Elective in Robotics

Haptic and Locomotion Interfaces

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Haptic and Locomotion interfaces

"*Haptic interfaces* refers to interfaces involving the human hand and to manual sensing and manipulation" (Durlach et al., 1994)

- a haptic interface is made of
  - a mechanical position tracker
  - actuated joints
- it is just a *robot attached to a human*

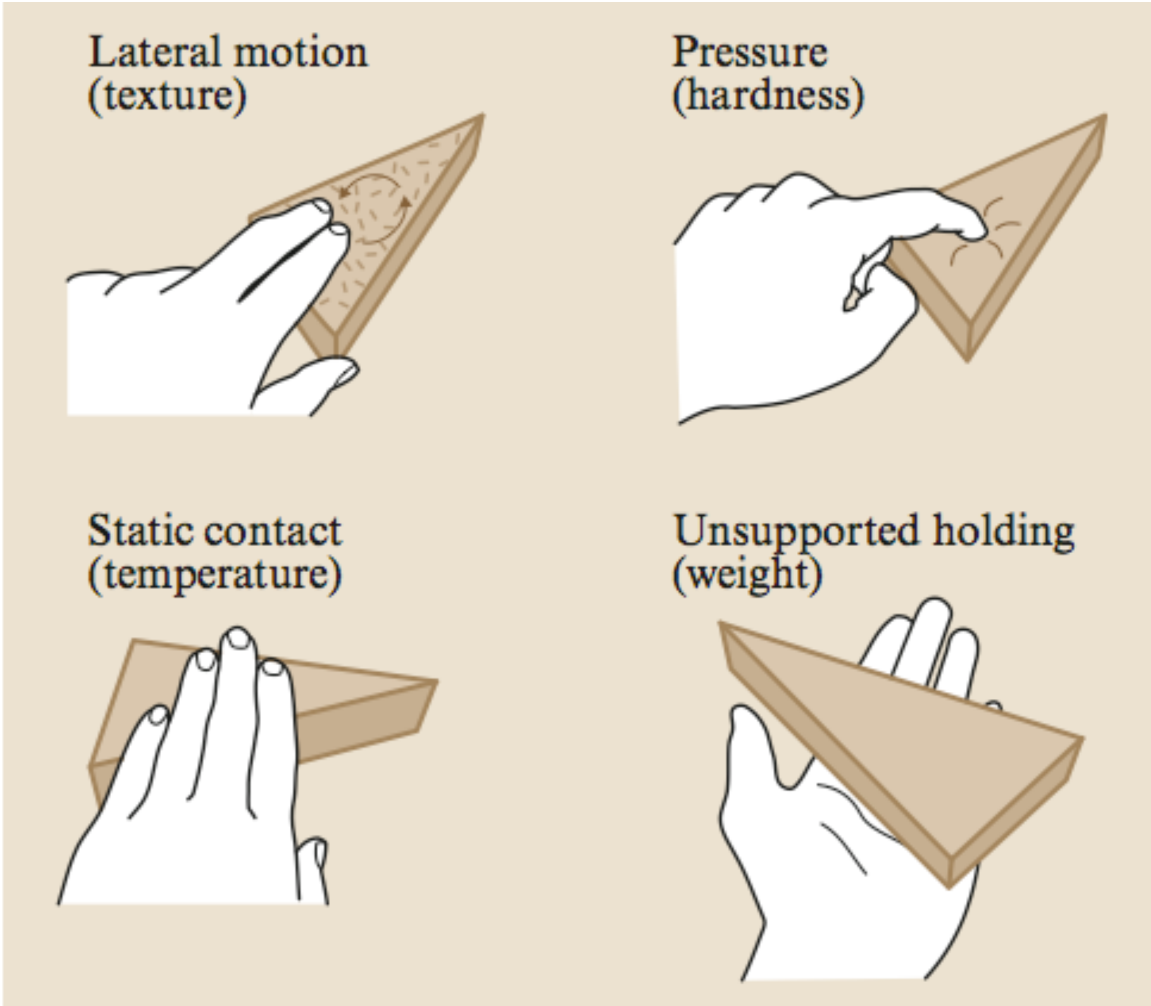
Locomotion interfaces refers to interfaces involving the human body/legs/feet and to natural or induced locomotion

What is “haptic”?

from Merrian-Webster dictionary

- from the Greek ἅπτεσθαι = *haptesthai* = to touch
- an adjective (the word is “haptics”)
- circa 1890
- relating to or based on the sense of touch
- or, characterized by a predilection for the sense of touch <a haptic person>

Human exploratory procedures



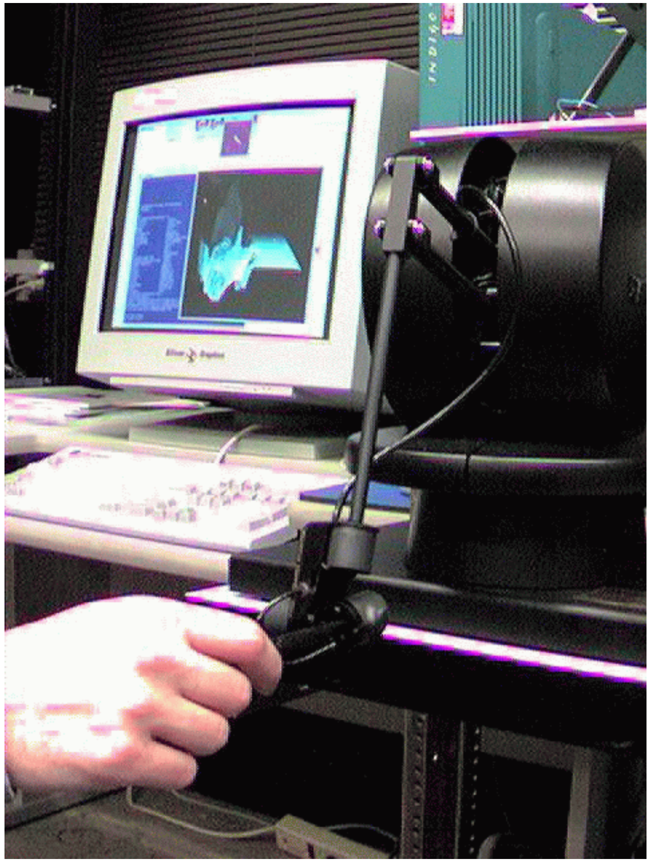
A force-exchange point of view

Haptic interfaces are robots that apply forces to the human body to display or relocate information

where are forces typically applied?

- conventional haptics: on arms and/or hands
- foot haptics (e.g., Iwata's GaitMaster)
- whole-body haptics (e.g., Sarcos Treadport, inertial emulators)

Conventional haptic interfaces



ground based
(Phantom)

body based
(UTAH teleoperator arm)

Haptic hand devices

PHANTOM Desktop
⇒ now Geomagic Touch X

PHANTOM Omni
⇒ now Geomagic Touch

(SensAble Technologies ⇒ now 3D Systems)

PHANTOM Desktop data sheet

3D force feedback

PHANTOM Desktop Technical Specifications

Force feedback workspace	~6.4 W x 4.8 H x 4.8 D in. > 160 W x 120 H x 120 D mm.
Footprint (Physical area the base of device occupies on desk)	5 5/8 W x 7 1/4 D in. ~143 W x 184 D mm.
Weight (device only)	6 lbs. 5oz.
Range of motion	Hand movement pivoting at wrist
Nominal position resolution	> 1100 dpi. ~ 0.023 mm.
Backdrive friction	< 0.23 oz. (0.06 N)
Maximum exertable force at nominal (orthogonal arms) position	1.8 lbf. (7.9 N)
Continuous exertable force (24 hrs.)	0.4 lbf. (1.75 N)
Stiffness	X axis > 10.8 lbs. / in. (1.86 N / mm.) Y axis > 13.6 lbs. / in. (2.35 N / mm.) Z axis > 8.6 lbs. / in. (1.48 N / mm.)
Inertia (apparent mass at tip)	~0.101 lbm. (45 g)
Force feedback	x, y, z
Position sensing [Stylus gimbal]	x, y, z (digital encoders) [Pitch, roll, yaw (± 3% linearity potentiometers)
Interface	Parallel port and FireWire® option*
Supported platforms	Intel or AMD-based PCs
OpenHaptics® SDK compatibility	Yes
Applications	Selected Types of Haptic Research, the FreeForm® Modeling™, and the FreeForm® Modeling Plus™ systems

Geomagic Touch X data sheet

Geomagic Touch X

~6.4 W x 4.8 H x 4.8 D in > 160 W x 120 H x 120 D mm
Hand movement pivoting at wrist
> 1100 dpi ~0.023 mm
1.8 lbf/7.9 N
x-axis > 10.8 lb/in (1.86 N/mm) y-axis > 13.6 lb/in (2.35 N/mm) z-axis > 8.6 lb/in (1.48 N/mm)
x, y, z
x, y, z (digital encoders) [Roll, pitch, yaw (± 3% linearity potentiometers)]
IEEE 802.3 Ethernet port (USB option)

Geomagic Touch

available at the DIAG Robotics Lab (more on this specific device later)

A VR application in surgery

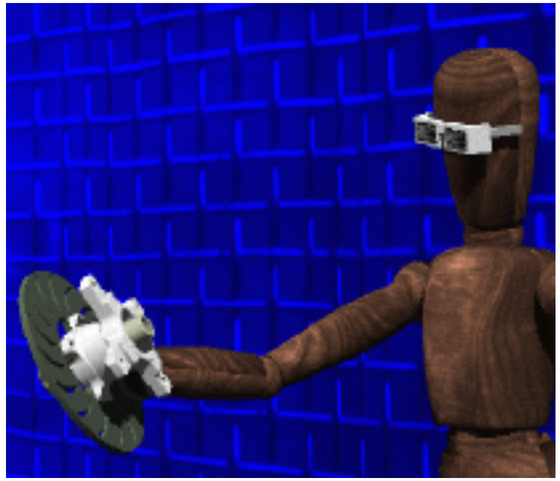
video

Immersive Touch

OMEGA 6D hand device

6D force feedback, Stewart platform
(Force Dimension)

