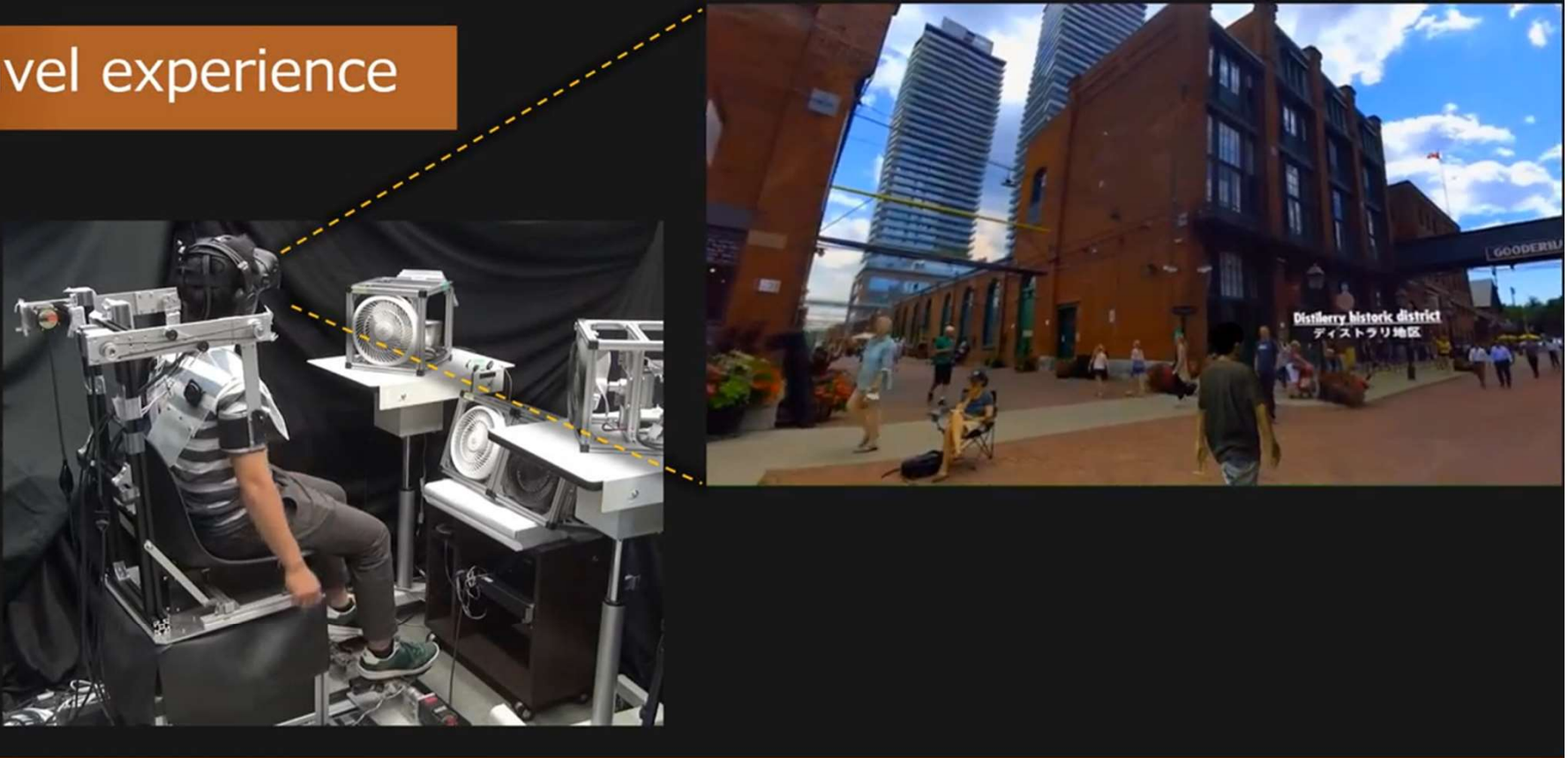


Figure 2: Users climb down with March-and-Reach by grasping a virtual rung with one button, and then raising a foot to virtually step down to the next rung. Once the other foot contacts the rung, virtual travel stops until the user's raised foot returns to the ground.



(SIGGRAPH ASIA2018) FiveStar VR: shareable travel experience through multisensory stimulation to the whole body, Shimizu et al.

Travel experience



FiveStar VR is a multisensory virtual reality system that enables participants to relive other's behavior.

<https://www.youtube.com/watch?v=mOS5JJBSZ3c>

- 腕振り、足振りをパッシブに再現。他に風提示、HMD等。
- The body parts are forced to move, which are synchronized with those of an avatar in VR.



触覚提示による歩行感覚の代替

Around-head haptics for walking



We proposed WalkingVibe that provide vibro-tactile feedback on u

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

(IEEEVR2019) PhantomLegs: Reducing Virtual Reality Sickness using Head-Worn Haptic Devices
Shi-Hong Liu, Neng-Hao Yu, Liwei Chan, Yi-Hao Peng, Wei-Zen Sun, Mike Y. Chen

歩行の感覚を「耳の下少し前」を叩くことで提示してVR酔いを軽減

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

(CHI2020) WalkingVibe: Reducing Virtual Reality Sickness and Improving Realism while Walking in VR using Unobtrusive Head-mounted Vibrotactile Feedback, Yi-Hao Peng

振動子によってVR酔いを軽減



(CHI2020) Miniature Haptics: Experiencing Haptic Feedback through Hand-based and Embodied Avatars, Bo-Xiang Wang; Yu-Wei Wang; Yen-Kai Chen; Chun-Miao Tseng; Min-Chien Hsu; Cheng An Hsieh; Hsin-Ying Lee; Mike Y. Chen



- <https://www.youtube.com/watch?v=joO-F2Gzlm0>
- ゲーム中のキャラクターをユーザの手指に対応させ、手指に触覚フィードバックを行うことでキャラクターの身体への触覚提示を代替する。
- By mapping the character in the game to the user's fingers and providing haptic feedback to the fingers, walking sensation is provided.



歩行感覚の再現

How to present “Walking” Sensation?

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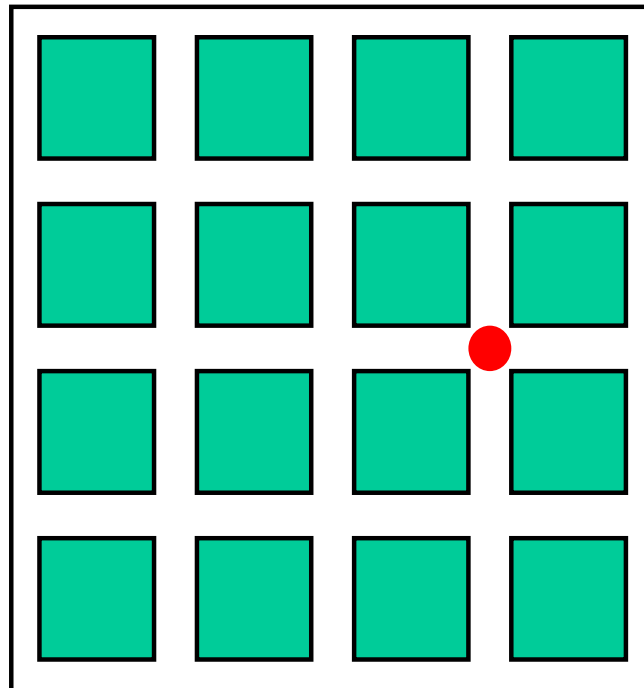


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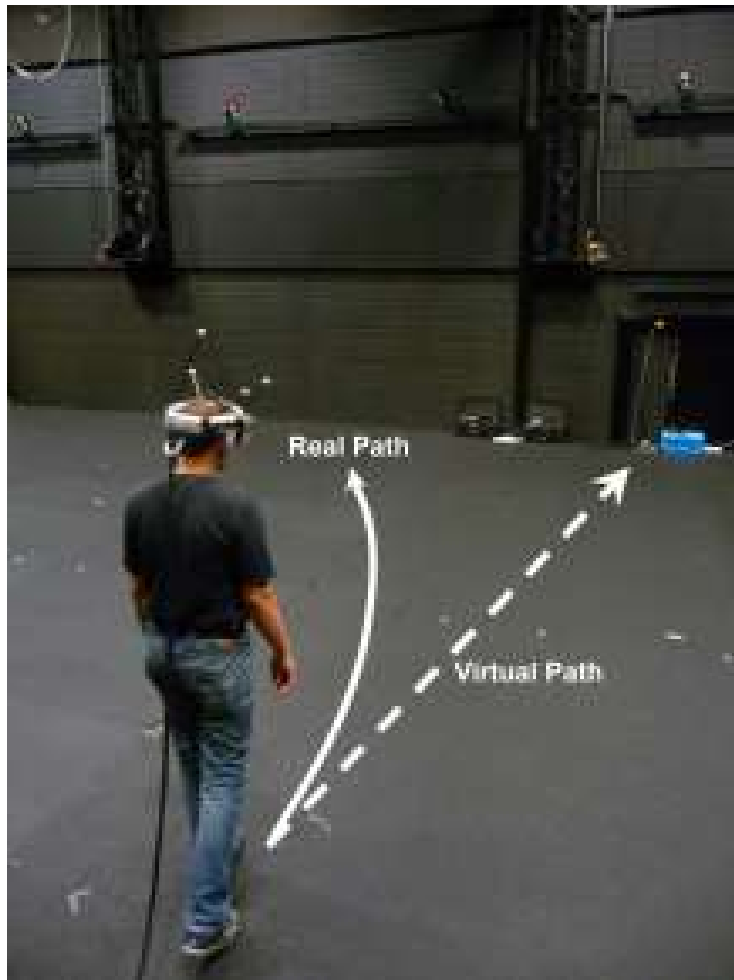
ルールベース Rule base



- 沢山の十字路で構成された部屋
- HMDを装着して移動
- 十字に立つたびに世界が回転



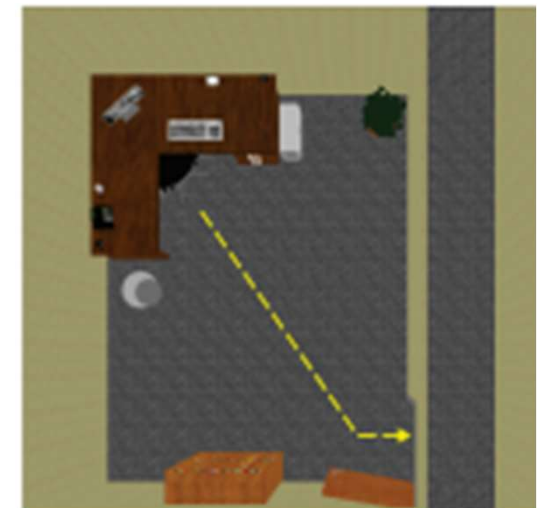
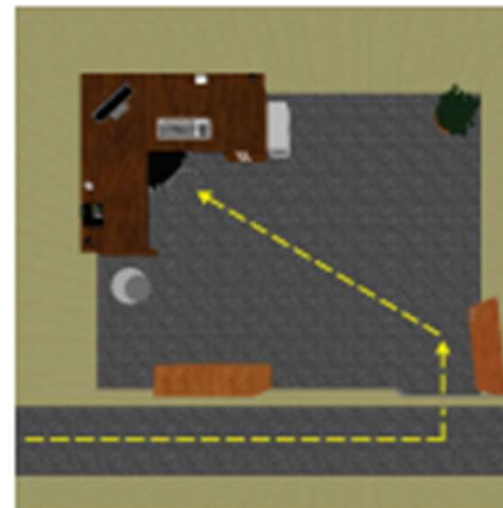
視覚によるリダイレクション Redirected Walking



(a) Before Scene Change



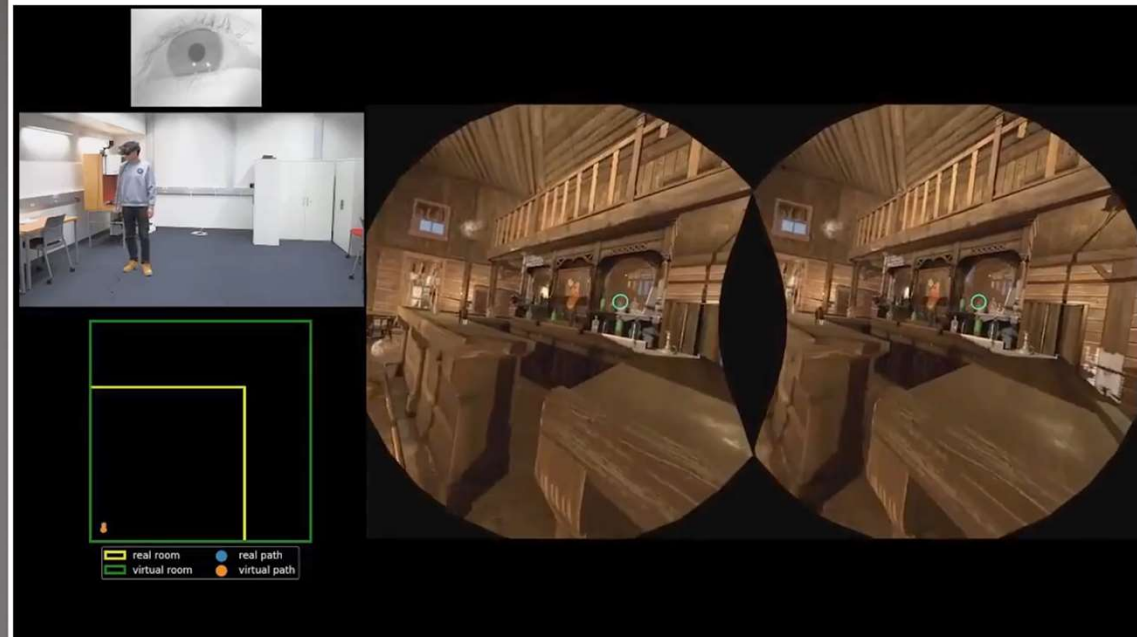
(b) After Scene Change



- Neth.: Velocity-Dependent Dynamic Curvature Gain for Redirected Walking, IEEE-VR2011
 - Suma: Leveraging Change Blindness for Redirection in Virtual Environments, IEEE-VR2011
- HMD画面をこっそり動かして限られた空間を無限歩行空間にする。

眼球計測によるリダイレクションのロバスト化

More robust redirection by eye movement



<https://www.youtube.com/watch?v=BAur1X523wg>
(SIGGRAPH2018) Towards Virtual Reality Infinite Walking: Dynamic Saccadic Redirection, Sun et al.

(IEEEVR2015) Subliminal Reorientation and Repositioning in Immersive Virtual Environments using Saccadic Suppression

- サックード中だけ視点を回転させることで気付かれないようにする
- Rotate the scene during saccadic eye movement.

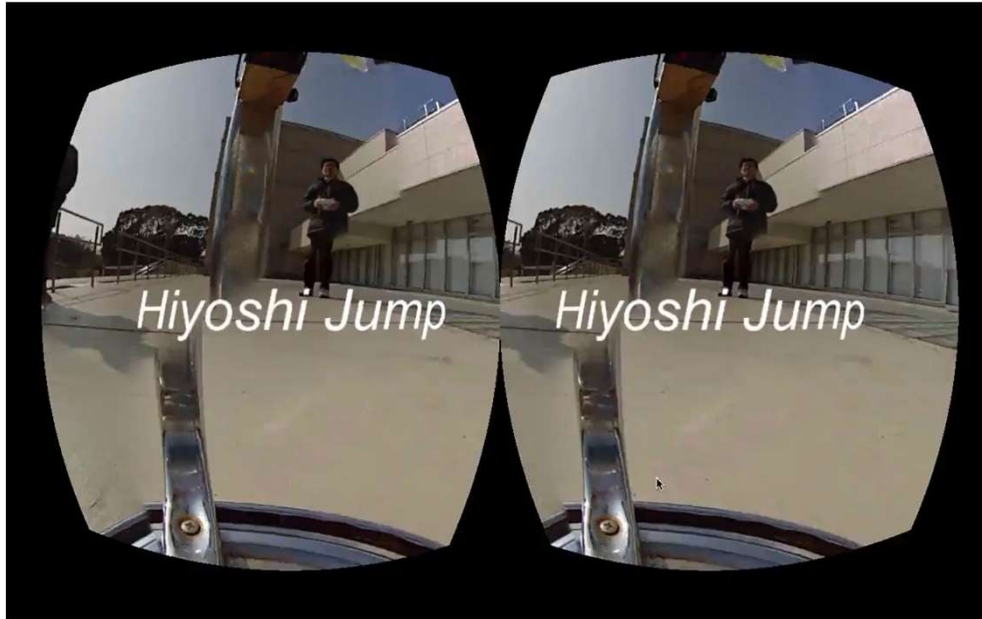


(SIGGRAPH2018) In the Blink of an Eye: Leveraging Blink-Induced Suppression for Imperceptible Position and Orientation Redirection in Virtual Reality
Eike Langbehn Frank Steinicke Markus Lappe Gregory F. Welch Gerd Bruder



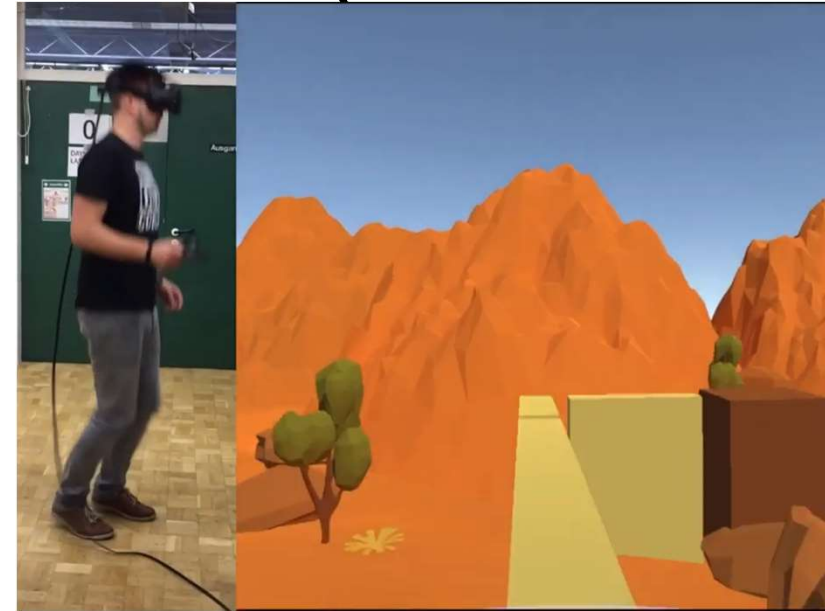
- <https://www.youtube.com/watch?v=d2uxTwCuuoA>
- HMD中に目の開閉センサを内蔵. 瞬きの瞬間に映像を動かす Redirected Walkingの一種 

ジャンプの増強 Enhancement of Jump



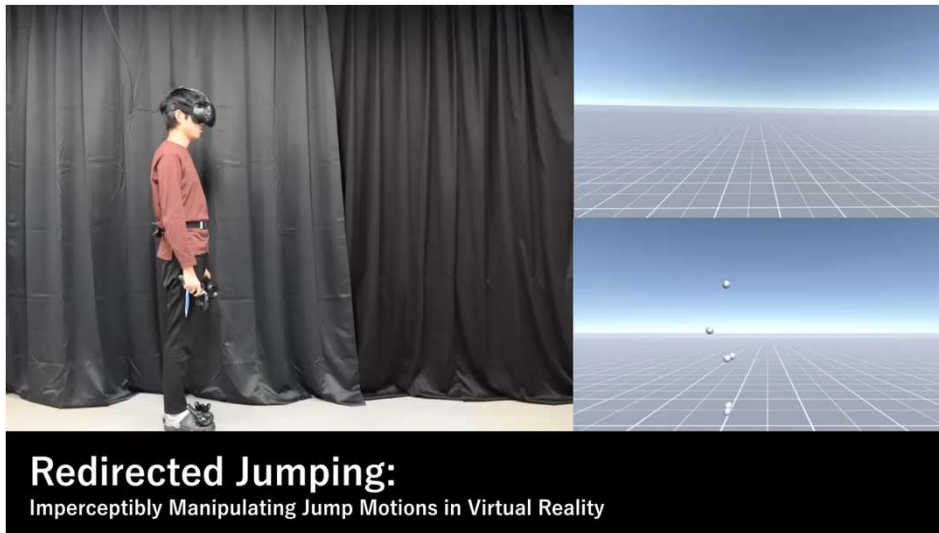
https://www.youtube.com/watch?v=3_u8XXyDarw

Hiyoshi Jump, Ito et al., 2014 ドローン映像とジャンプを同期



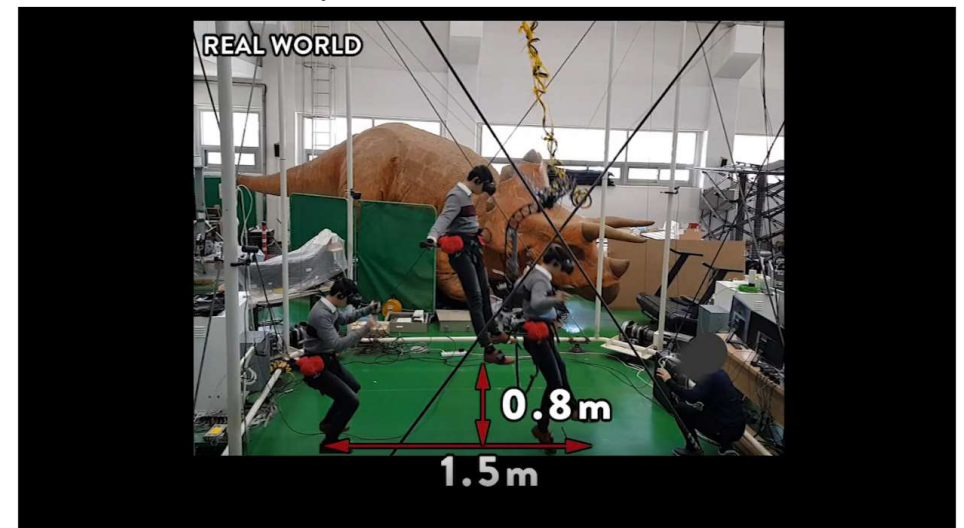
<https://www.youtube.com/watch?v=cWBxh3I5IHg>

(CHI2020) JumpVR: Jump-Based Locomotion Augmentation for Virtual Reality, Wolf et al. VR



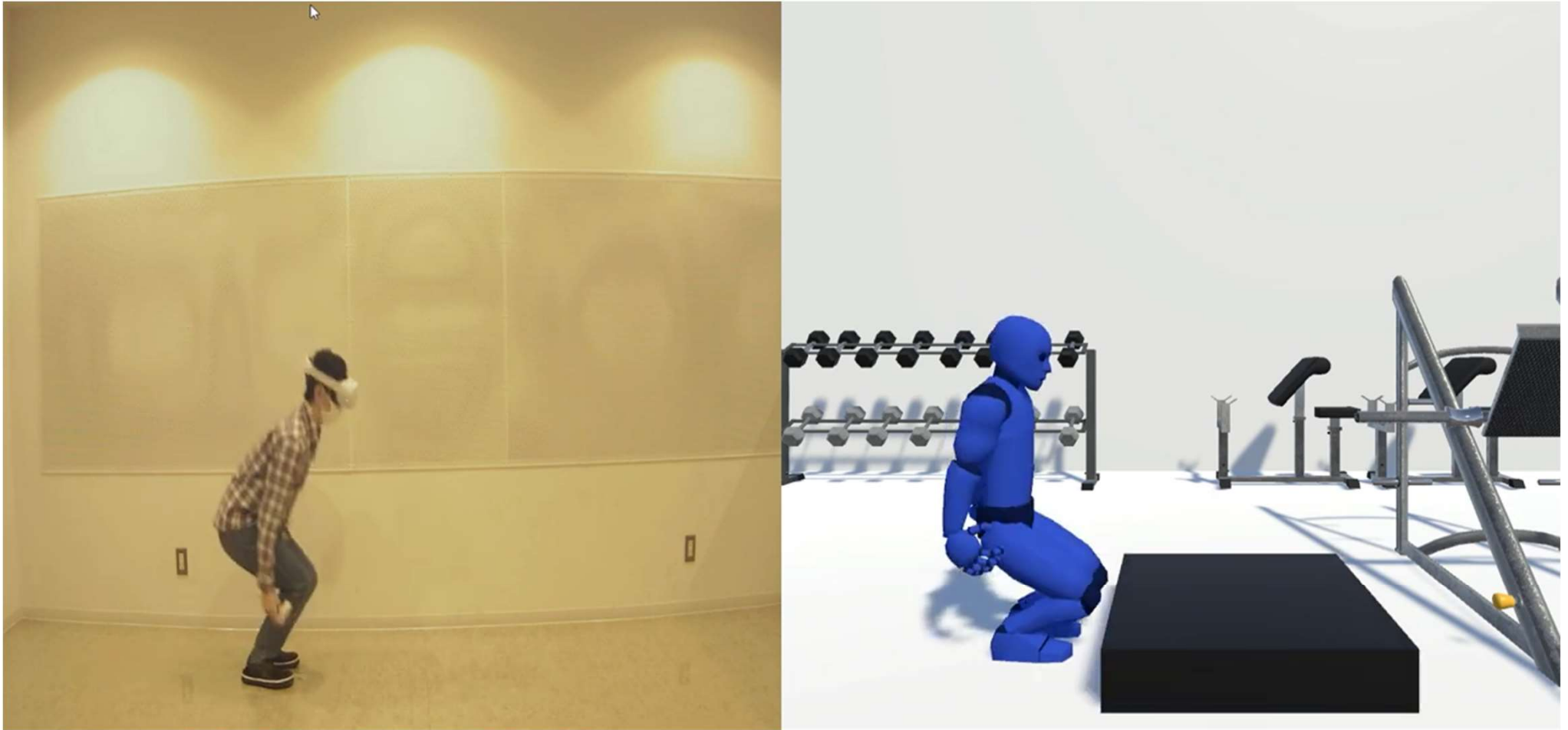
<https://www.youtube.com/watch?v=kR9YI4kdgJI>

(IEEEVR2019) Redirected Jumping: Imperceptibly Manipulating Jump Motions in Virtual Reality, Hayashi et al.



(IEEEVR 2019) Jumping Further: Forward Jumps in a Gravity-reduced Immersive Virtual Environment, Kang et al. ハーネスで身体を持ち上げて月世界ジャンプ。

段差とジャンプ / Jumping onto Steps



We propose PseudoJumpOn, a novel VR locomotion technique that allows the user to experience virtual step-up jumping motion, only using a common VR setup.

PseudoJumpOn: Jumping onto Steps in Virtual Reality, Kumpei Ogawa, Kazuyuki Fujita, Kazuki Takashima, Yoshifumi Kitamura (IEEEVR2022)

<https://www.youtube.com/watch?v=2nppa8iAMzg&list=PLqhXYFYmZ-VeKUIuttbQWomTQ-oXF6PLf&index=43>

(CHI2018) Flotation Simulation in a Cable-driven Virtual Environment – A Study with Parasailing, HyeongYeop Kang, Geonsun Lee, Seongsu Kwon, Ohung Kwon, Seongpil Kim, JungHyun Han



- <https://www.youtube.com/watch?v=HrnVf8emmWE>
- パラセイリング体験.



VR to Fly: Large Space (Univ. Tsukuba)



- <https://www.youtube.com/watch?v=5xkpokHHR-Y>
- 高鳥光, 圓崎祐貴, 矢野博明, 岩田洋夫. “大規模没入ディスプレイ LargeSpaceの開発”. 日本バーチャルリアリティ学会論文誌, 21(3). pp.493-502. 2016.

視覚＋触覚手がかりによる補強

Visual + Haptics feedback for more robust redirection



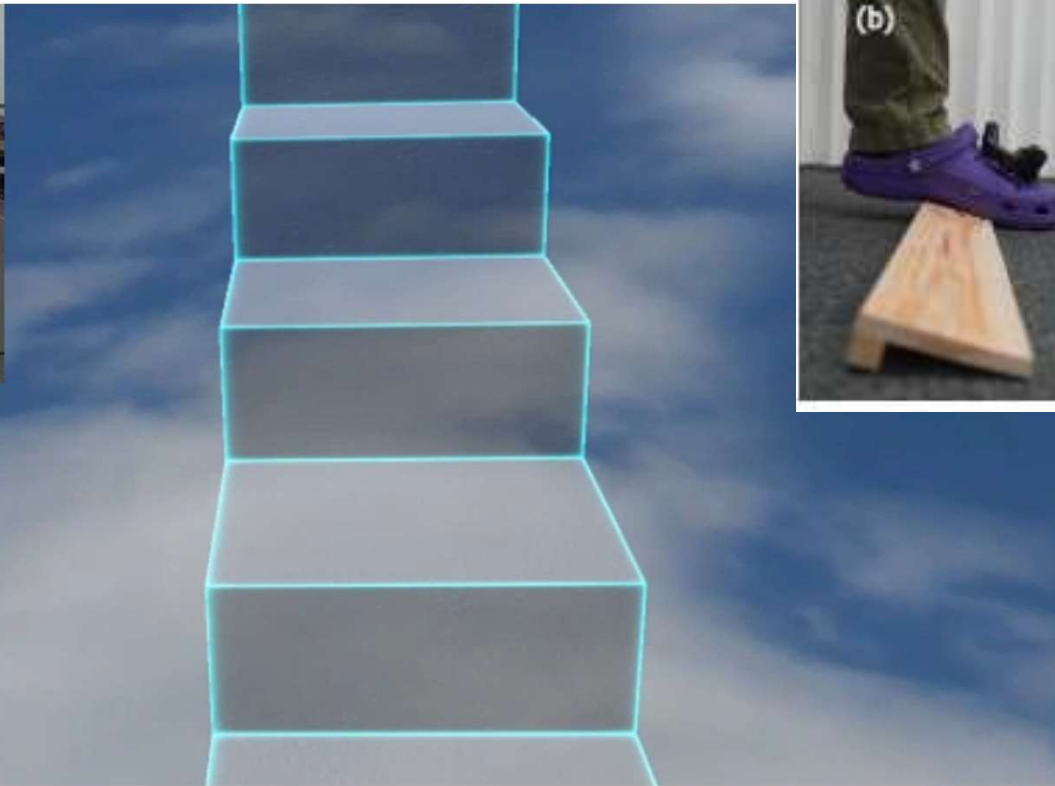
<https://www.youtube.com/watch?v=THk92rev1VA>

Keigo Matsumoto, Yuki Ban, Takuji Narumi, Tomohiro Tanikawa, Michitaka Hirose,
Curvature Manipulation Techniques in Redirection using Haptic Cues, IEEE 3DUI2016



視覚＋触覚手がかりによる補強

Visual + Haptics feedback for more robust redirection



This paper presents a novel interactive system that provides users with virtual reality (VR) experiences, wherein users feel as if they are ascending/descending stairs through passive haptic feedback.