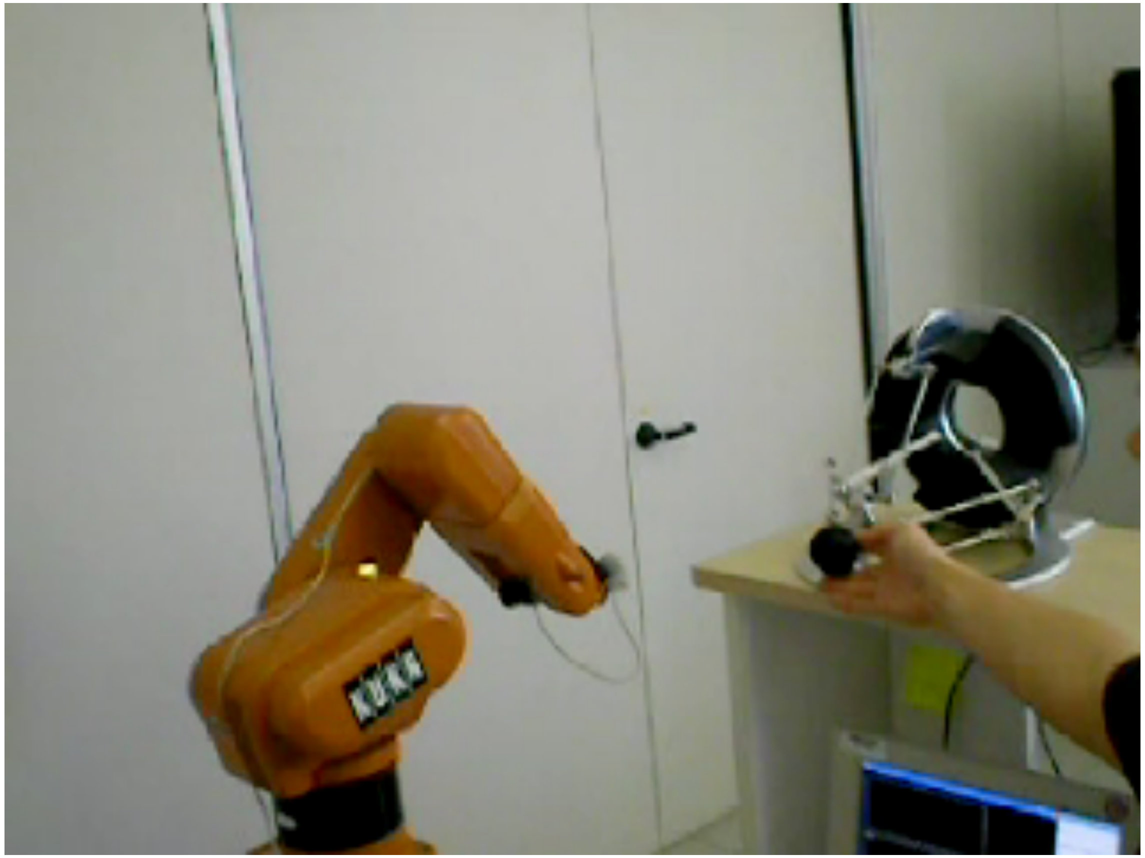
Haptic interfaces:
Teleoperation and Virtual Reality



teleoperation
in the real world

an agent
in the virtual world

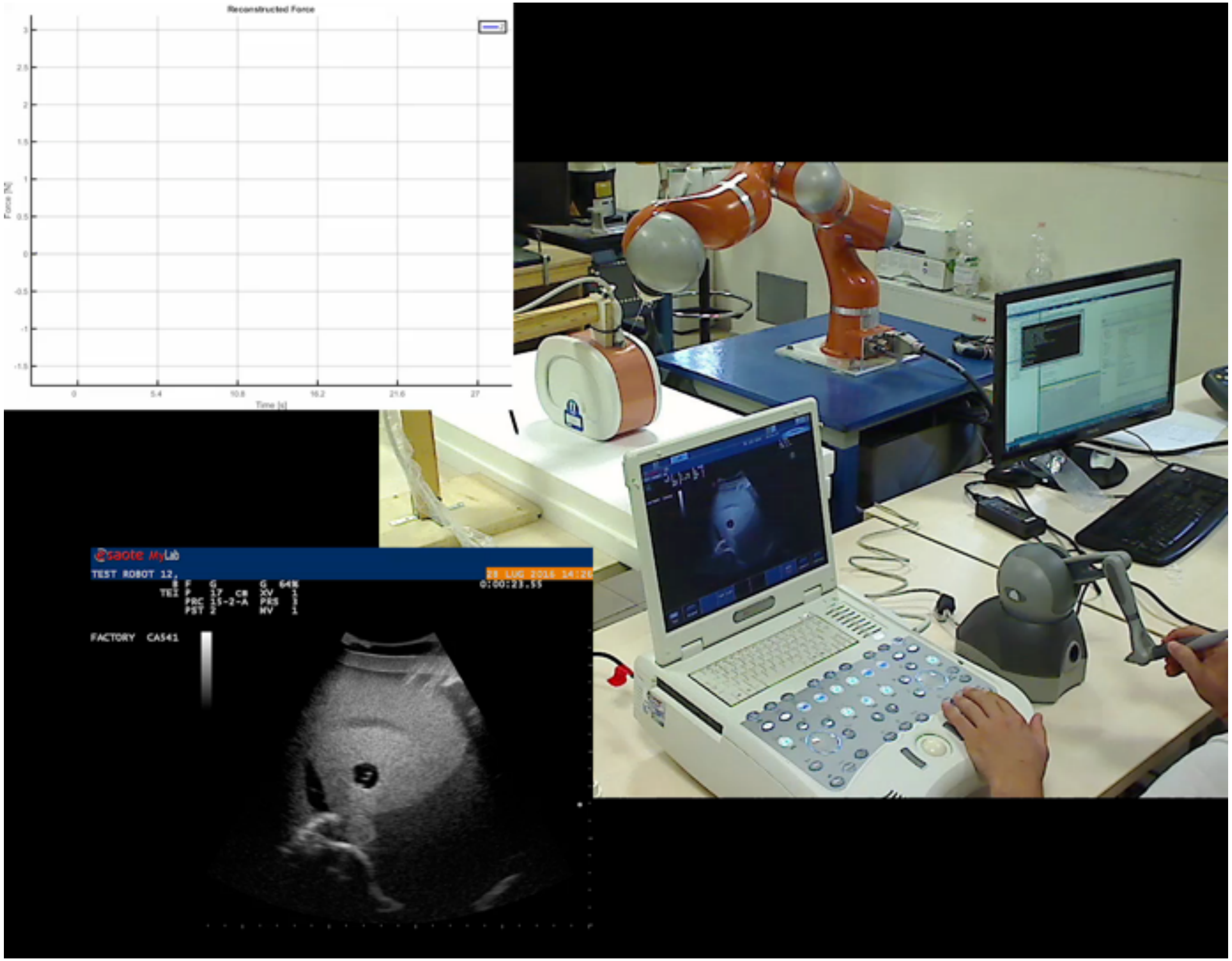
Teleoperation with an haptic interface



video

using an Omega device
(European project Robocast: http://131.175.32.10/Robocast)

Haptic control in medical applications
(needle steering)