<https://www.youtube.com/watch?v=cWBxh3I5IHg>

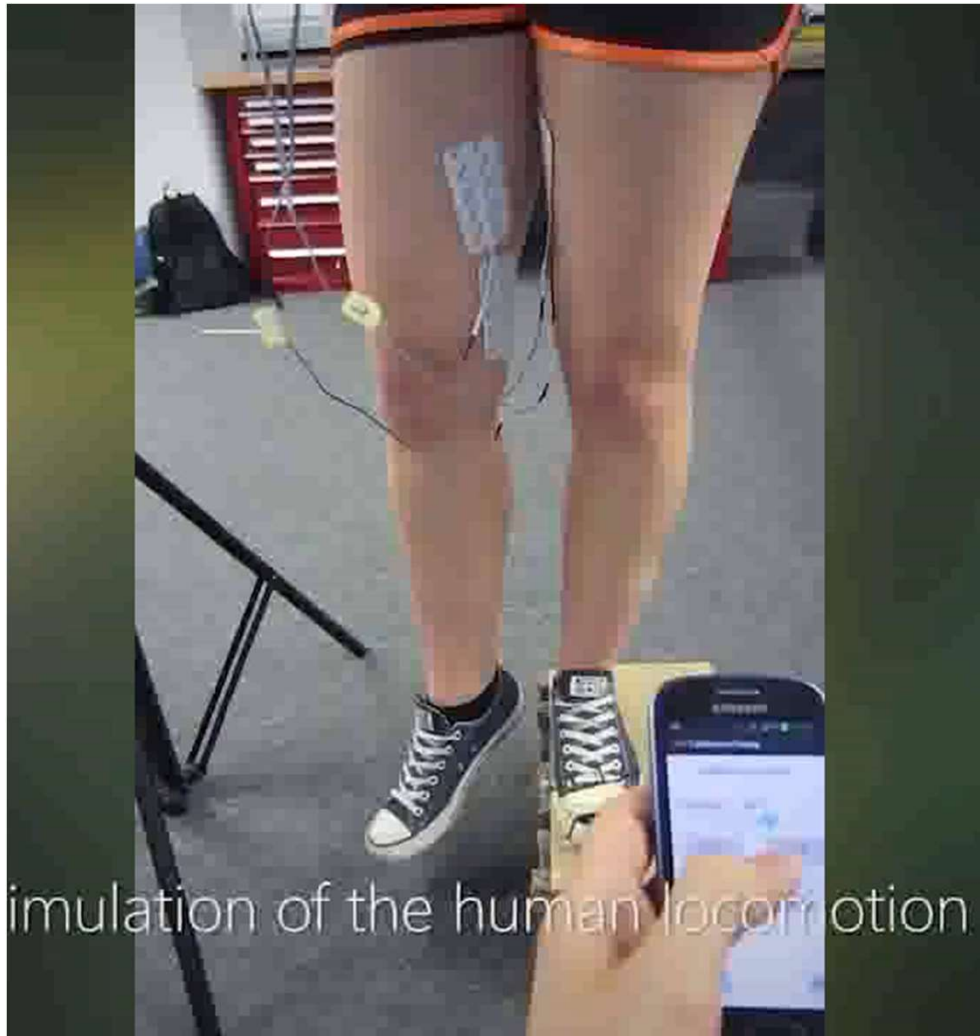
(IEEEVR2018) Ascending and Descending in Virtual Reality: Simple and Safe System using Passive Haptics, Ryohei Nagao, Keigo Matsumoto, Takuji Narumi, Tomohiro Tanikawa, Michitaka Hirose

- 階段のかわりに階段のエッジだけを用意。映像と組み合わせて上昇下降を知覚。
- The edge of the stairs are prepared to present up and down stairs.



筋電気刺激による歩行誘導

Walk control by electrical muscle stimulation



imulation of the human locomotion

<https://www.youtube.com/watch?v=CszCx40tli8>

(CHI2015) Cruise Control for Pedestrians:
Controlling Walking Direction Using Electrical
Muscle Stimulation, Pfeiffer et al.

実世界での歩行ナビゲーション用途



tuates the users in a way that they move
d while still walking straightforward in vir

<https://www.youtube.com/watch?v=q6tTFzSJHTM>

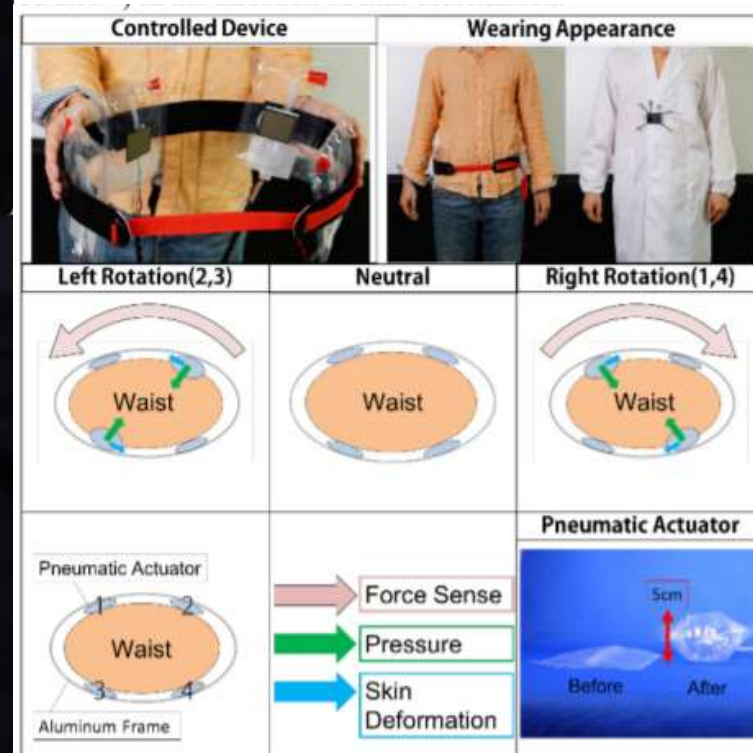
(CHI2019) Around the (Virtual) World: Infinite Walking in
Virtual Reality Using Electrical Muscle Stimulation, Auda
et al.

VRでのリダイレクション用途



腰部ハンガー反射による歩行制御

Walking navigation by waist-type hanger reflex



https://www.youtube.com/watch?v=7_LpCgLUu0Y

Yuki Kon, Takuto Nakamura, Hiroyuki Kajimoto: HangerON: A Belt-type Human Walking Controller Using the Hanger Reflex Haptic Illusion, ACM SIGGRAPH 2017 Emerging Technologies



Pulling ears

Y. Kojima, Y. Hashimoto, H. Kajimoto, "Pull-Navi," Emerging Technologies Session, ACM SIGGRAPH, 2009.



歩行感覚の再現

How to present “Walking” Sensation?

- 足踏み、パッシブ / Footstep, Passive
- 歩行制御 / Redirection
- **トレッドミル / Treadmill**
- 装着型 / Wearable
- 応用例 / Application



最近の詳細な分類は例えばこちら: Nilsson et al. Natural Walking in Virtual Reality, Computers in Entertainment 16(2):1-22 · April 2018

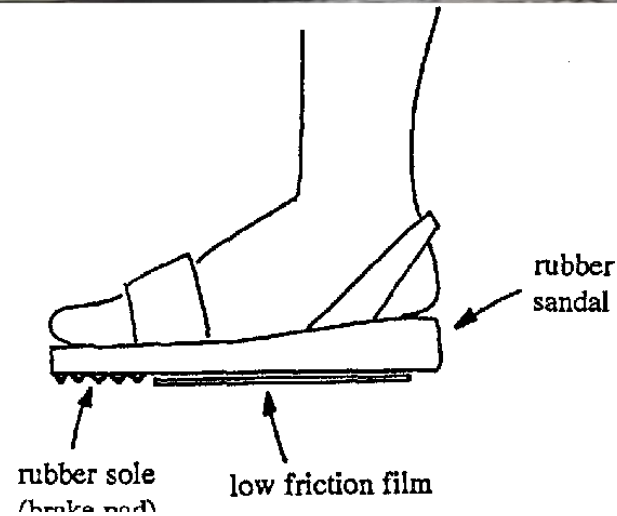
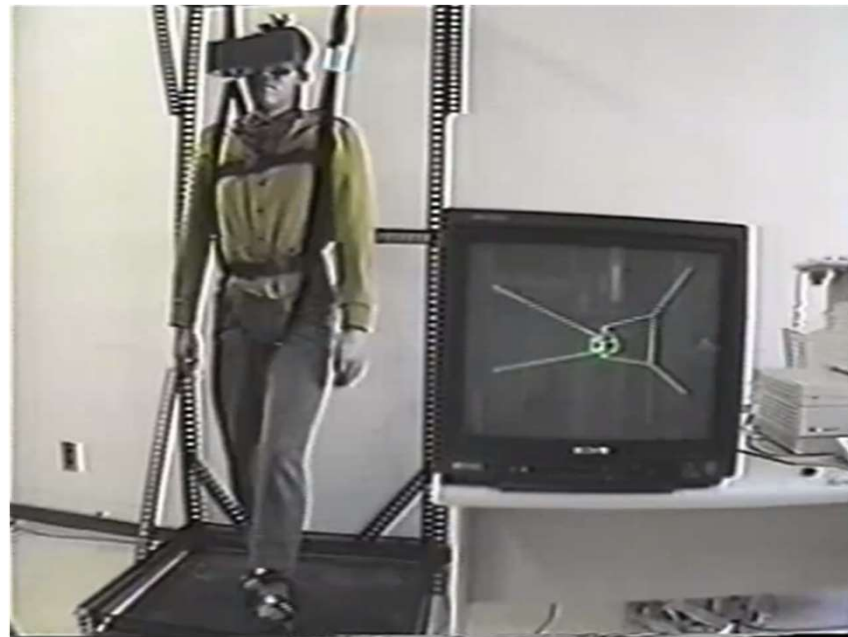
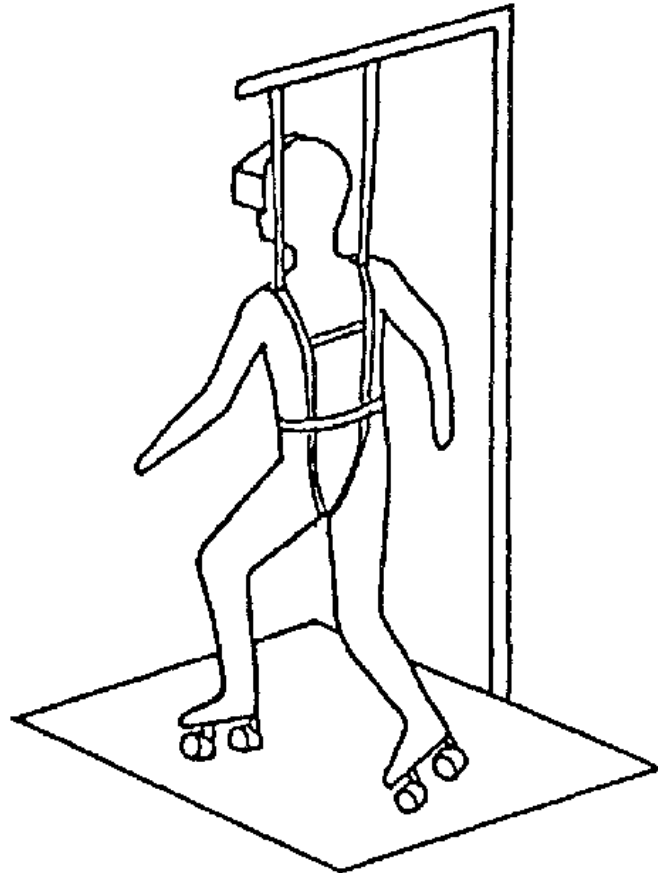
トレッドミル／Treadmill Type



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

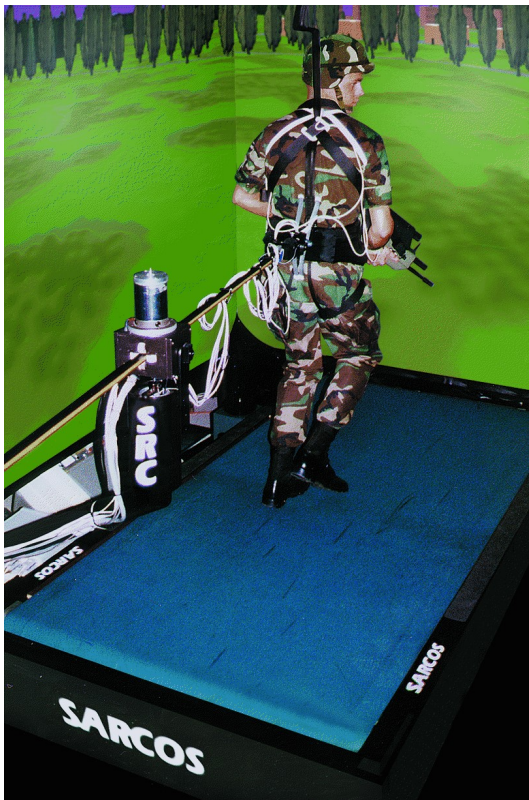
The belt is controlled so that user's position is kept (almost) constant. 

Virtual Perambulator (1989)



キャスターを使ったローラースケート+パラシュートのようなハーネス
Hiroo Iwata, Takashi Fujii, Virtual perambulator: a novel interface device for locomotion
in virtual environment (1996)

1次元トレッドミル / Linear Treadmill Devices

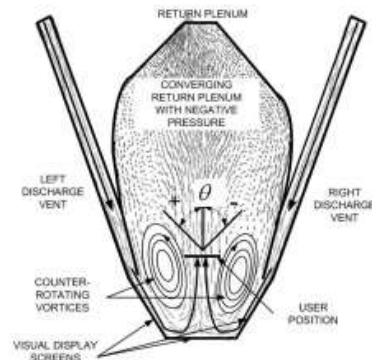


Sarcos Treadport

(ASME DSC2000) Design specifications for the second generation Sarcos Treadport locomotion interface," Haptics Symposium, Hollerbach et al.

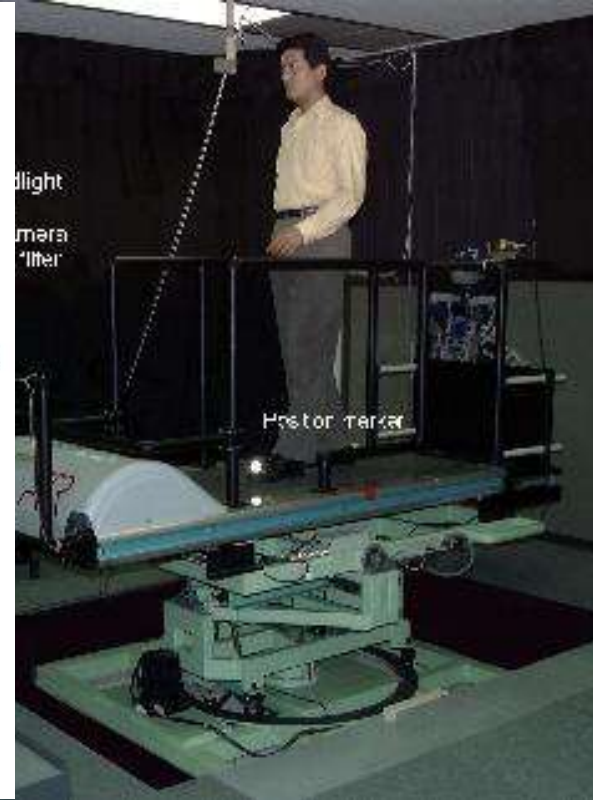


Figure 1 Treadport Virtual Environment comprising a CAVE-like visual display and locomotion interface



Wind Display

(World Haptics Conference 2009) Wind display device for locomotion interface in a virtual environment," Kulkarni et al.



ATR ATLAS

ASME-DSC(1998) Design for Locomotion Interface in a Large Scale Virtual Environment, ATLAS: ATR Locomotion Interface for Active Self Motion", Noma et al.

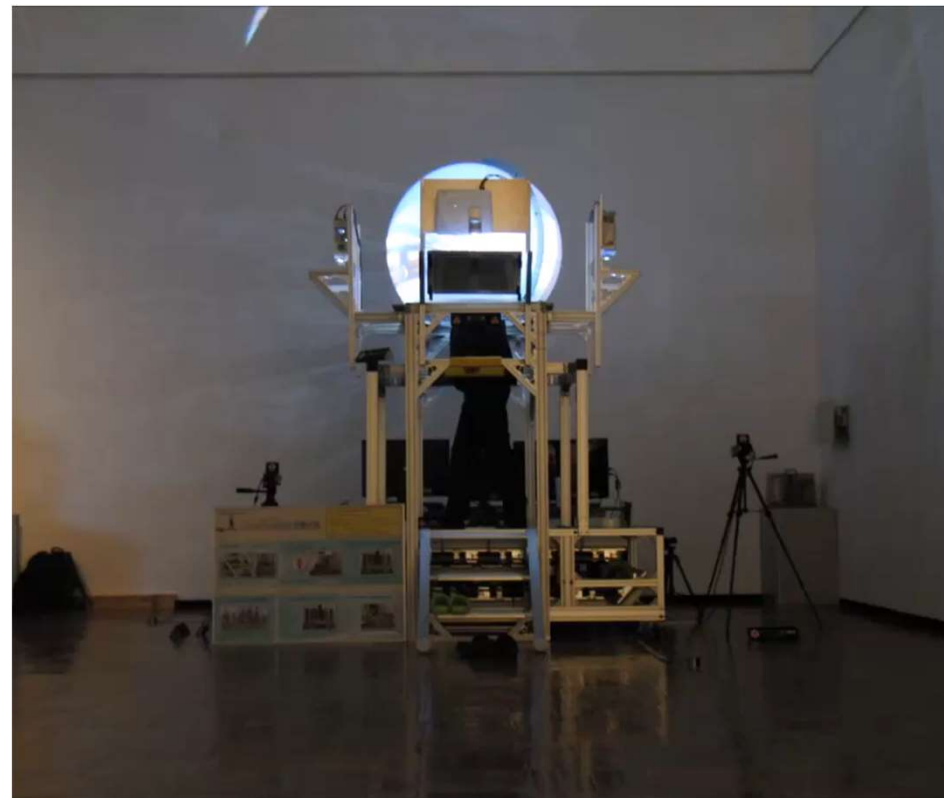


ATR GSS

(IEEEVR2000) Development of Ground Surface Simulator for Tel-E-Merge system, Noma et al.



2次元の動きを実現する: Torus Treadmill

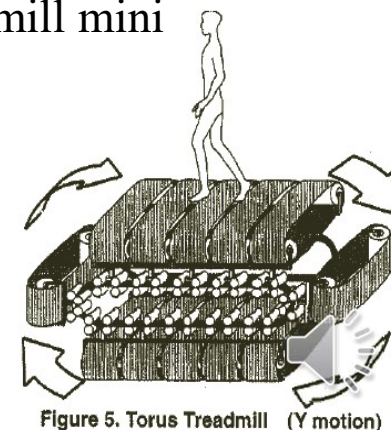
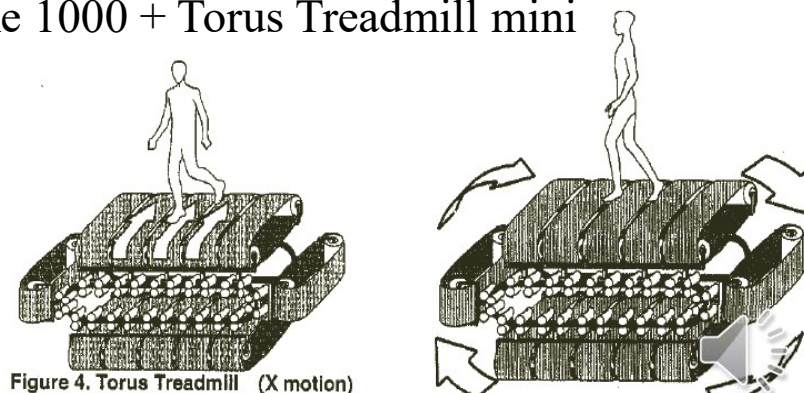


Hiroo Iwata : Walking about Virtual Environments on an Infinite Floor , IEEE'99

<https://www.youtube.com/watch?v=K-v2MiKuvpw>

Rear Dome 1000 + Torus Treadmill mini

トーラス構造のトレッドミル群
Treadmills with torus structure.



Other 2D treadmills



<http://www.vsd.bz>

Virtual Space Devices Inc.,

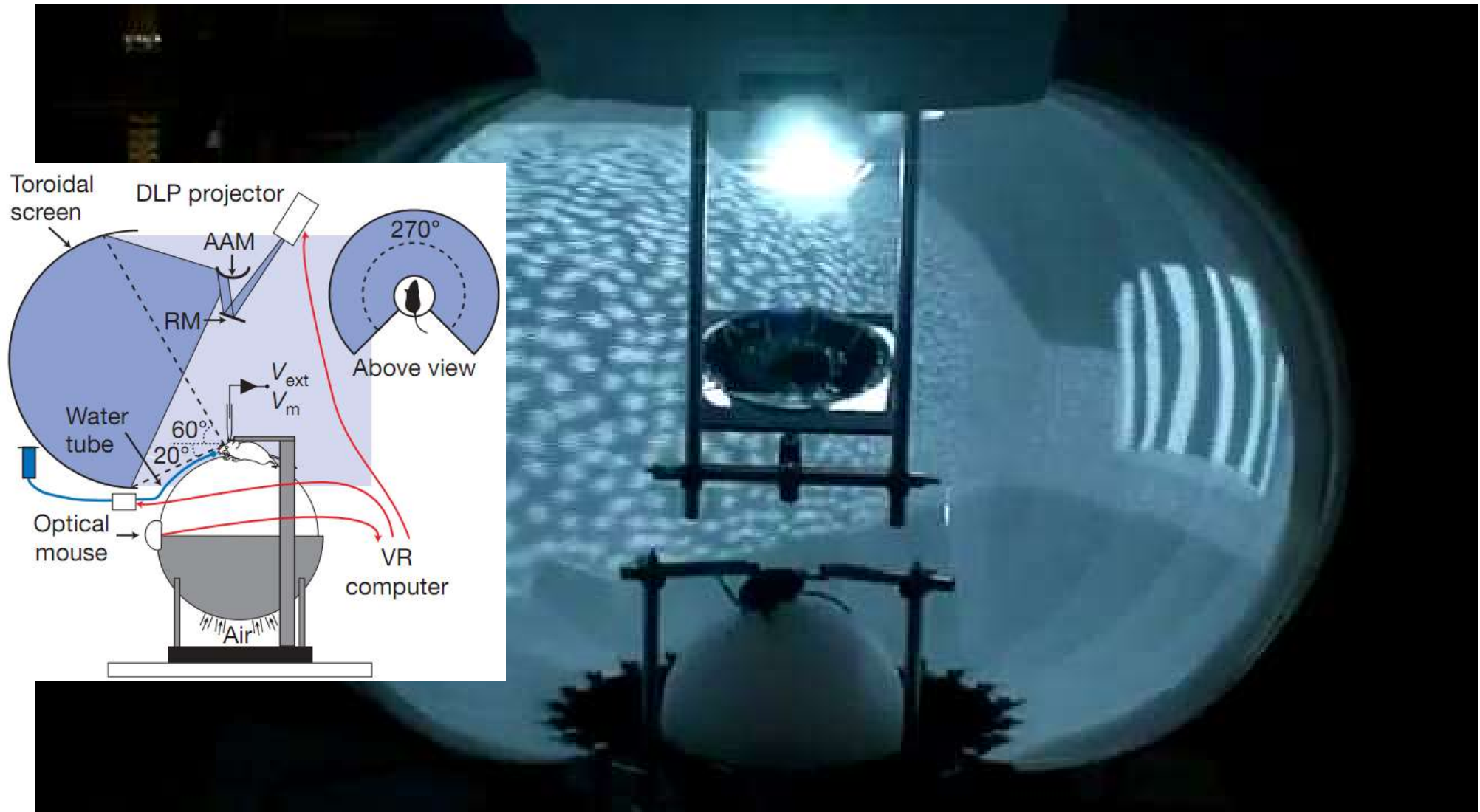


<https://www.youtube.com/watch?v=foHmSC-MeGA>

Infinadeck(2018)



参考：マウス迷路課題実験のためのVR環境 VR environment for mouse maze task



<http://www.youtube.com/watch?v=1DJOTEDBA2c>

Intracellular dynamics of hippocampal place cells during virtual navigation

Harvey, Collman, Dombeck, Tank, Nature 2009.



滑れば良い？ Virtuix Omni (2013)



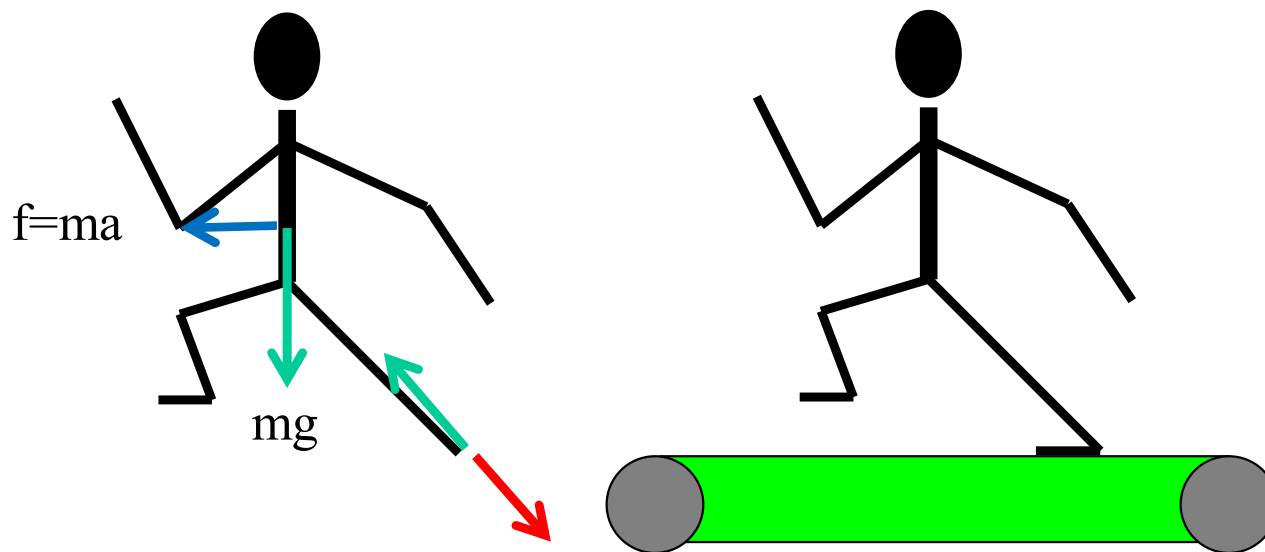
<http://www.youtube.com/watch?v=5QpLUKGDFVM>


- 中央が凹んだ床 + 滑る靴
- 腰を固定、HMDと併用、ゲーム向けに有望視



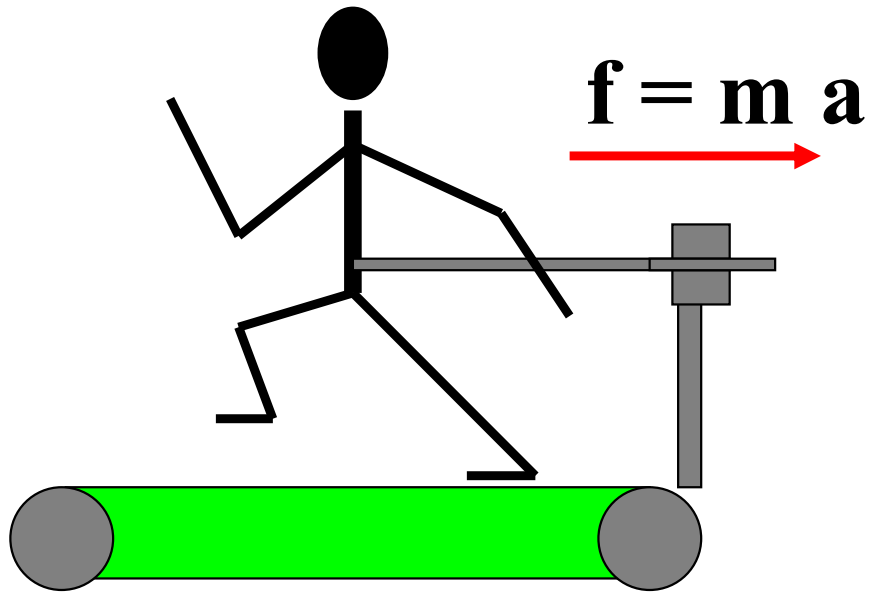
通常の床と「滑る床」の違い

Difference between normal floor and treadmill



- 通常: キック力の反作用 + 重力 \Rightarrow 推進力.
Driving force = Repulsive Force of Kick + Gravity Force
- トレッドミル: 推進力による仕事になされない. 氷上に近い?
Treadmil: No work by driving force.
- 通常の解決: なるべく大きなトレッドミルを使い, 加速を抑える.
Ordinary solution: Use large treadmill and keep acceleration small. 