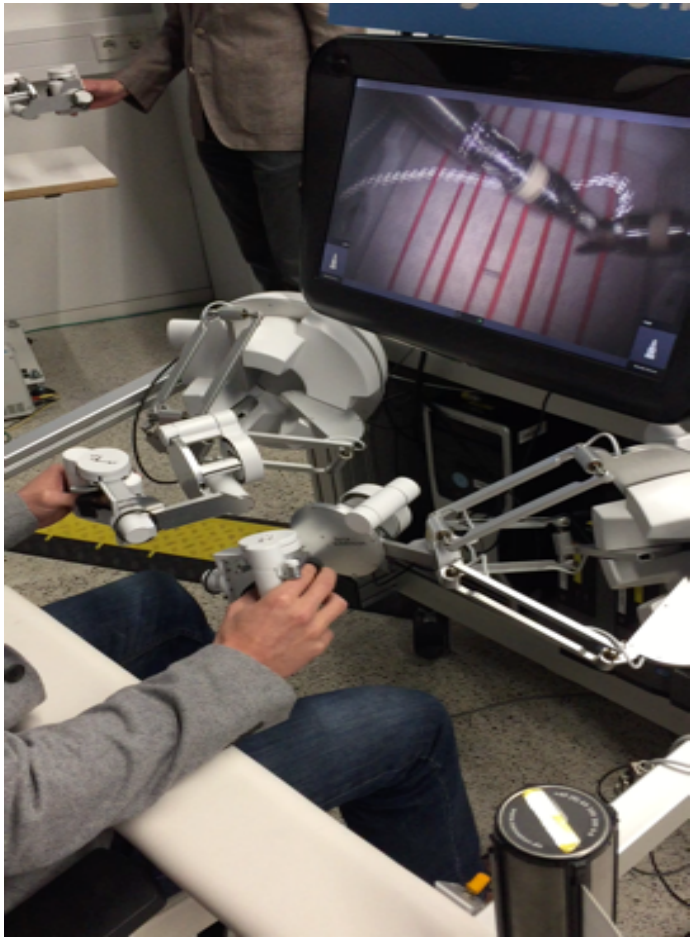
KUKA LWR holding the needle

Geomagic Touch haptic device

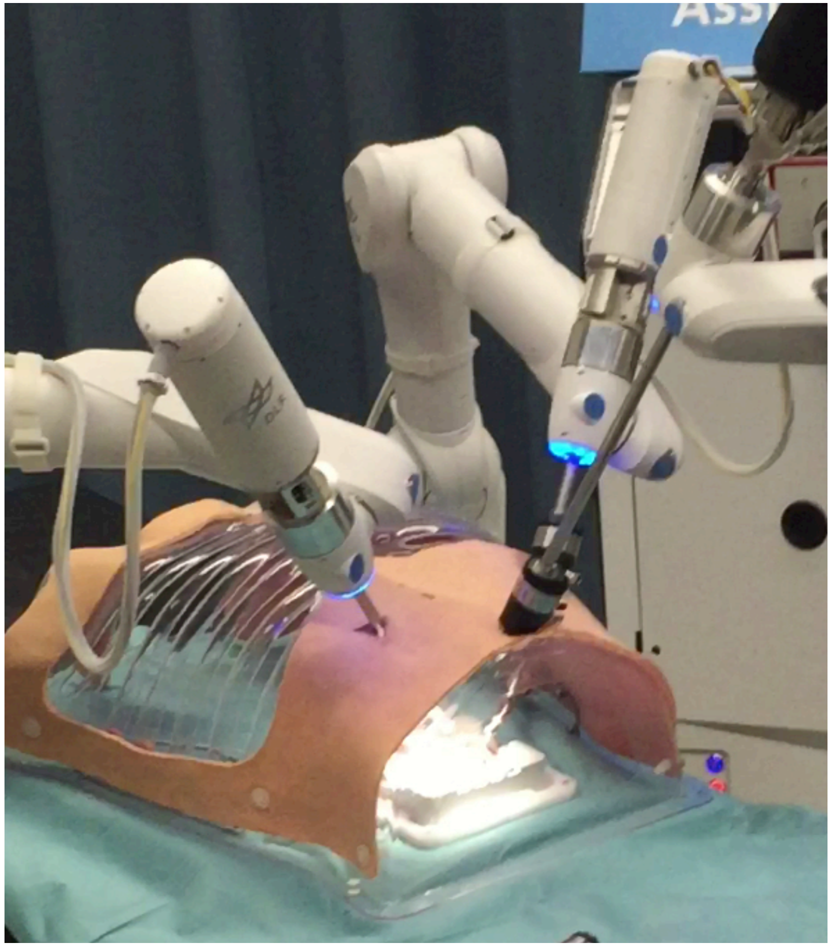
video

Bimanual haptic control in medical robotics

video

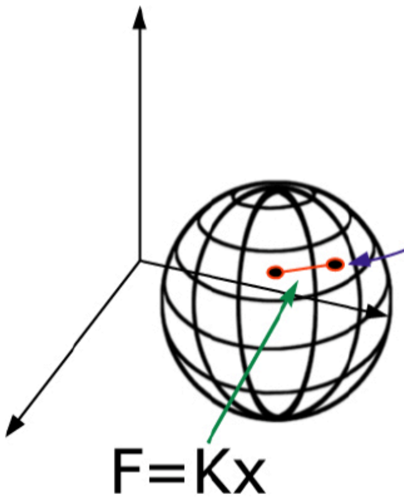


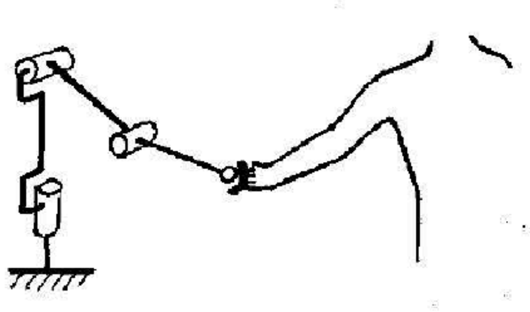
Two DLR 7-dof haptic devices (Omega-type)



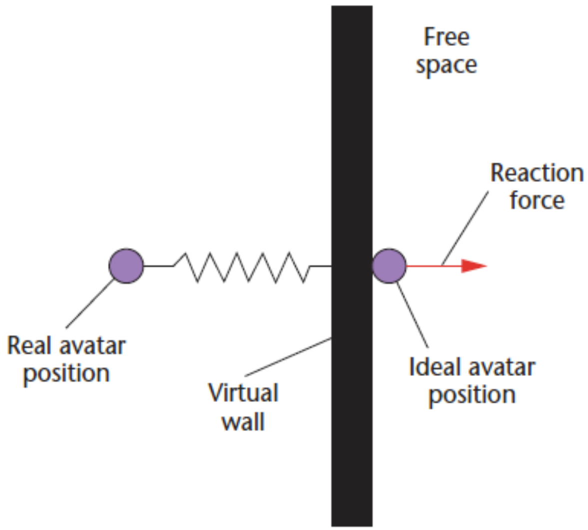
DLR MIRO robot (three arms, each 7-dof, one with camera)

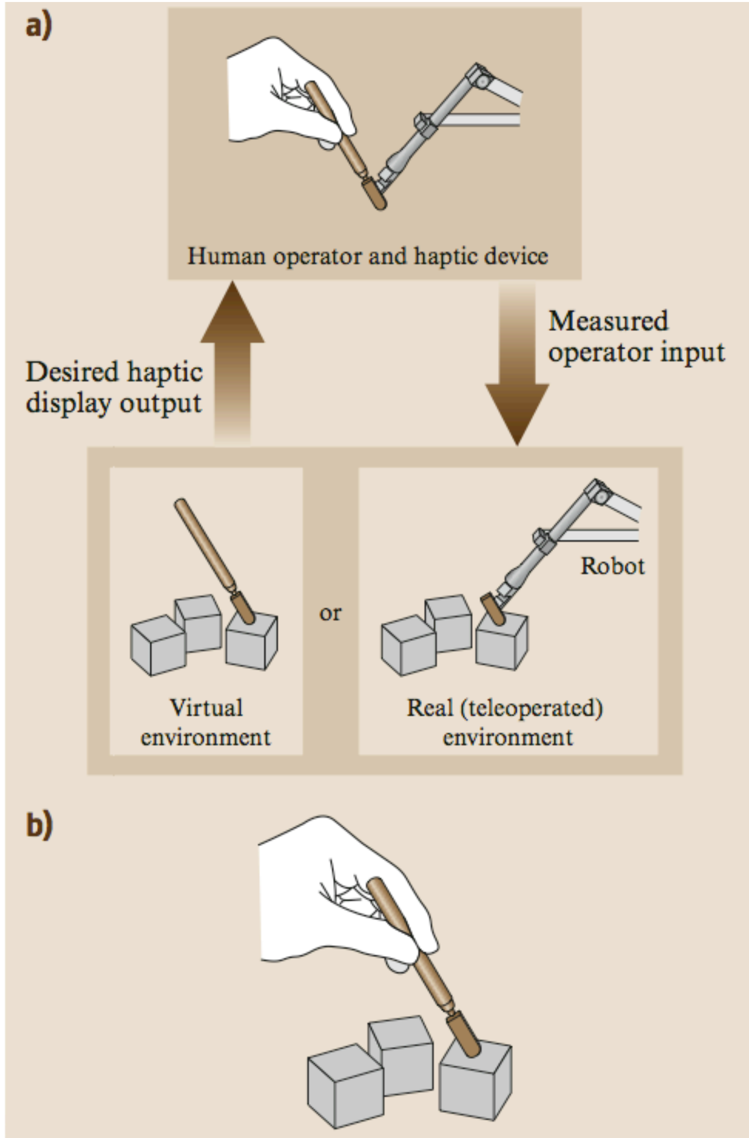
Force feedback from Virtual or Real world





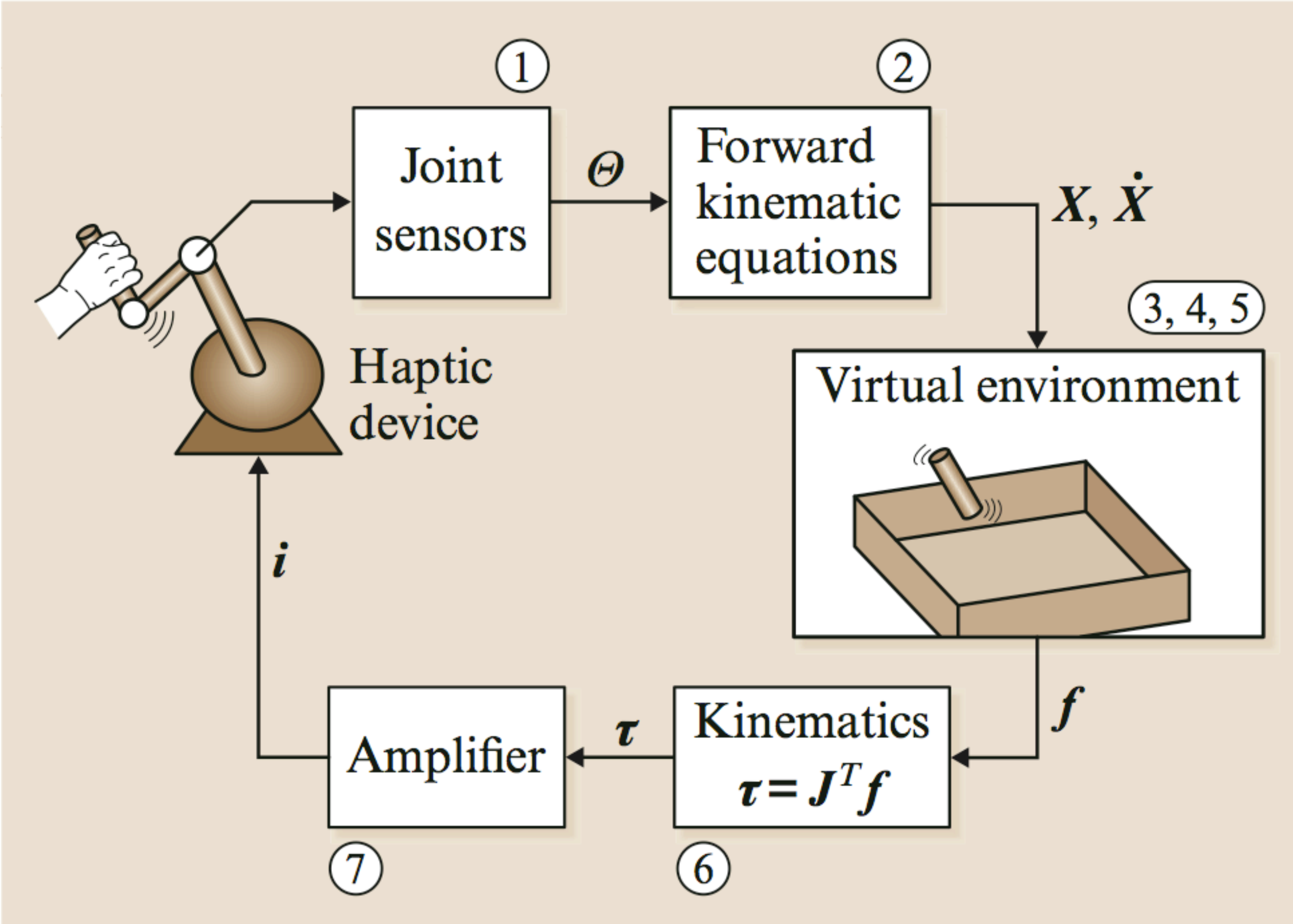
virtual environment compliance modeled with a spring/damper





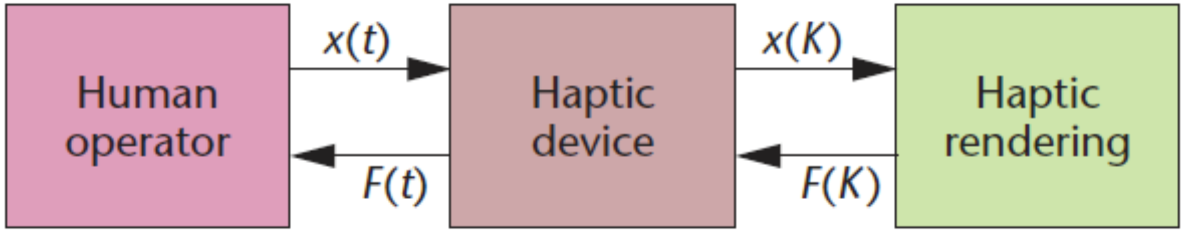
Haptic rendering control loop

① joint displacement sensing (on device)
② (direct) kinematics
③ collision detection (environment geometry)
④ surface point determination
⑤ force calculation
⑥ kineto-statics
⑦ actuation (on device)



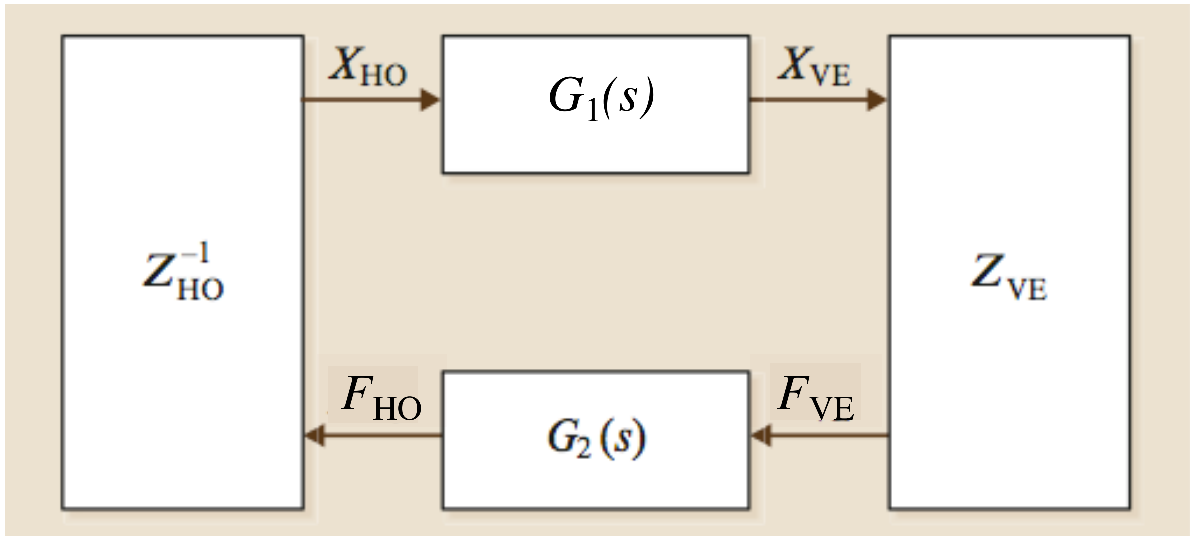
Haptic rendering control loop

continuous time t



discrete time $t_K = KT$

human operator side



virtual environment side

impedance (linear) models of operator and environment

$$Z_{HO}(s) = \frac{F_{HO}(s)}{X_{HO}(s)} \qquad Z_{VE}(s) = \frac{F_{VE}(s)}{X_{VE}(s)}$$

\+

(Laplace) transfer functions of haptic device for operator's

$G_1(s)$ position sensing

$G_2(s)$ force display

=

local stability analysis (e.g., by Nyquist criterion) of closed-loop system

$$G_{loop} = G_1 G_2 \frac{Z_{VE}}{Z_{HO}}$$

Telemanipulation (1-dof) control loop - 1

master (operator side)

$$M_m\ddot{\theta}_m + D_m\dot{\theta}_m = \tau_m + F_h$$

τ_m: master coordination torque (applied by motors)

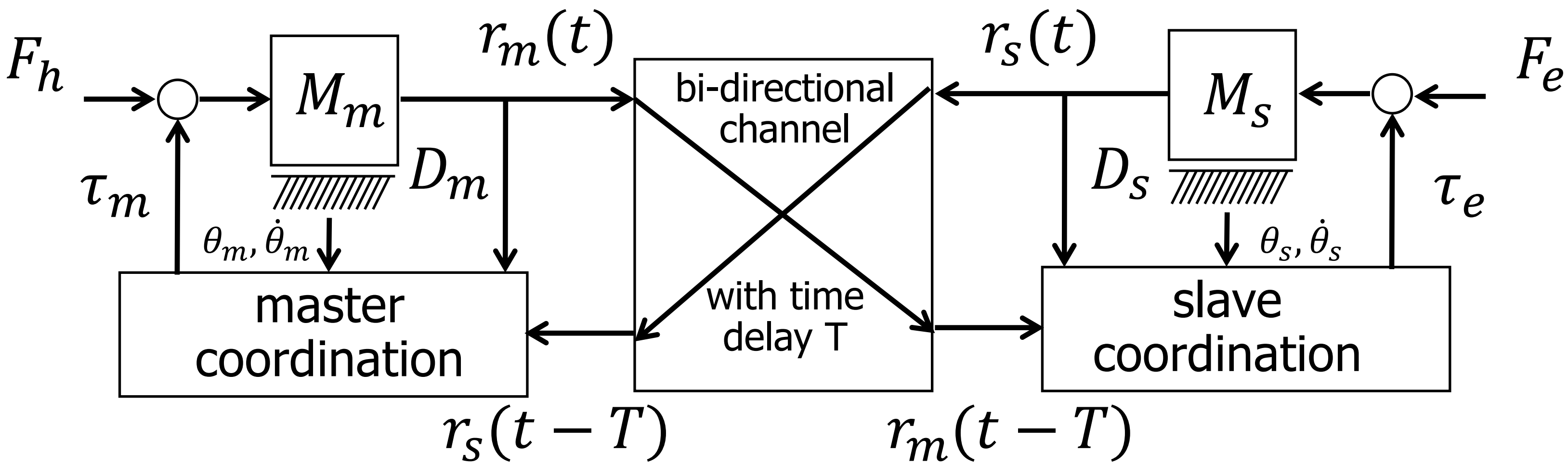
F_h: applied by human

slave (environment side)

$$M_s\ddot{\theta}_s + D_s\dot{\theta}_s = \tau_s + F_e$$

τ_s: slave coordination torque (applied by motors)

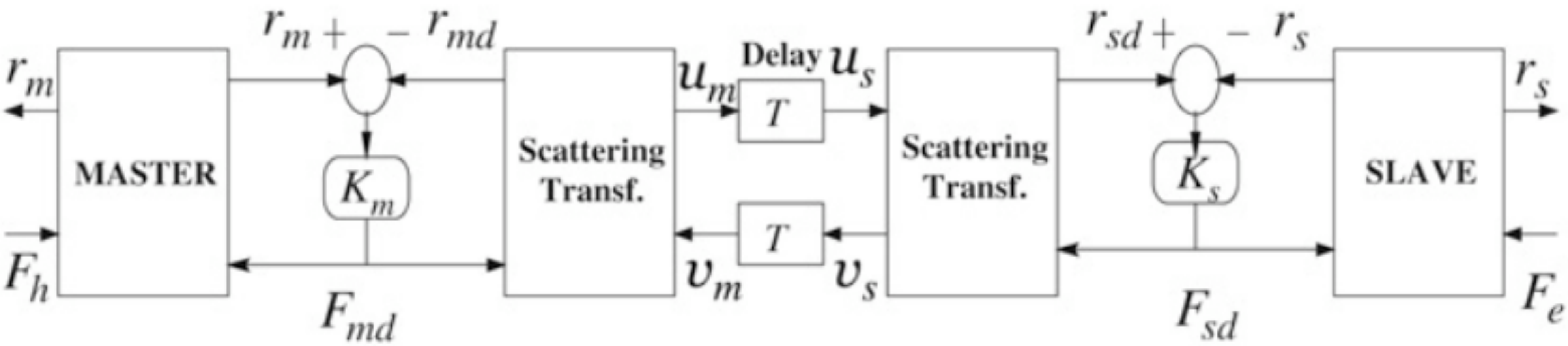
F_e: reaction by environment



$$r_i = \dot{\theta}_i + \lambda\theta_i \qquad i = m, s$$

Telemanipulation (1-dof) control loop - 2

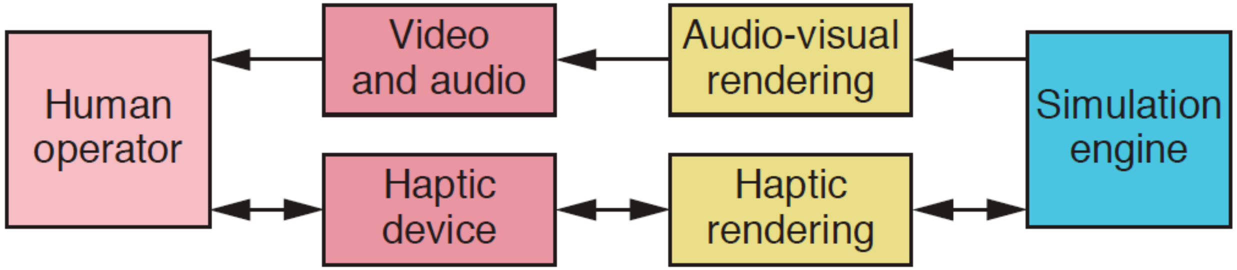
to preserve passivity of the closed-loop in the presence of a delay T, scattering transformations are often introduced