TreadPort (Hollobach et al. Univ. of Utah)



牽引力により適切な仕事をさせ、トレッドミルの違和感を解決

Pulling force generates appropriate work, solving strangeness of treadmill.

Vijayakar, A., and Hollerbach, J.M., "Effect of turning strategy on maneuvering ability using the Treadport locomotion interface," *Presence: Teleoperators and Virtual Environments*, 11 no. 3, 2002, pp. 247-258.



床面の振動によるテクスチャ触感 Floor “Texture” and Tactile Display



<http://www.youtube.com/watch?v=AsKBigMD7fg>

床タイルに振動子(大型スピーカ)と, 四隅に圧力センサを敷設.
足を付いた瞬間の触覚(雪, 氷, 砂, etc)を再現.

Large vibrator and four pressure sensors are under each floor tile.

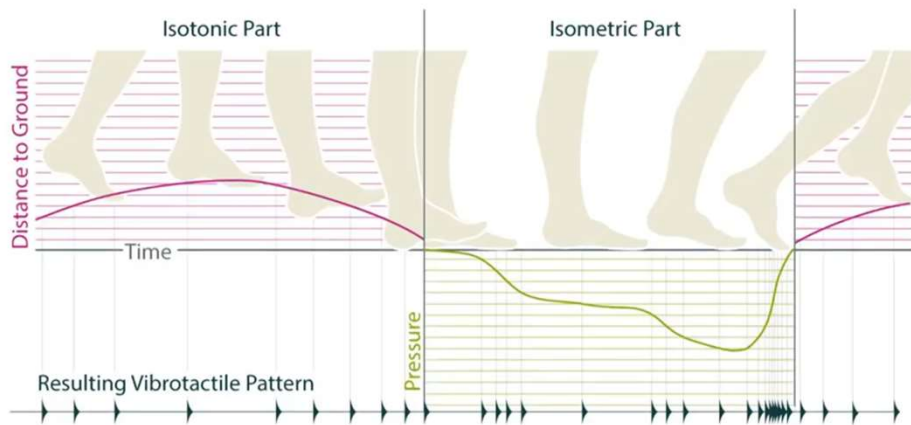
Tactile sensation at the instance of foot-floor contact is reproduced.

Y. Visell, A. Law, J. Cooperstock, Touch is Everywhere: Floor Surfaces as Ambient Haptic Interfaces. IEEE Trans on Haptics, 2 (3), 2009.



床面の振動によるテクスチャ触感 Floor “Texture” and Tactile Display

bARefoot provides **quick vibrations pulses (grains)**
based on the user input to create **virtual material experiences**



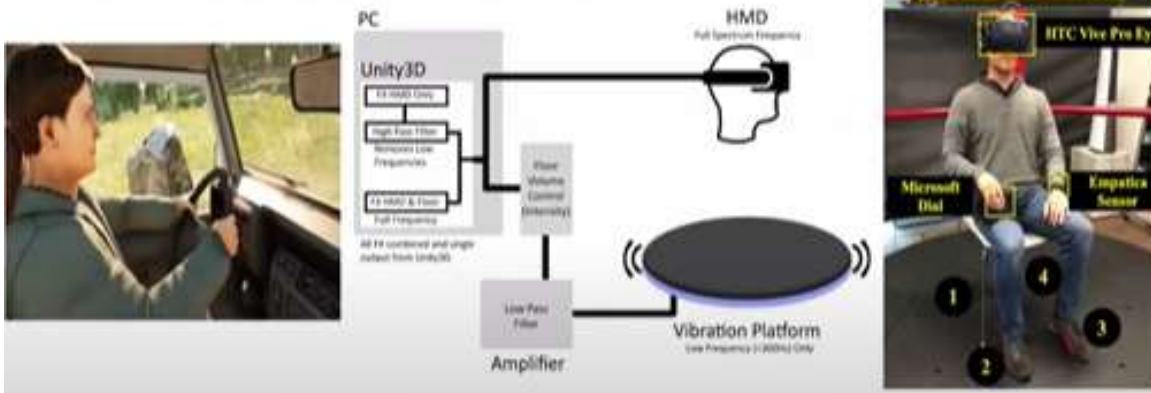
(UIST2020) HERMITS: Dynamically Reconfiguring the Interactivity of Self-propelled TUIs with Mechanical Shell Add-ons
Ken Nakagaki, Joanne Leong, Jordan L Tappa, Joao Wilbert, Hiroshi Ishii

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

足裏振動提示で地面のテクスチャ表現

Experimental Platform

- o Intel core i7 CPU with an NVIDIA GeForce RTX 2080 GPU and 32GB of RAM
- o HTC Vive Pro Eye, 1080 x 1200, 90 Hz, and 110 degrees



(IEEEVR2021) Sungchul Jung, Richard Chen Li, Ryan Douglas McKee, Mary C. Whitton, Robert W. Lindeman
Floor-vibration VR: Mitigating Cybersickness Using Whole-body Tactile Stimuli in Highly Realistic Vehicle Driving Experiences

<https://youtu.be/ktb20KDP8Xs?t=4595>

VRドライビングをしたときに床も振動させるとVR酔いが減る



(CHI2021) Elevate: A Walkable Pin-Array for Large Shape-Changing Terrains

Seungwoo Je, Hyunseung Lim, Kongpyung Moon, Shan-Yuan Teng, Jas Brooks, Pedro Lopes, Andrea Bianchi



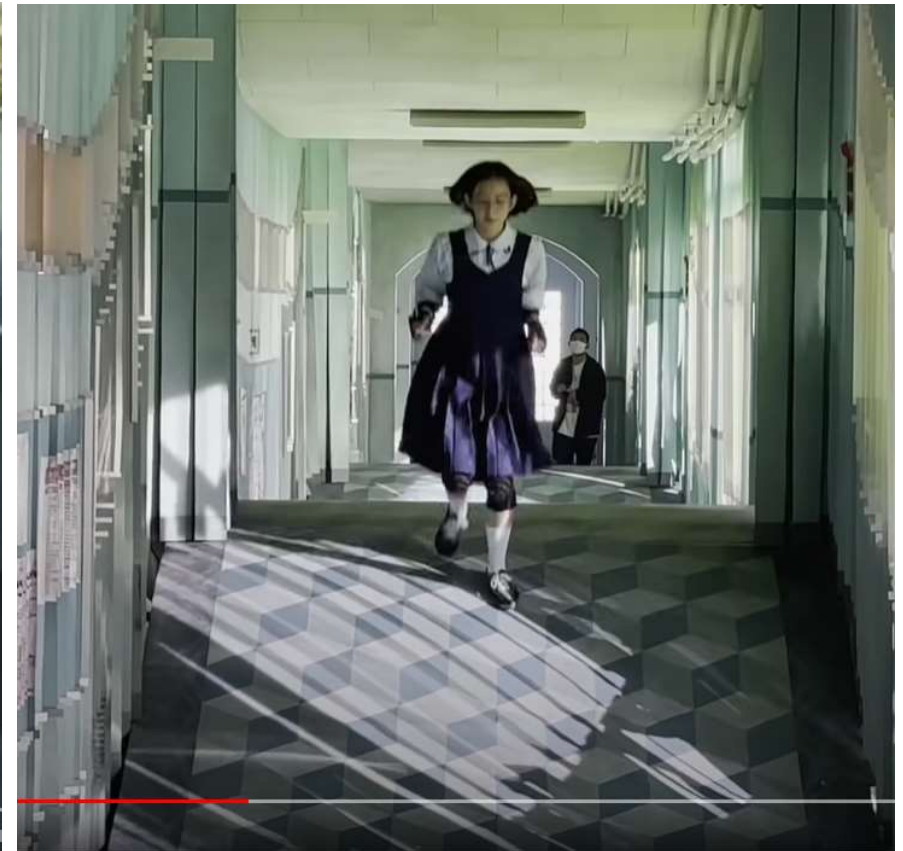
<https://www.youtube.com/watch?v=R1NzSW3MdPw>

- ピンマトリクスで凸凹の地面を表現
- Pin matrix to represent uneven ground.



ポカリスエットCMにみる動く床(2021)

Floor Really Moves



<https://www.youtube.com/watch?v=gn5lk6isyGc>

<https://www.youtube.com/watch?v=tzSGgGm7kjY>

床が細かいパーツに分かれて上下運動.

Large vibrator and four pressure sensors are under each floor tile.

Tactile sensation at the instance of foot-floor contact is reproduced.







歩行感覚の再現

How to present “Walking” Sensation?

- 足踏み、パッシブ / Footstep, Passive
- 歩行制御 / Redirection
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- **装着型 / Wearable**
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最近の詳細な分類は例えばこちら: Nilsson et al. Natural Walking in Virtual Reality, Computers in Entertainment 16(2):1-22 · April 2018

フットパッド／Foot-Pad type



Iwata: Gait Master

Sarcos: Biport



- 各足が平行リンク機構の上に乗る
Each foot is mounted on parallel link platform.

Iwata et al., "Gait Master: A Versatile Locomotion Interface for Uneven Virtual Terrain" IEEE-VR2001.



靴底 Sole

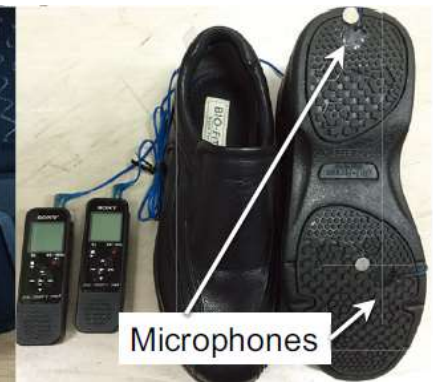
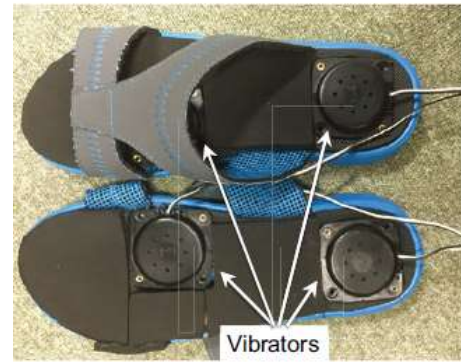
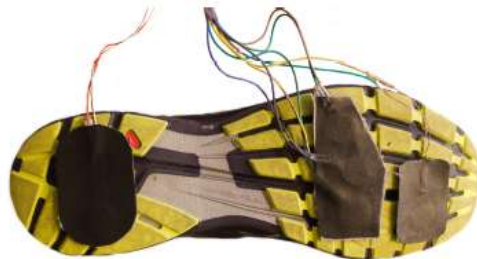
VRsneaky: Increasing Presence in VR Through Gait-Aware Auditory Feedback



Matthias Hoppe¹, Jakob Karolus¹, Felix Dietz¹, Paweł W. Woźniak², Albrecht Schmidt¹, Tonja Machulla¹

¹ LMU Munich, Munich, Germany. {firstname.lastname}@ifi.lmu.de

² University Utrecht, Utrecht, the Netherlands. p.w.wozniak@uu.nl



https://www.youtube.com/watch?v=f_axV2ZFJkc

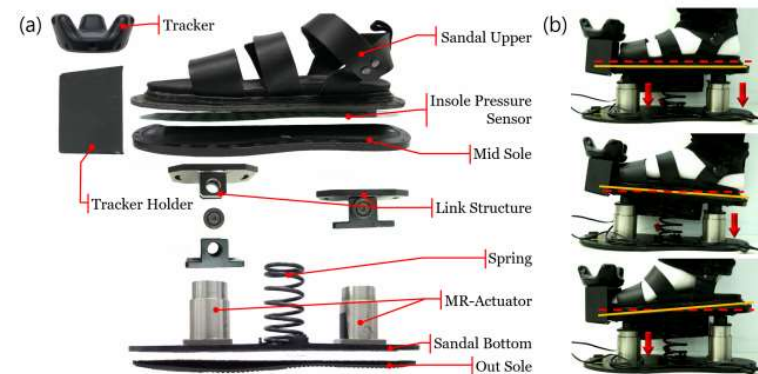
(CHI2019) VRsneaky: Increasing Presence in VR Through Gait-Aware Auditory Feedback, Matthias Hoppe, Jakob Karolus, Felix Dietz, Paweł W. Woźniak, Albrecht Schmidt, Tonja-Katrin Machulla

VR空間中の足音を、歩様によって変化させることでより臨場感が高まる。歩様は足裏センサで取得

Rhythmic Vibrations to Heels and Forefeet to Produce Virtual Walking IEEEVR2016
Ryota Kondo, Keisuke Goto, Katsuya Yoshiho, Yasushi Ikei, Koichi Hirota, Michiteru Kitazaki

歩行時の映像と足裏振動を記録しておき、再生時に両方共出すと臨場感等が向上する。

靴底を動かす Move soles



<http://www.youtube.com/watch?v=zzRw0nA0mho>

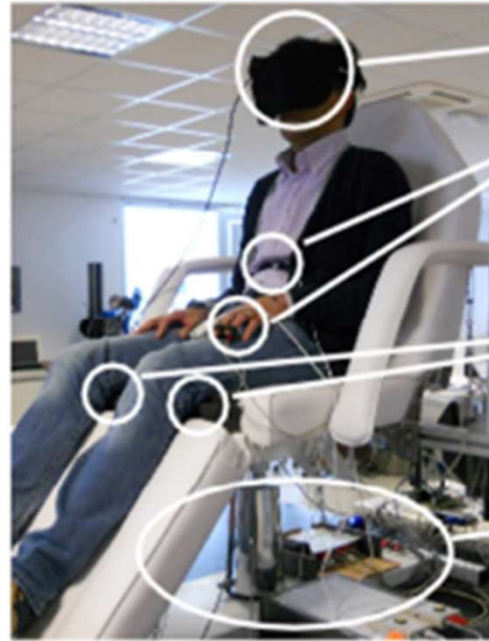
靴底の傾きを制御し、自然な歩行ナビゲーションを実現 Natural Walking navigation by controlling tilt of shoe sole. Martin Frey, “CabBoots” 2005 Ars Electronica

(WorldHaptics2019) RealWalk: Haptic Shoes Using Actuated MR Fluid for Walking in VR, Hyunki Son, Inwook Hwang, Tae-Heon Yang, Seungmoon Choi, Sang-Youn Kim, Jin Ryong Kim

MRブレーキを使って色々な高さを表現できる靴



運動錯覚の利用 Application of Kinesthesia



Head Mounted Display
(Virtual Scenario)

Bio-signals acquisition
(GSR, SpO₂, Heart Rate, Respiration)

Proprioceptive stimulation
(actuators placed under the knee joints)

Mobile Platform
(body angular velocities and accelerations)

D. Leonardis, A. Frisoli, M. Barsotti, M. Carrozzino, and M. Bergamasco: Multisensory Feedback Can Enhance Embodiment Within an Enriched Virtual Walking Scenario. *Presence*, 23(3) 253-266 (2014)

視覚と足の運動錯覚の組み合わせによる歩行感覚を実現

Realization of the sensation of walking through a combination of visual and foot Kinesthetic illusions



E. Narita et al.: Manipulation of Body Sway Interpretation through Kinesthetic Illusion Induced by Ankles Vibration. *World Haptics Conference* (2023)

足首の前後に振動子を装着し、前→後→前→後…と刺激する。切り替え周波数が遅いと自分自身の揺れに感じ、5Hzよりも早くなると環境（地面）の揺れに解釈される。

The vibrators are attached to the front and back of the ankle. The interpretation of “body sway” and “ground sway” is strongly affected by switching frequency.