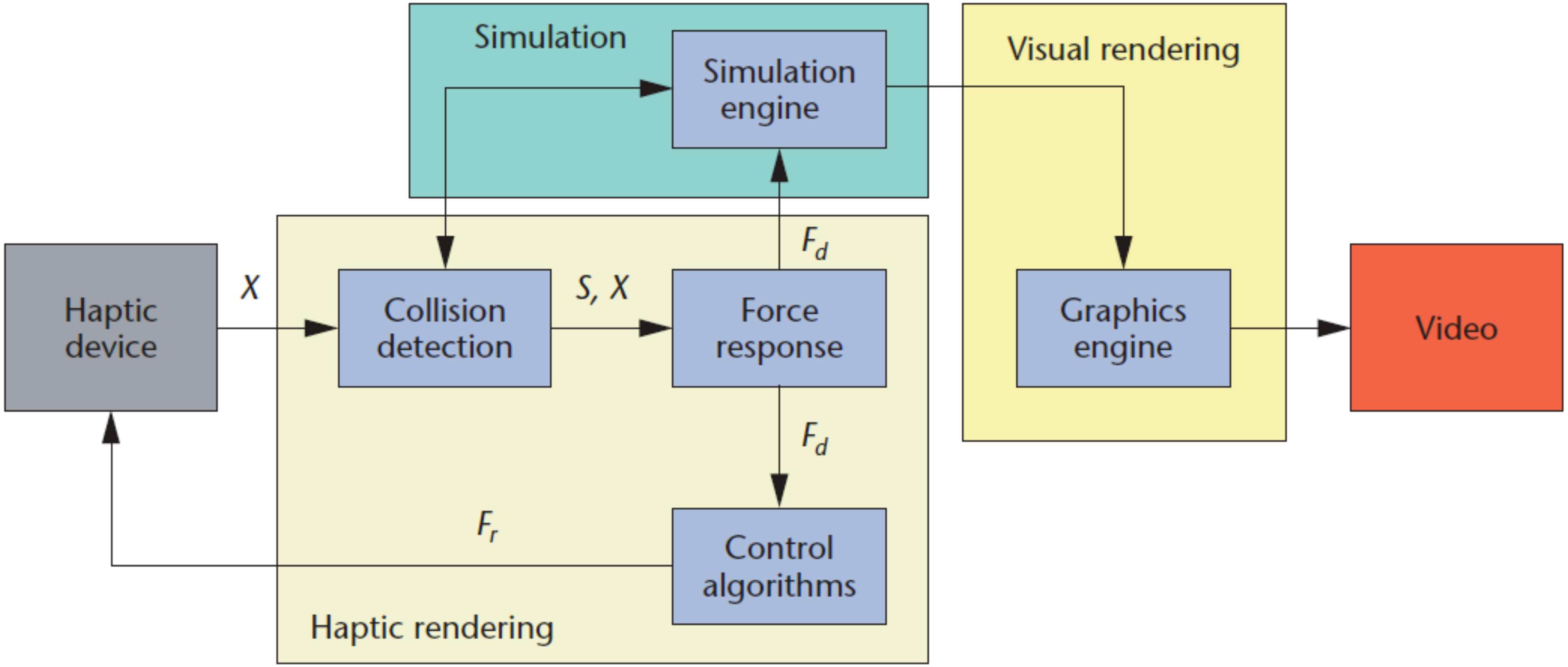


scattering variables u_m, v_s (and their delayed versions) are suitable combinations of local torque and position/velocity variables

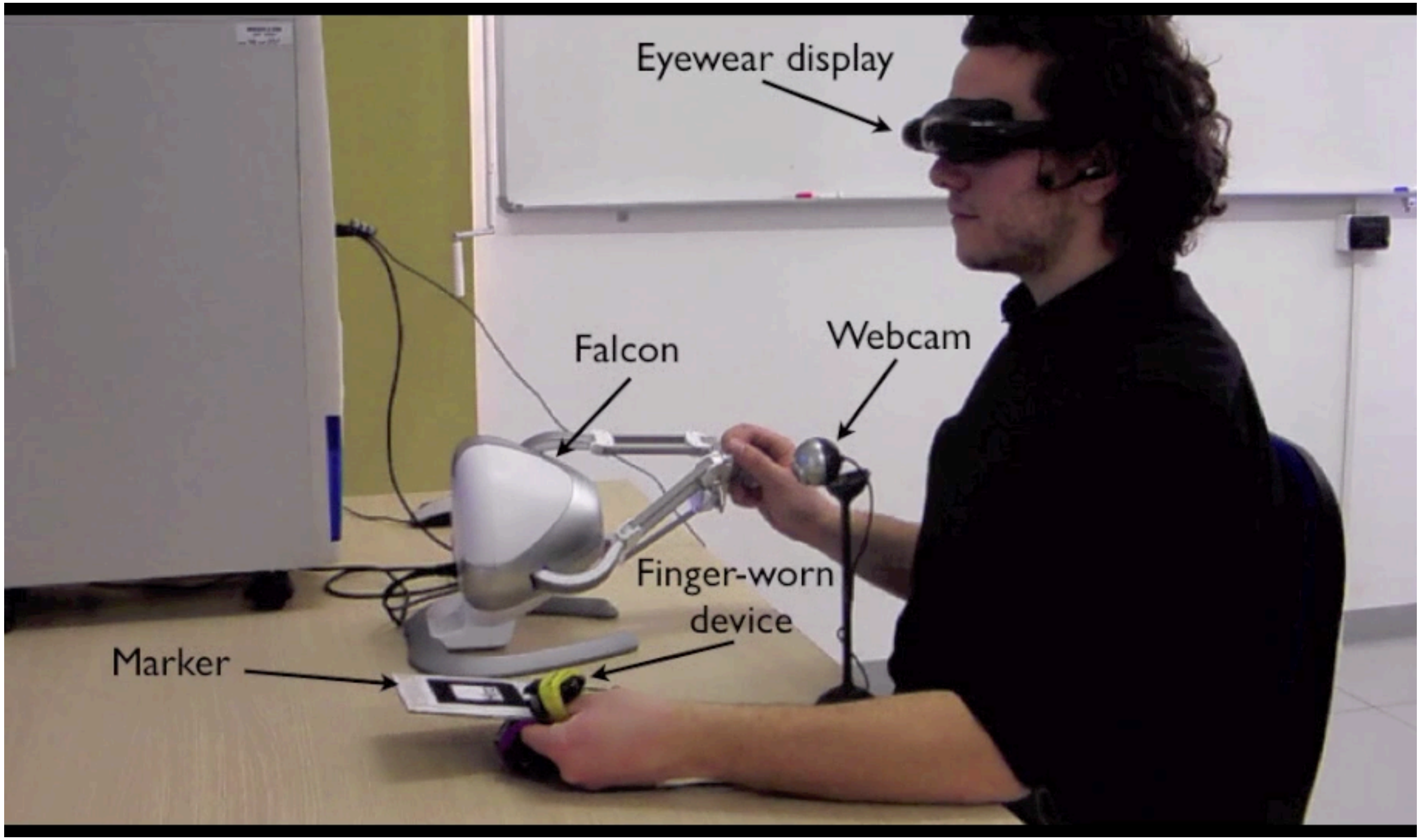
(see, e.g., Chopra, Spong, Lozano:
"Synchronization of bilateral teleoperators with time delay," Automatica, 2008)

Haptic/visual rendering architecture





Haptic rendering and augmented reality

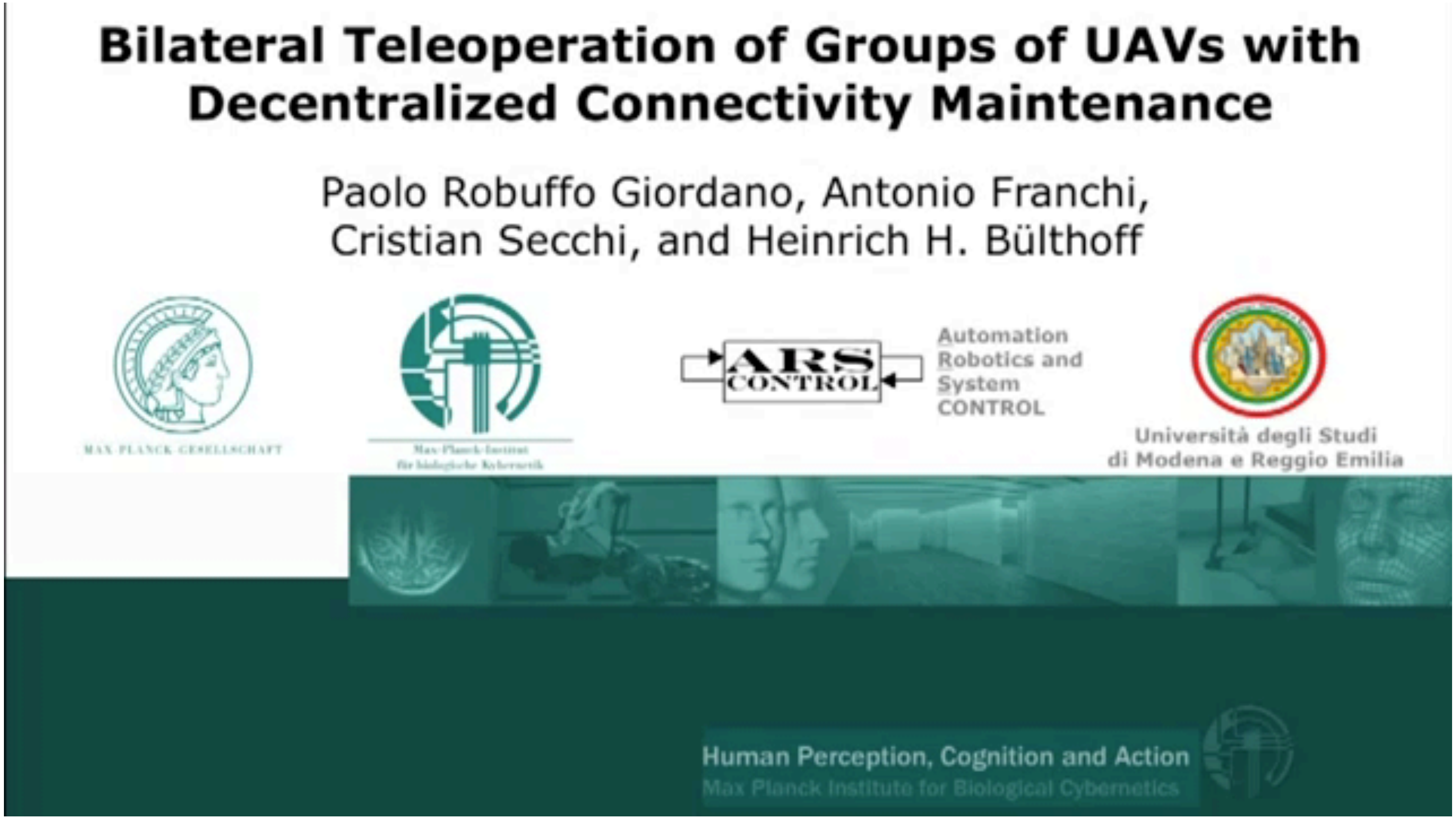


video

University of Siena (http://sirslab.dii.unisi.it)

Human-machine interface for team formation

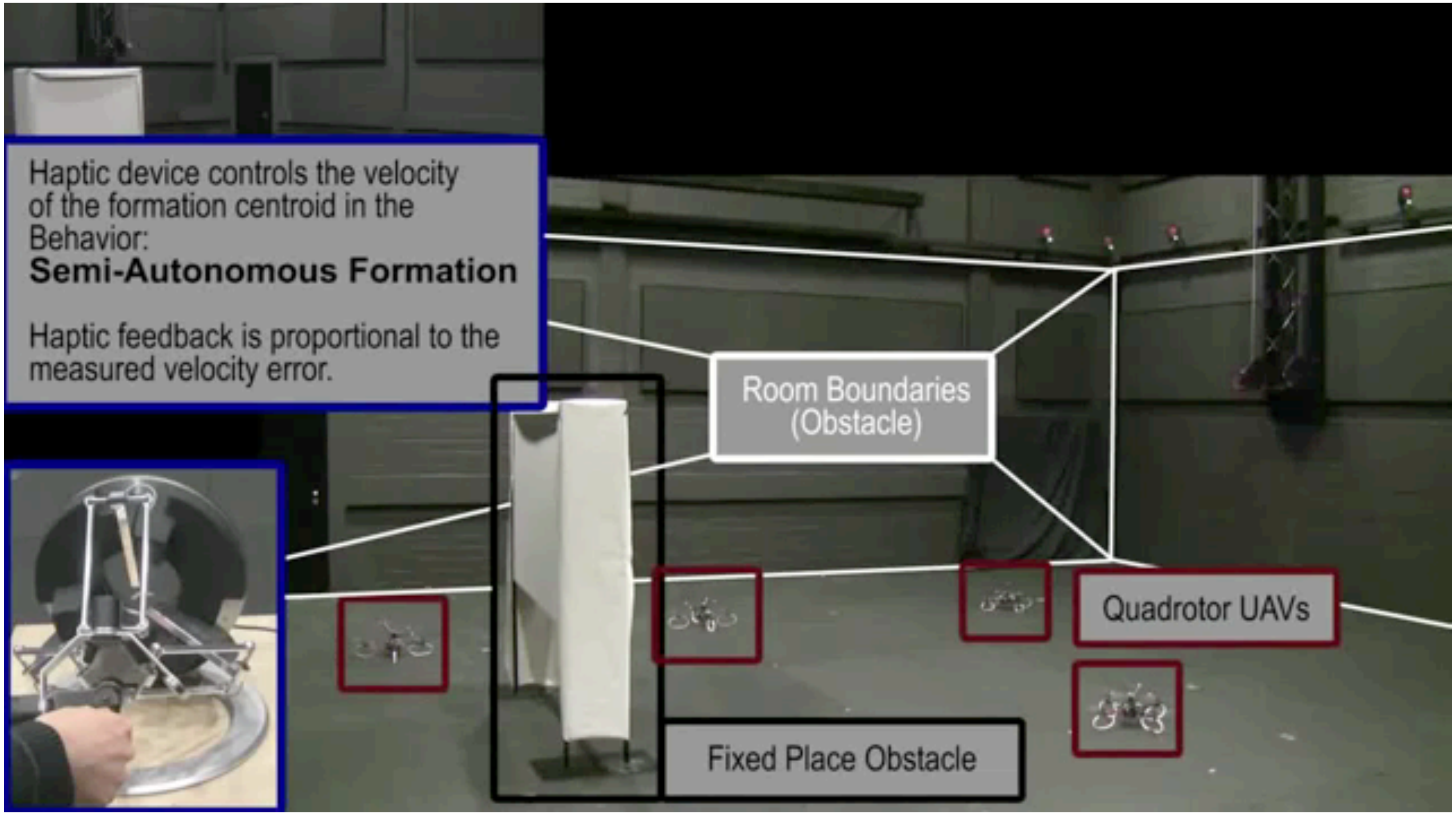
video



Max Planck Institute of Biological Cybernetics, Tübingen

Human-machine interface for team formation

video



Max Planck Institute of Biological Cybernetics, Tübingen

Mobile haptic devices - 1

+

=

- Force controlled
- Limited workspace
- Fast dynamics

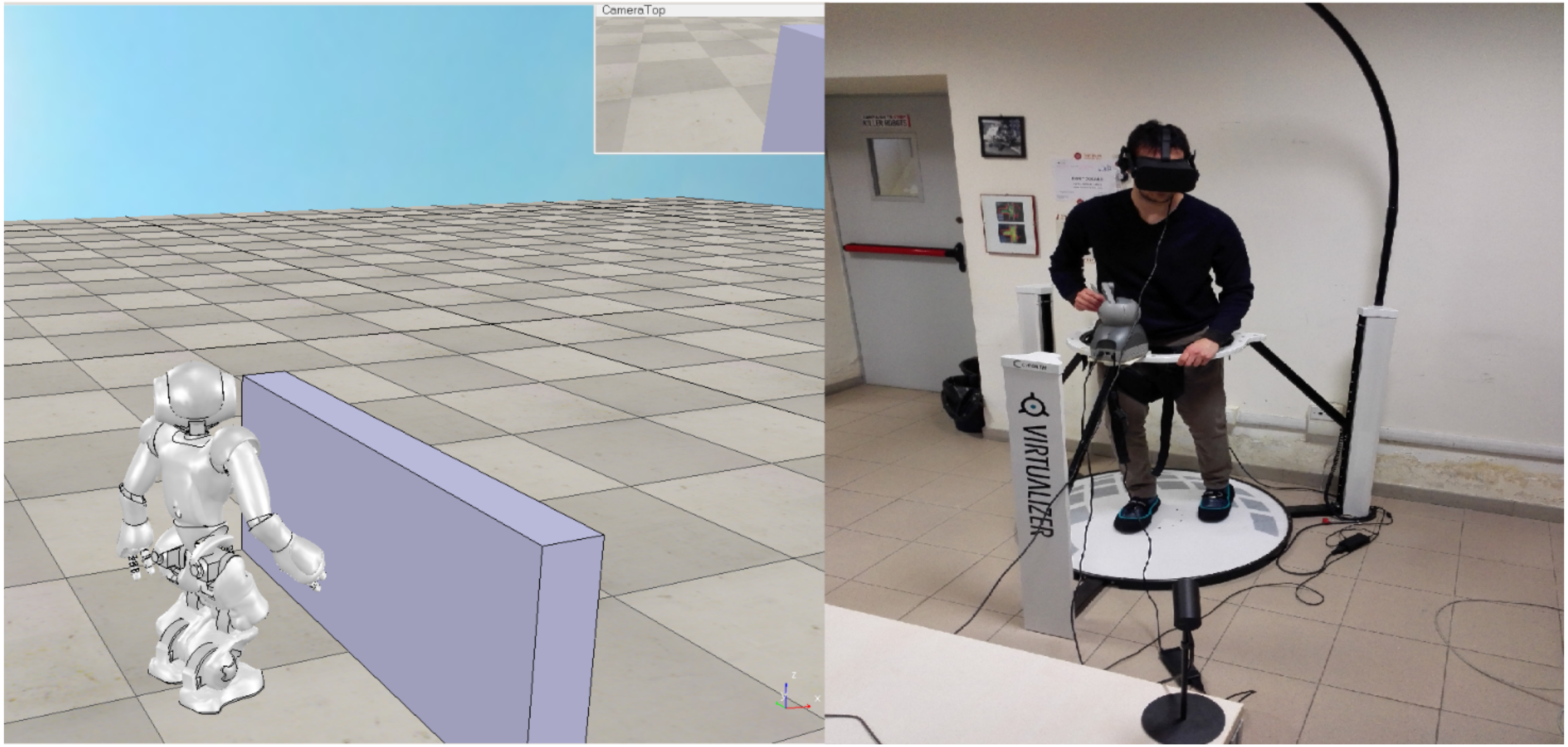
- Position controlled
- Unlimited workspace
- Slow dynamics

Unlimited workspace

University of Siena (http://sirslab.dii.unisi.it)

Mobile haptic devices - 2

Mobile haptic devices - 3



@DIAG Sapienza, Jan 2019
(Andrea Perica, MSc thesis in Control Engineering)

Powered exoskeletons
for human walking augmentation

Berkeley Lower Extremity Exoskeleton (BLEEX)

ExoHiker™

Medical Exoskeleton™

H. Kazerooni (http://bleex.me.berkeley.edu)

ExoHiker™

- designed for carrying heavy loads during long missions
- weight: 13.5 kg (with power unit, batteries, and on-board computer)
- payload: >65 kg (while the wearer feels no load)
- noise: virtually imperceptible
- duration:
  - 150 km/kg (Lithium Polymer) battery, at average speed 4 km/h
  - e.g., 80 W/hour battery of 0.52 kg & 65 kg load, sufficient for 21 h
  - unlimited with a small pack-mounted solar panel
- interface: small hand-held LCD display
- features: easy-stow retractable legs, quick release emergency
- completed in February 2005