歩行感覚の再現

How to present “Walking” Sensation?

- 足踏み、パッシブ / Footstep, Passive
- 歩行制御 / Redirection
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- 装着型 / Wearable
- 応用例 / Application



最近の詳細な分類は例えばこちら: Nilsson et al. Natural Walking in Virtual Reality, Computers in Entertainment 16(2):1-22 · April 2018

スキーシミュレータ／Ski Simulator



- ある特定の用途に限定すると移動感覚インタフェースの設計が明確となる好例.

Good example of locomotion interface for particular situation.

- スキーは市場も大きい⇒シミュレータは既に商品化
Market is large, so simulator is already commercialized.
- 移動感覚インタフェースの大体の方式が試されている.
Most types of locomotion interface was utilized.



パッシブ+振動

Passive input & Vibration



SKIGYM



Endlesslope



<http://www.youtube.com/watch?v=QUQgtRD7tk8&NR=1>

- 傾いたトレッドミルによるスキートレーナー
- Ski Trainer with sloped treadmill



SkyTec Interactive Simulator

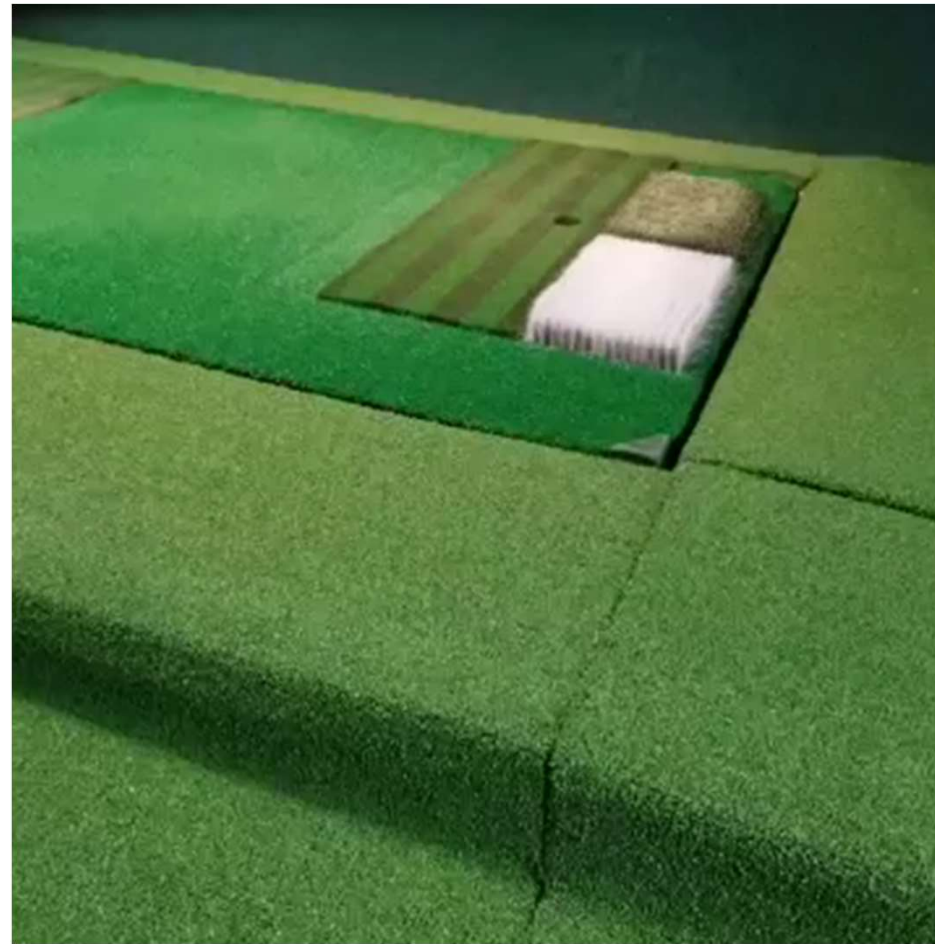


<https://www.youtube.com/watch?v=0TuF-RqBhWs>

- 上下回転以外の傾きを両足それぞれ再現
- 正確な物理シミュレーションによる板の挙動再現
- All tilts except pan is represented to each foot.
- Accurate physical simulation



ゴルフシミュレータ / Golf Simulator



<https://www.youtube.com/watch?v=yjM5nmaJOwg>

<https://www.youtube.com/watch?v=9tJF4dUE9Ng>

- ある特定の用途に限定するとVRシステムの設計が明確となる好例。
Good example of VR system for specific situation.
- ゴルフは市場も大きい⇒シミュレータは既に商品化
Market is large, so the simulator is already commercialized.
- ボールの速度, 方向, 回転の計測. 床面のテクスチャと傾き再現まで
- Ball velocity, direction, rotation measurement. Floor inclination and texture are also represented.

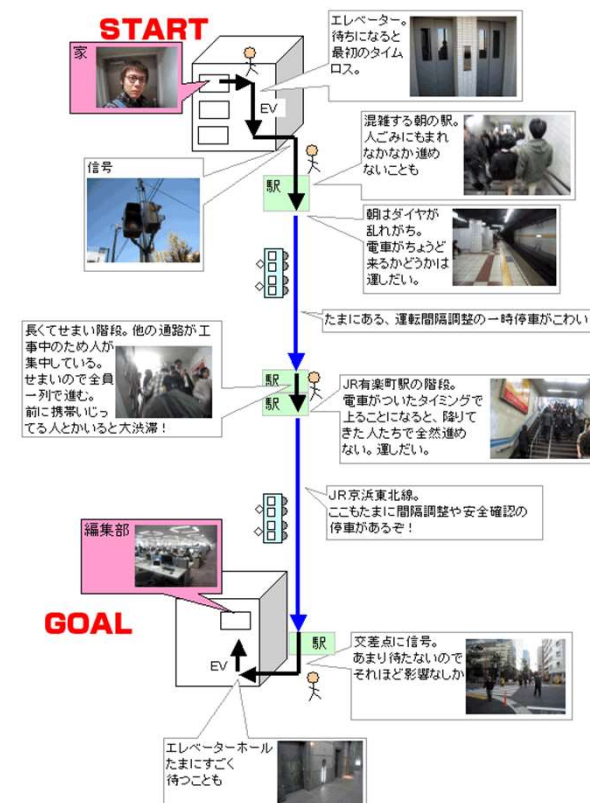


歩行、走行の「パートナー」を提示する Display “partner” for walking/running



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

(IEEEVR2022) Solitary Jogging with A Virtual Runner using Smartglasses, Takeo Hamada, Ari Hautasaari, Michiteru Kitazaki, Noboru Koshizuka
バーチャルパートナーと一緒にランニング。
Running with a virtual partner, using AR.



デイリーポータルZ「通勤タイムアタック」
<https://dailyportalz.jp/kiji/commuting-time-attack>

TODAY's TOPIC

1. 移動感覚のメカニズム Locomotive perception mechanism
2. 歩行感覚提示 How to present Walking sensation?
3. 搭乗感覚提示 How to present Riding sensation?
4. 巨大化を避ける試み Why are they so HUGE?



乗り物用移動感覚インタフェース

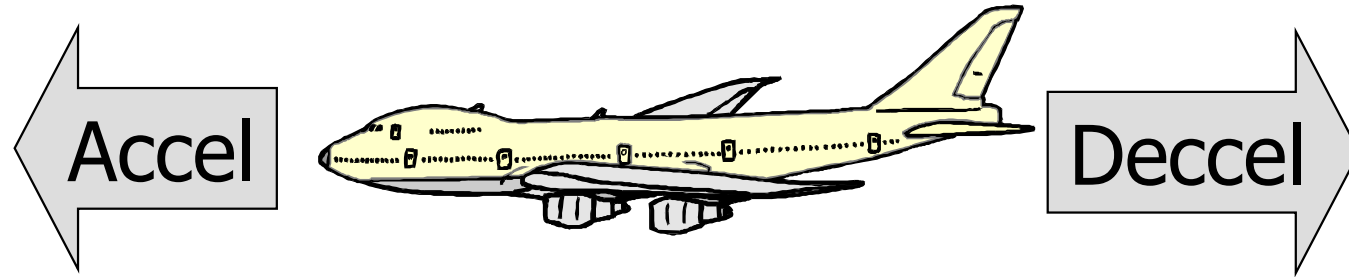
Locomotion Interface for riding situation



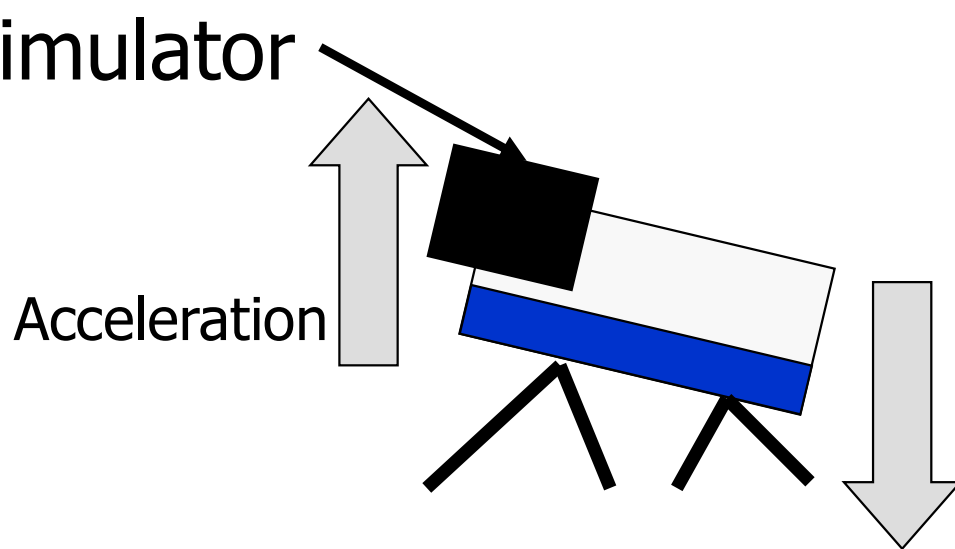
- 足の触覚は不要. Foot sensation is no longer necessary.
- 速度:視覚的に提示. Velocity is presented by optical flow.
- 加速度をいかに提示するかが鍵
Presentation of “acceleration” is the key point.



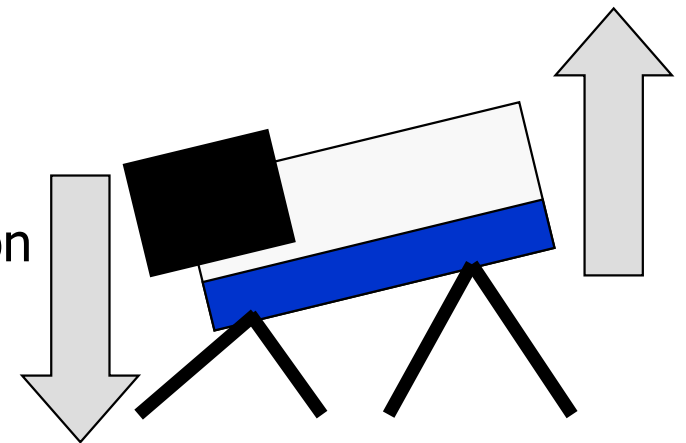
重力を利用する / Utilize Gravity



Simulator



deceleration

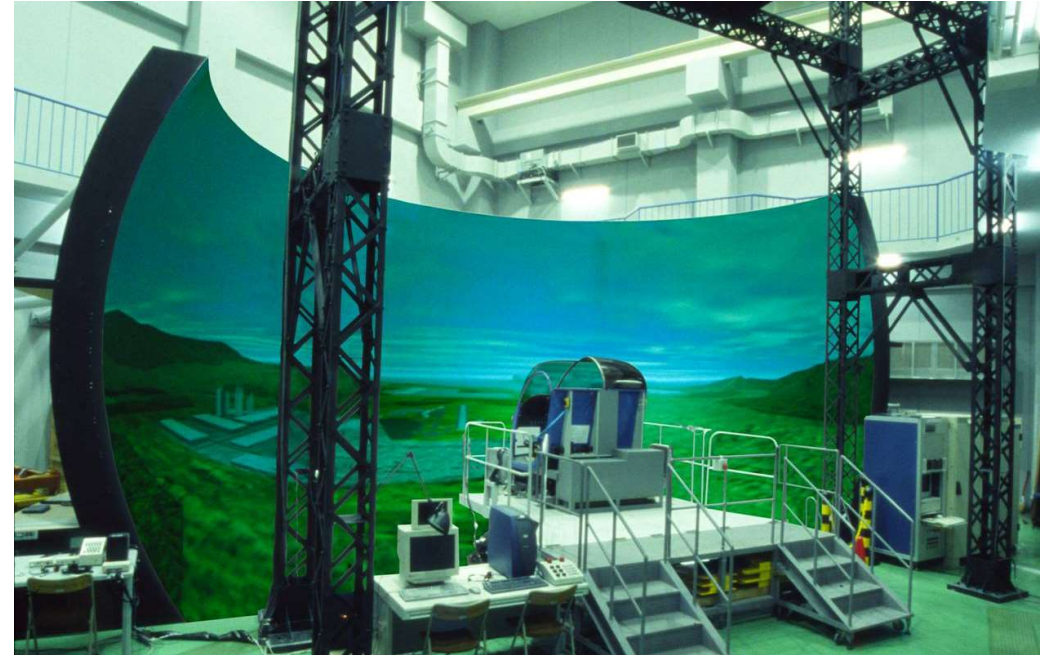


Incline the simulator, so that part of gravity can be felt as acceleration. 