ExoHiker™

BERKELEY BIONICS™

video on YouTube https://youtu.be/EdK2y3lphmE

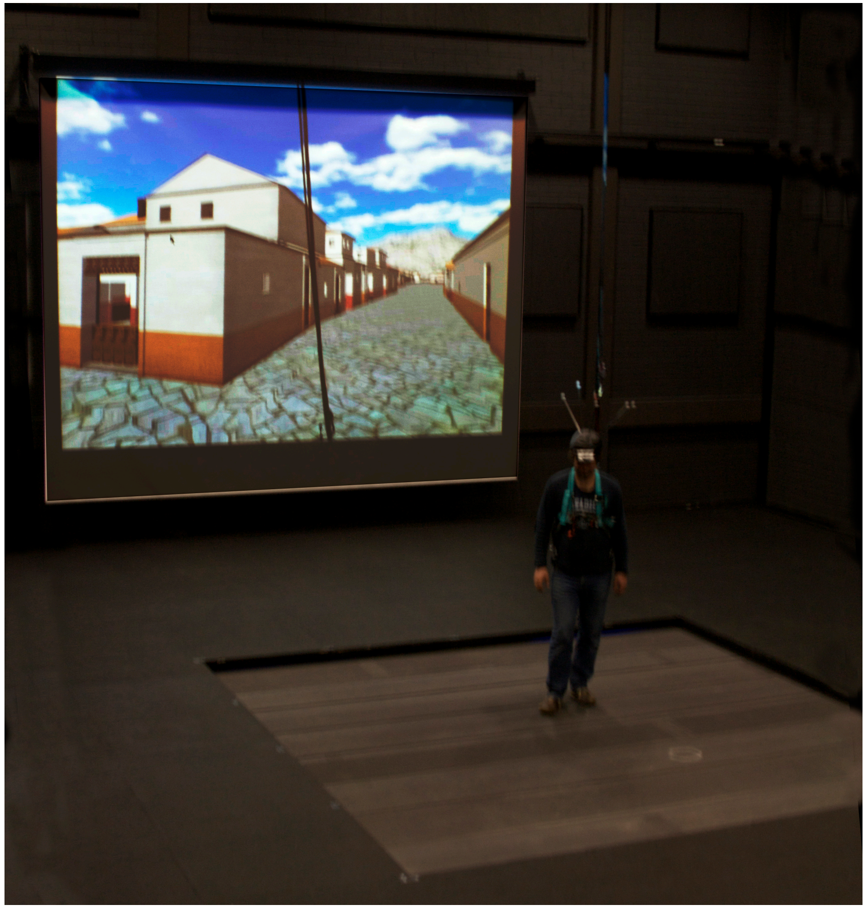
Foot haptics

Sarcos Biport

Iwata's GaitMaster

Whole-body haptics

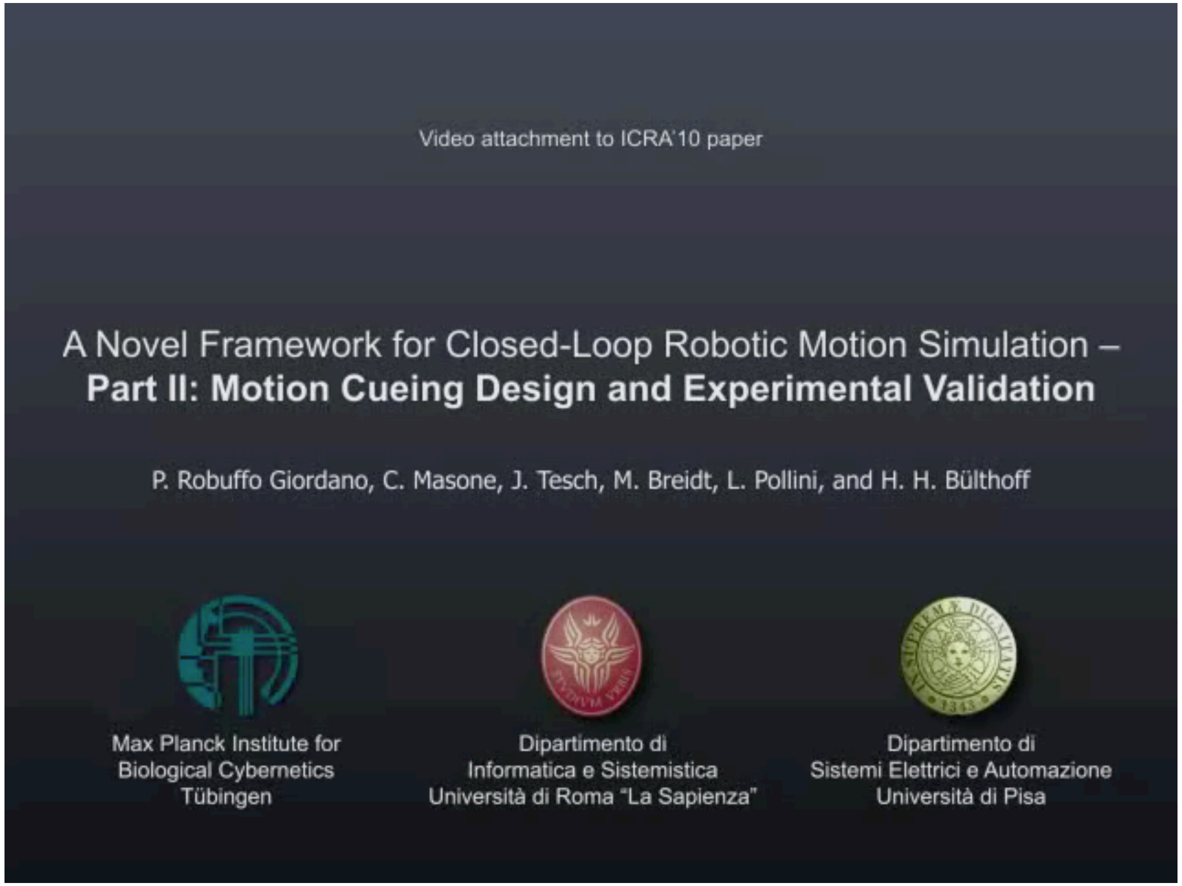
Sarcos Treadport II



CyberWalk platform

with immersion in Virtual Reality/Environment (VR/VE)

Whole-body haptics: The Ferrari race



video

with inertial immersion in Virtual Reality/Environment (VR/VE)

Other robots that apply forces to humans

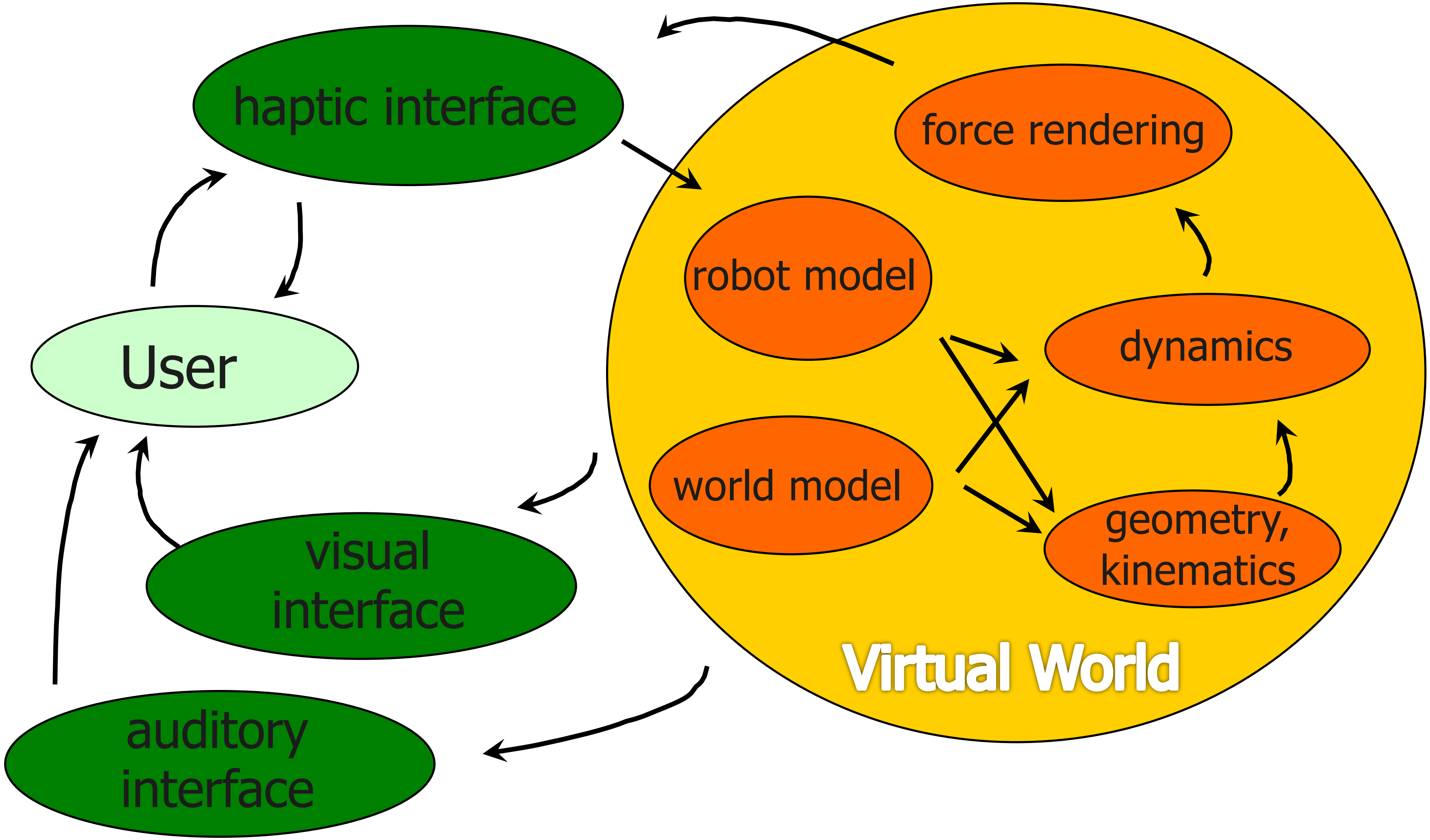
a thin line separates similar robotic devices

- programmable exercise machines
- rehabilitation robots
- assist devices
- powered exoskeletons

most are intended for interaction with the real world, but immersion in VR is also possible

- in fact, the most general interaction may involve not only vision (and sound) but also haptics
- similar case in human-computer interfaces (HCI)

A typical haptic/VR system



Relevant aspects for haptics & VR

- technical issues
  - device: specifications, design, control transparency & stability
  - simulated environment: fidelity
    - high for objects, low for haptic interaction
- device/hardware
  - precise registration to a simulation
  - human factors for device use
  - cost, size, and dissemination
- real-time simulation/software
  - visual displays: 30-60 Hz
  - haptic displays: 1 kHz, 1 msec delay
    - high-frequency contact transients
    - control instability (especially for hard environments)

Types and features of motion interfaces
from the user point of view

- passive motion interfaces
  - non-inertial systems (e.g., joysticks)
  - inertial systems (e.g., Stewart platforms)
  - rate control is used
  - user is seated and does not expend energy
- active motion interfaces
  - normal rooms with CAVE or HMD displays
  - locomotion interfaces (e.g., exercise machines) – actuated or not
  - cyclic proportional control is typically used (gait)
  - user expends energy to move through VE
  - sensorimotor integration for geometry
  - human power enhancers for locomotion

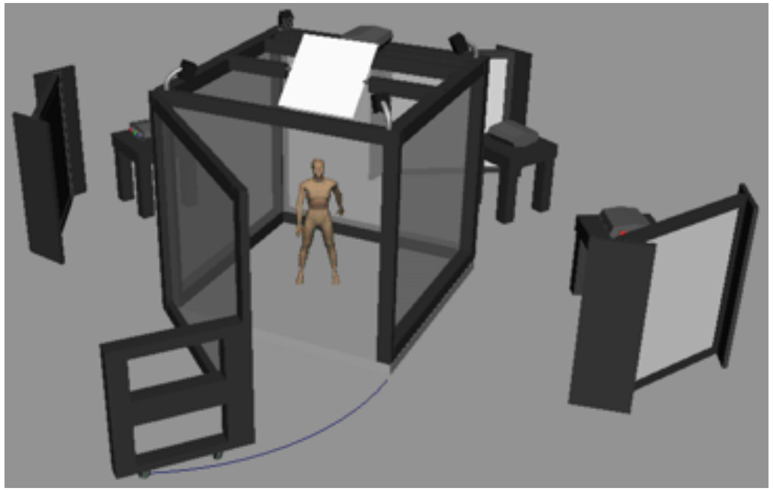
Possible applications

- entertainment: arcades and exercise
- health rehabilitation
- military training and mission rehearsal
- architectural walkthroughs
- education
- mobile interface (virtual tourist, e-travel)
- physio-psychological research

Types of locomotion interfaces

- instrumented rooms
- pedaling devices
- walking-in-place systems
- programmable foot platforms
- treadmills
- non-actuated platforms
- moving bases
- ...