訓練用シミュレータ Simulator for training



油圧6軸(10t)



電動6軸(1.5t)

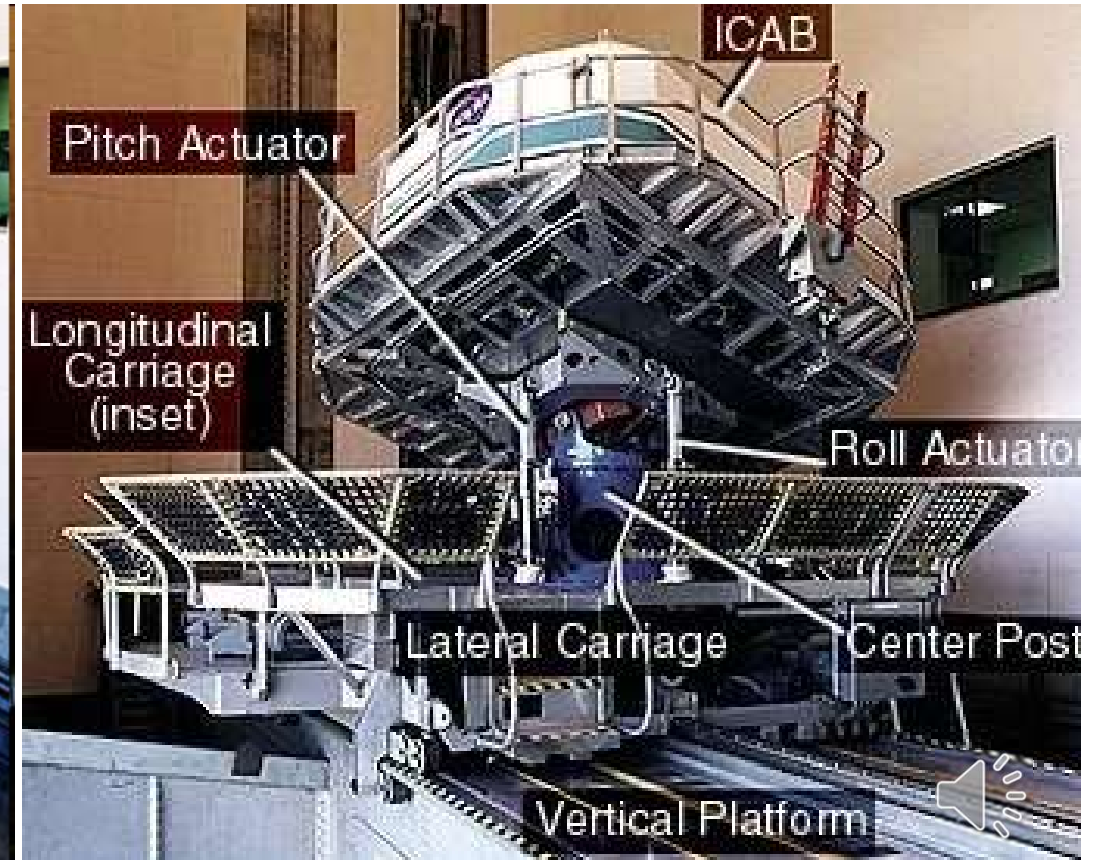
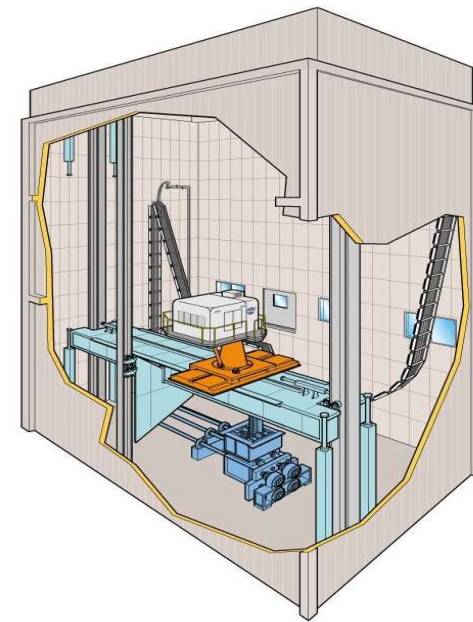
FSCAT(JAXA)

操縦系も含めて駆動するため、大型化. パラレルリンクを用いる.
To drive cockpit, huge power is required. Parallel link actuators are used.



VMS (NASA)

- 20x21m
- $1G \pm 0.75G$



トヨタのシミュレータ



http://www2.toyota.co.jp/jp/tech/safety/concept/driving_simu.html

直径7.1mのドーム内に実写を設置

ドーム内に360度球面スクリーン

ドームは縦35m・横20mの範囲を移動

走行時の速度感、加減速感、乗り心地を忠実に模擬



(IEEEVR2021) Guillaume Vailland, Louise Devigne, Francois Pasteau, Florian Nouviale, Bastien Fraudet,, Emilie Leblong, Marie Babel, Valérie Gouranton
VR based Power Wheelchair Simulator: Usability Evaluation through a Clinically Validated Task with Regular Users



Figure 4: Real circuit number 3 designed by clinicians.

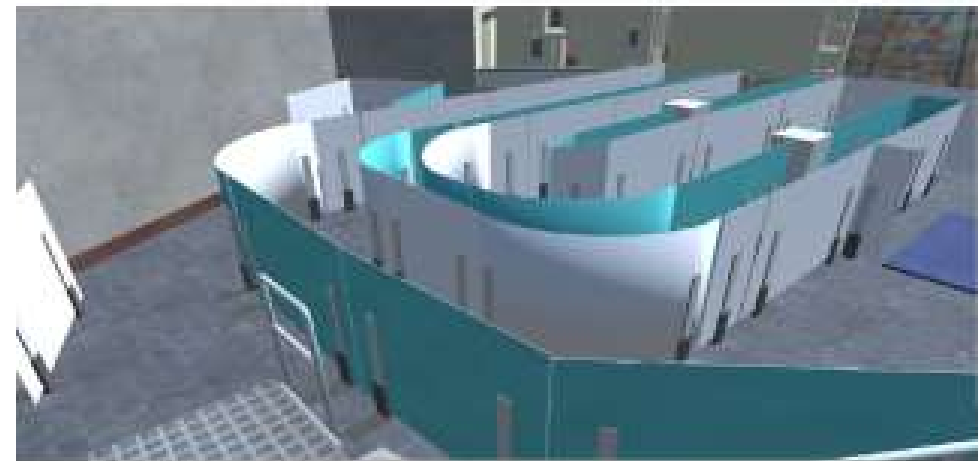


Figure 5: Virtual circuit number 3 designed by clinicians.

<https://youtu.be/Ds-h1J4MFMI?t=4615>

- 電動車いすのためのVRシミュレータ。乗る前に練習する用。
- VR simulator for electric wheelchairs. For practicing before real riding.



ロボットアームの先端に座席を付ける Sheet at the tip of serial link robot arm



<http://www.youtube.com/watch?v=CoA-m5iHG9s&feature=related>



RoboCoaster (<http://www.robocoaster.com/content/>)



<http://www.youtube.com/watch?v=gY6T6iSLO30>



(参考) シリアルリンク・パラレルリンク

Serial Link & Parallel Link

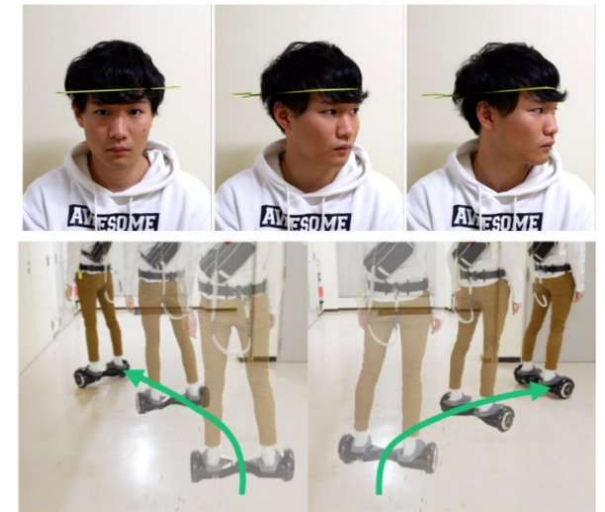
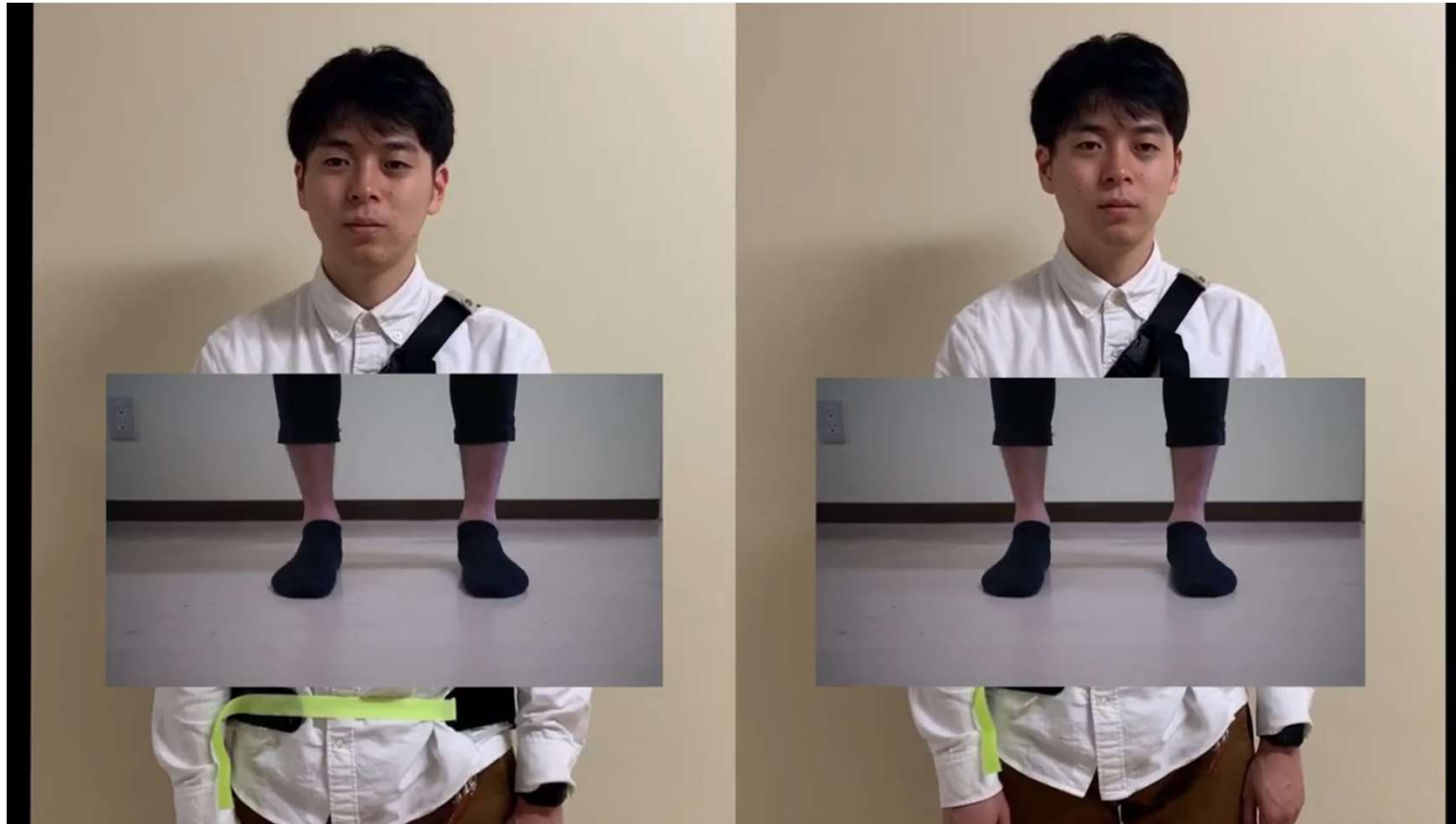


- シリアルリンクは大きな動きを出すのに向く
- パラレルリンクは大きな力(剛性)を出すのに向く
- Serial link is good for large workspace.
- Parallel link is good for large force.



腰部ハンガー反射 + パーソナルモビリティ

Wrist-type hanger reflex + self-balancing transporter



<https://www.youtube.com/watch?v=1of4z7K-qW8>

(SIGGRAPH ASIA 2018) Hanger Drive: Driver Manipulation System for Self-balancing Transporter, Kobayashi, Kon, Zhang, Kajimoto

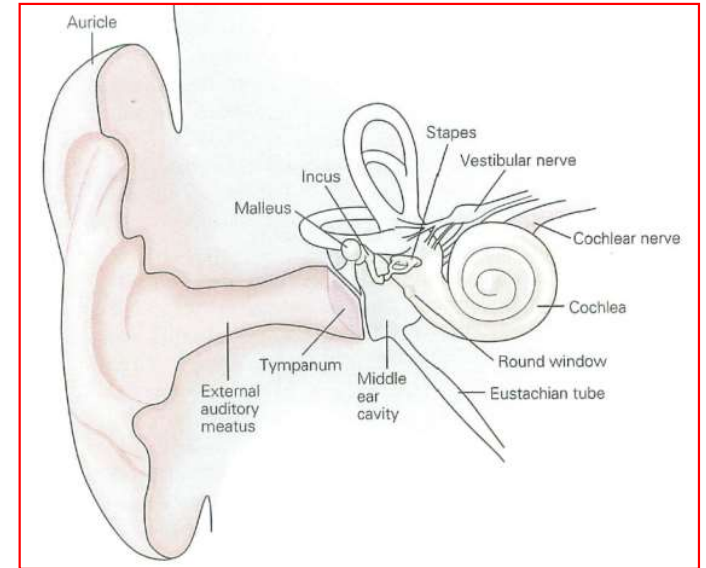
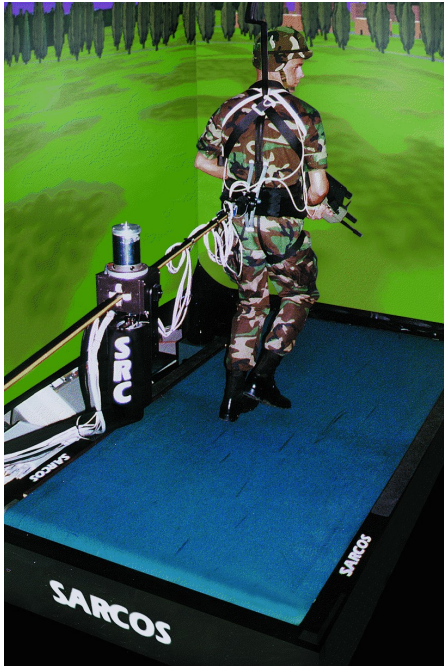


TODAY's TOPIC

1. 移動感覚のメカニズム Locomotive perception mechanism
2. 歩行感覚提示 How to present Walking sensation?
3. 搭乗感覚提示 How to present Riding sensation?
4. 巨大化を避ける試み Why are they so HUGE?



Why are they so huge?



- 前庭器官は視覚・聴覚・触覚と異なり, 感覚器が露出していない⇒エッセンスだけを取り出して「だます」ことが難しい.
- Vestibular system is not exposed to environment⇒We can not display “essence”, but rather, we must reproduce environment.



前庭を外部から刺激する

Stimulate Vestibular Stimulation from around



<http://www.youtube.com/watch?v=H4iQkFUgG6k>

- 温度刺激: 耳に水／温水を流しこむことによる神経活動. 温度眼振検査(カロリックテスト)に応用 Temperature change by water produce vestibular activity.
- 電気刺激: 直流を流すことによる神経活動
Electrical Direct Current from Around Ear Produce Vestibular Activity

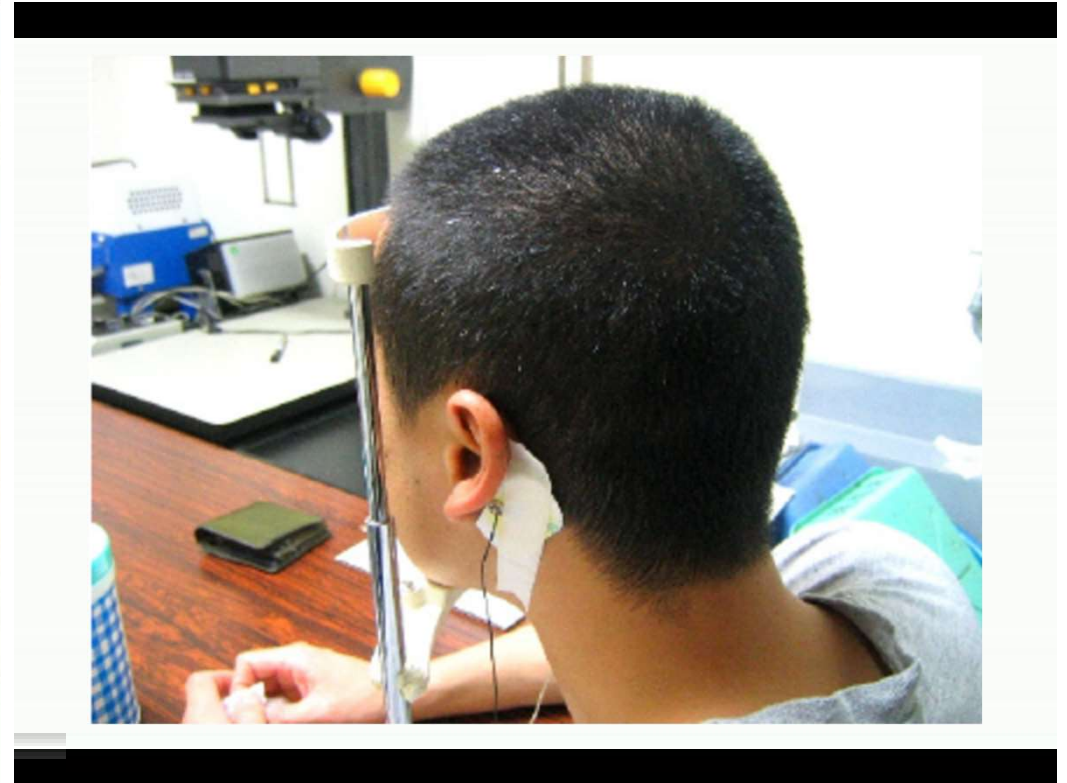


前庭電気刺激 Galvanic Vestibular Stimulation



<http://www.youtube.com/watch?v=OIXYqfQHNuA>
<http://www.youtube.com/watch?v=guaiDZdsDjI>
<http://www.youtube.com/watch?v=pmoUU4M4xkc>

Maeda et al., “Virtual Acceleration with Galvanic Vestibular Stimulation in Virtual Reality Environment”, IEEE VR 2005



(ACE2006) Nagaya et al., Gravity jockey: a novel music experience with galvanic vestibular stimulation, ACE2006.

比較的高周波でのGVSは、自己の揺れではなく世界の揺れと知覚される
Relatively high-freq. GVS produces sensation of “world shake”, rather than self motion.



(IEEEVR2022) Omnidirectional Galvanic Vestibular Stimulation in Virtual Reality
Colin Groth, Jan-Philipp Tauscher, Nikkel Heesen, Max Hattenbach, Susana Castillo,
Marcus Magnor



多自由度のGVSで酔いを止める。

Multi-DoF GVS to stop cyber-sickness

<https://www.youtube.com/watch?v=z91PZpejFeE>

NoisyGVS



ノイズ刺激をGVSで与えると揺れ感覚をなくせる(前庭感覚の信頼性を低下させることで視覚刺激の信頼性を相対的に高める)

Noise stimuli by GVS decreases the reliability of vestibular sensation and increase the relative reliability of visual stimuli.

Matsumoto, Aoyama, Narumi, Kuzuoka: Redirected Walking using Noisy Galvanic Vestibular Stimulation, ISMAR2021

<https://ieeexplore.ieee.org/document/9583785>



(CHI2014) Haptic Turk: a Motion Platform Based on People, Cheng et al.



<https://www.youtube.com/watch?v=QFsNmSrgOY4>



Visualift:エレベータを用いた運動感覚提示



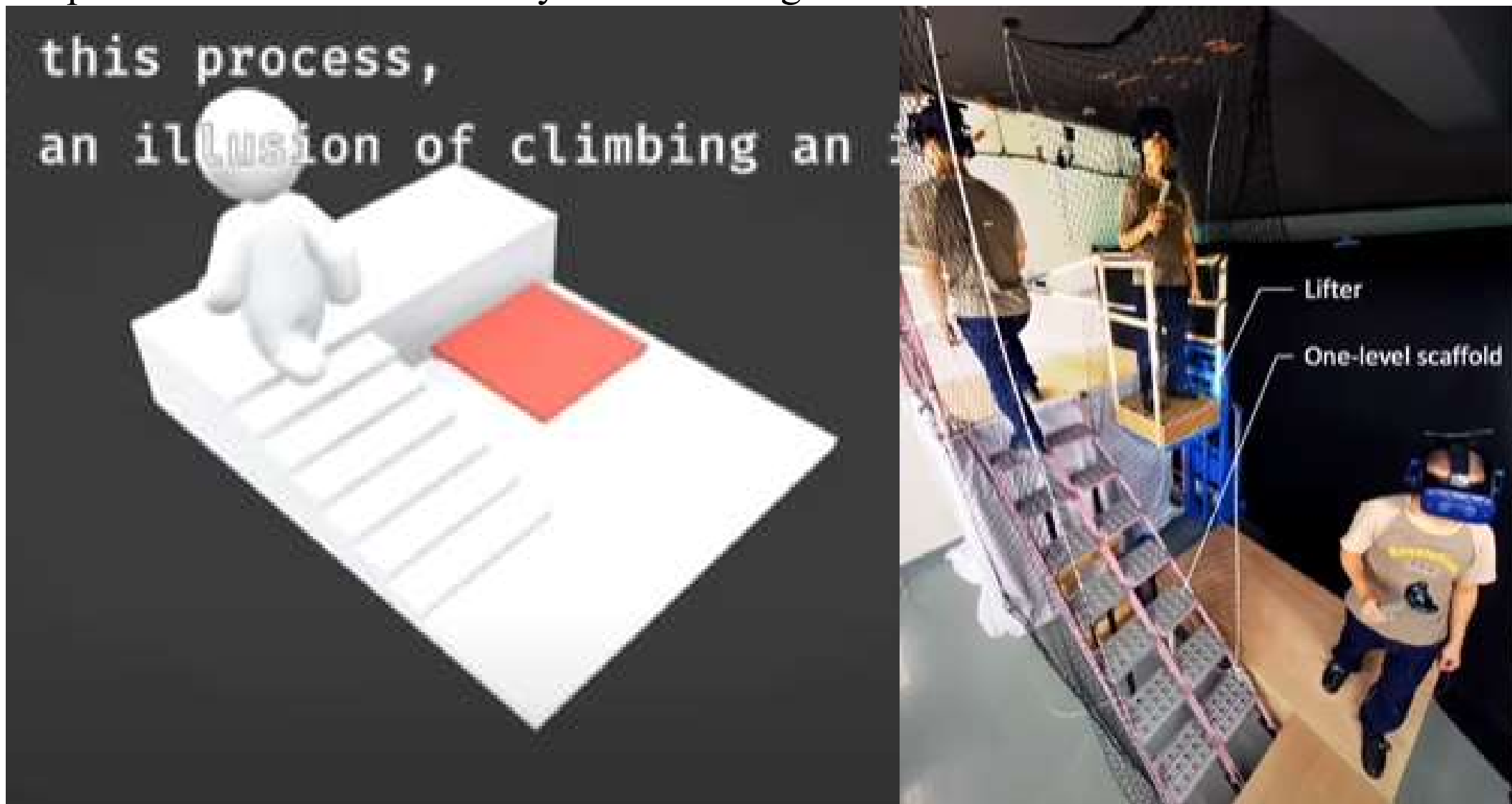
This is demonstrations of VR content using VisuaLift Studio, such as free-fall experience using sensory illusion of movement.

M. Koge, T. Hachisu, H. Kajimoto: VisuaLift Studio: Study on Motion Platform using Elevator. IEEE 3DUI 2015, March 23-24, 2015, Arles, France.



(IEEEVR2021) Jen-Hao Cheng, Yi Chen, Ting-Yi Chang, Hsu-En Lin, Po-Yao (Cosmos) Wang, Lung-Pan Cheng

Impossible Staircase: Vertically Real Walking in an Infinite Virtual Tower



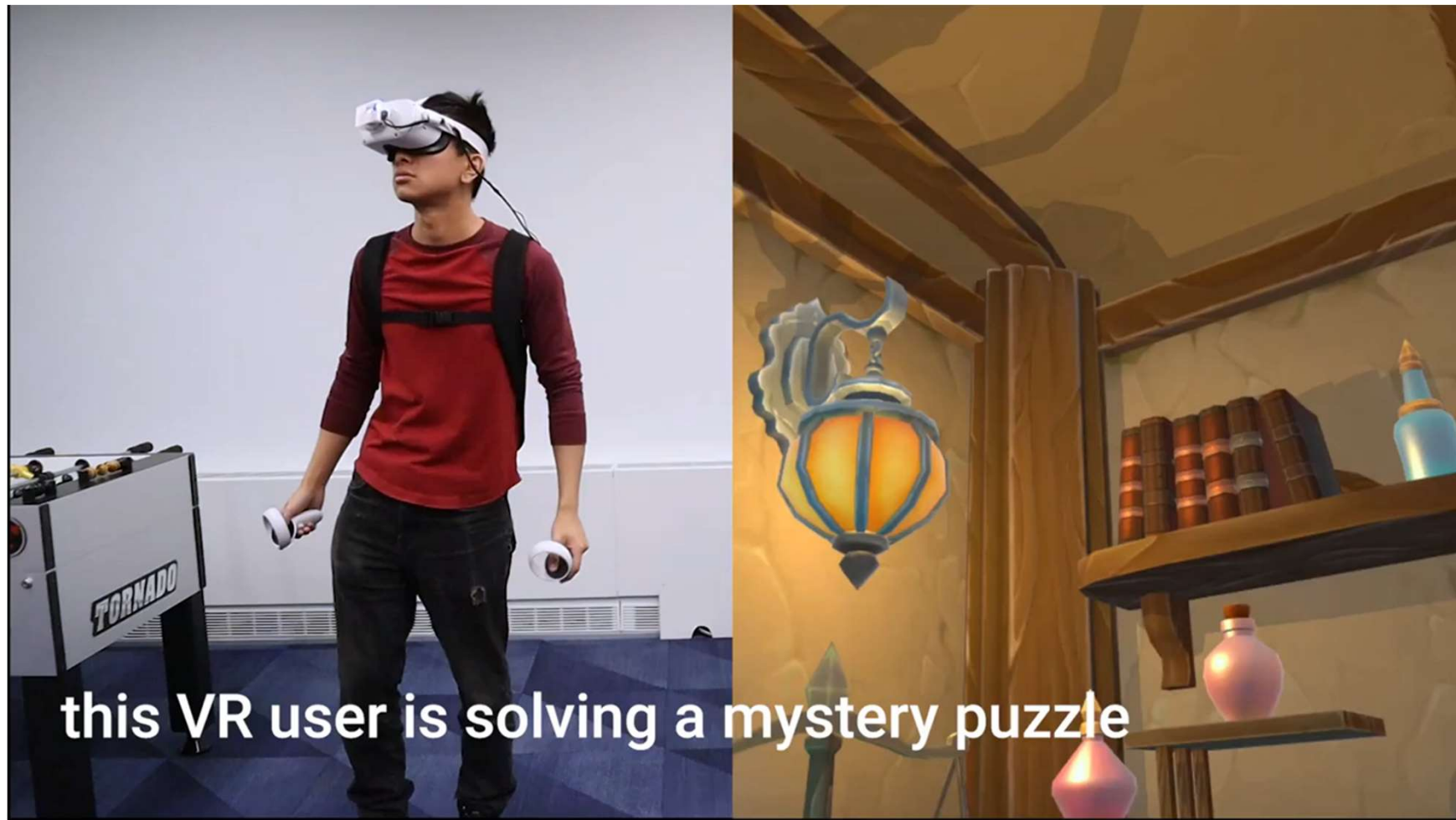
<https://youtu.be/ob7y6ms48fc?t=4158>

- 階段 + 昇降器で無限に登れる、降りれるVR世界を作った。
- AVR world where you can climb up and down infinitely with stairs + elevators.



(UIST2022) Integrating Real-World Distractions into Virtual Reality

Yujie Tao, Pedro Lopes



<https://www.youtube.com/watch?v=G9zn40zGyTg&list=PLqhXYFYmZ-VdaPIMTFVH5K5brMDJClfAn&index=68>

VR環境において、物理的環境からの気を散らす刺激（ファンがオンされるなど）を直接VR体験に組み込むことでプレゼンスを向上させることを提案

Proposed to enhance presence in VR environments by incorporating distracting stimuli from the physical environment (e.g., fans being turned on) directly into the VR experience

ジェットコースター+VR



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

Kraken Unleashed 2017 FULL Virtual Reality POV at SeaWorld Orlando



自動車+VR



Ryo Kodama, Masahiro Koge, Shun Taguchi, Hiroyuki Kajimoto:COMS-VR: Mobile Virtual Reality Entertainment System using Electric Car and Head-mounted Display, IEEE 3DUI2017, Los Angeles, USA, March 2017.

Summary



[https://en.wikipedia.org/wiki/
/The_Matrix](https://en.wikipedia.org/wiki/The_Matrix)



[https://en.wikipedia.org/wiki/Ready
Player_One_\(film\)](https://en.wikipedia.org/wiki/ReadyPlayer_One_(film))



[https://en.wikipedia.org/wiki/
/Sword_Art_Online](https://en.wikipedia.org/wiki/Sword_Art_Online)

- 移動感覚インタフェースはVR世界構築のための最後かつ最大の課題。
Locomotion interface is the last and the most difficult.
- 特に歩行感覚に関しては、問題の半分はハプティック。
For walking, half part is haptics.
- 残る大問題は、前庭感覚を外部から刺激しにくいこと。このためエッセンスを提示するというよりは、実際に提示する巨大システムとなりがち。
Problem occurs since vestibular system cannot easily stimulated from around.
System becomes so huge.
- ほとんどの実応用はルールベースで良いのかもしれない。しかしそれではMATRIXで夢見た世界はつくり出すことが出来ない。
Most practical application may not require accurate vestibular stimulation. But we cannot realize the MATRIX world that we dreamed.



小テスト：一週間以内に提出

Mini Test: Submit in one week

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

1. ベクションについて説明せよ Explain vection.
2. 半規管の役割について説明せよ Explain role of semicircular canals.
3. 耳石器の役割について説明せよ Explain role of otolith.
4. 通常の床とトレッドミルの違いについて説明せよ Explain difference between normal floor and treadmill.
5. シリアルリンクの利点について説明せよ Explain merit of serial link manipulator
6. パラレルリンクの利点について説明せよ Explain merit of parallel link manipulator
7. 温度眼振検査について説明せよ Explain caloric test.
8. 前庭電気刺激について説明せよ Explain galvanic vestibular stimulation