CAVE and HMD



Cave Automatic Virtual Environment (ELV, Univ Illinois Chicago)

eMagin Z800

Head Mounted Display (with tracker)

Room-size environments

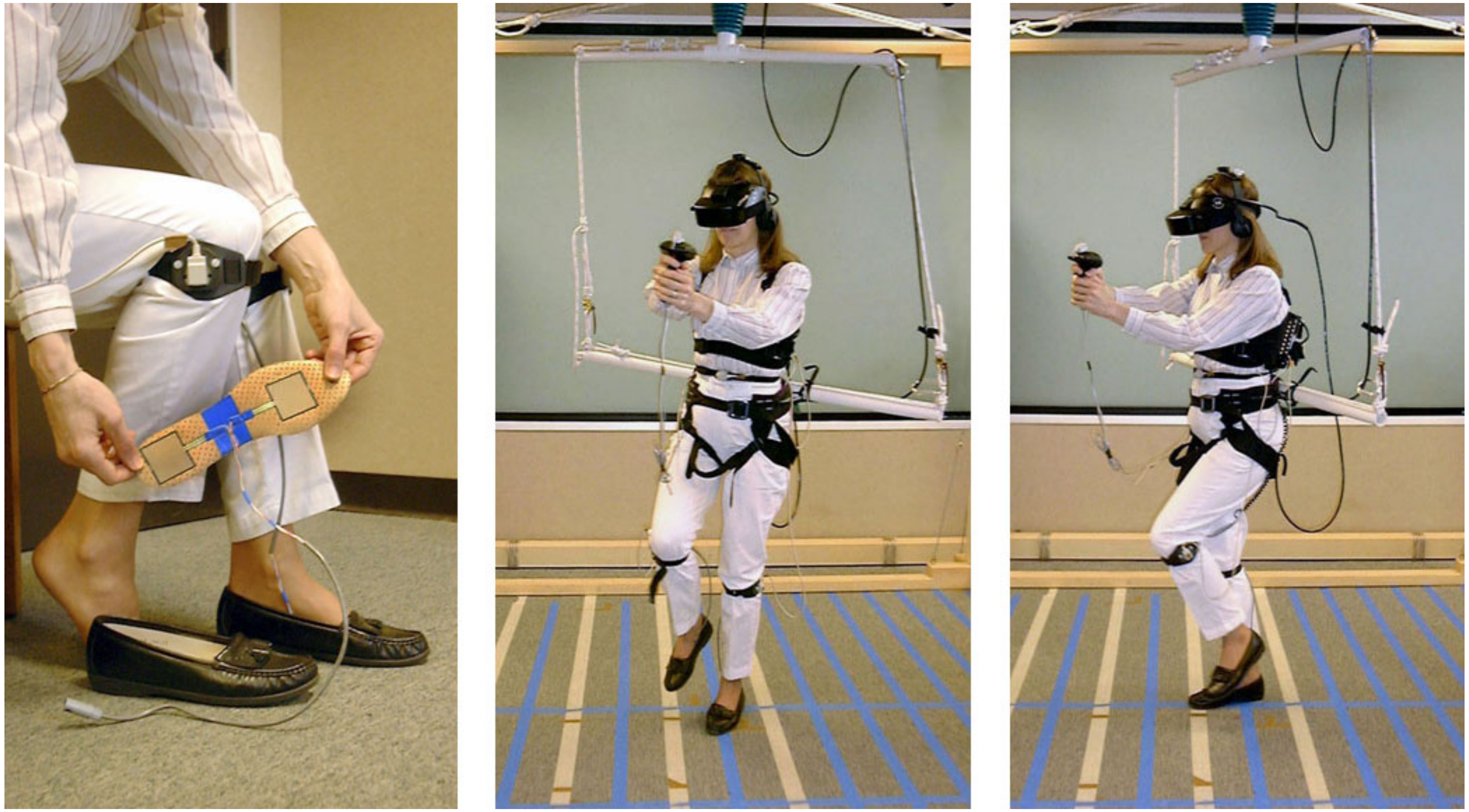
Room instrumentation

Pedaling devices

Tectrix VR bicycle
(Georgia Tech)

Sarcos Uniport

Walking-in-place systems



Templeman's Gaiter system
(US Navy Research Lab)

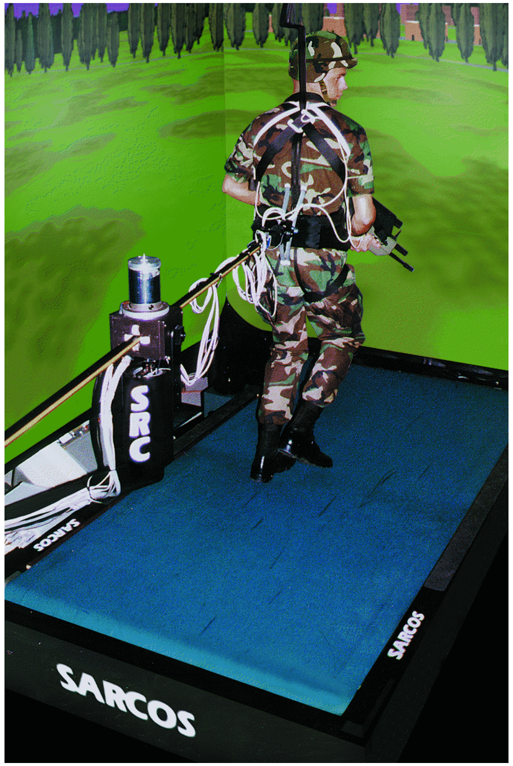
Programmable foot platforms

Sarcos Biport

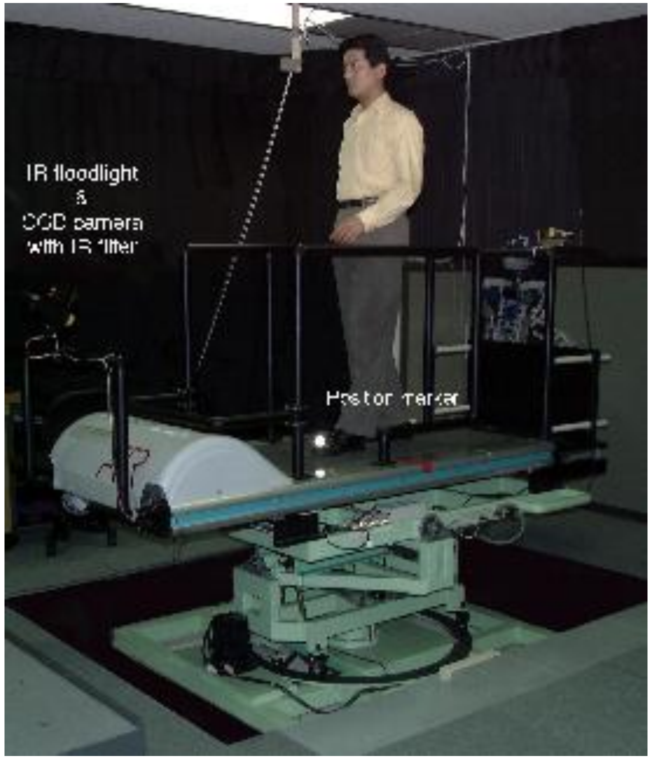
Iwata's GaitMaster

cyclic walking in 3D

1D linear treadmill platforms



Sarcos Treadport



ATR ATLAS

ATR GSS
(ground surface
simulator)

Sarcos Treadport

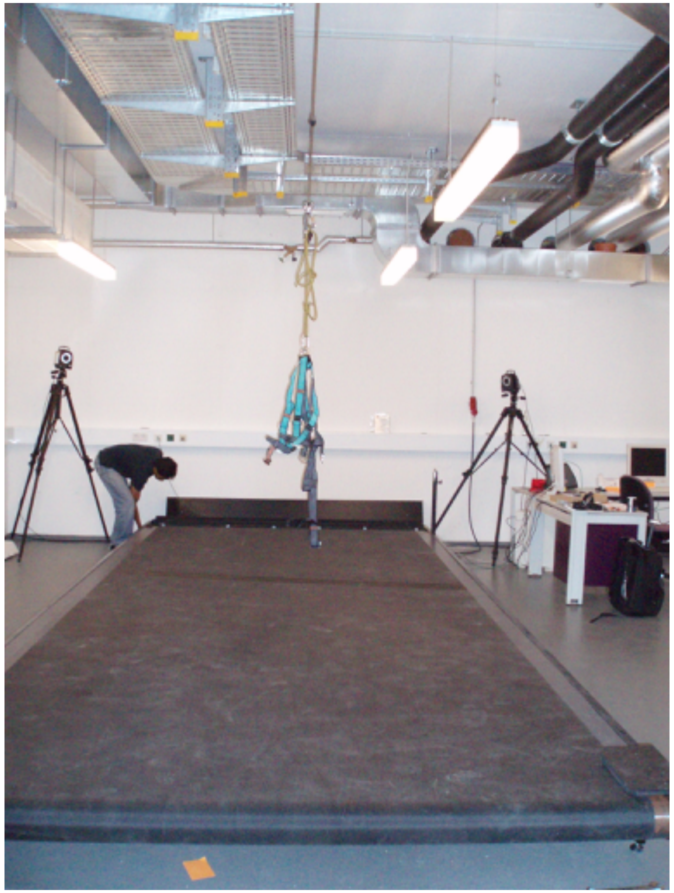
video

John Hollerbach (University of Utah)
on KSL Channel 5 TV, April 2008

Sarcos Treadport

platform has a moderate tilting capability (slow)
gravity emulation by a force applied through the tether

1D treadmill platforms

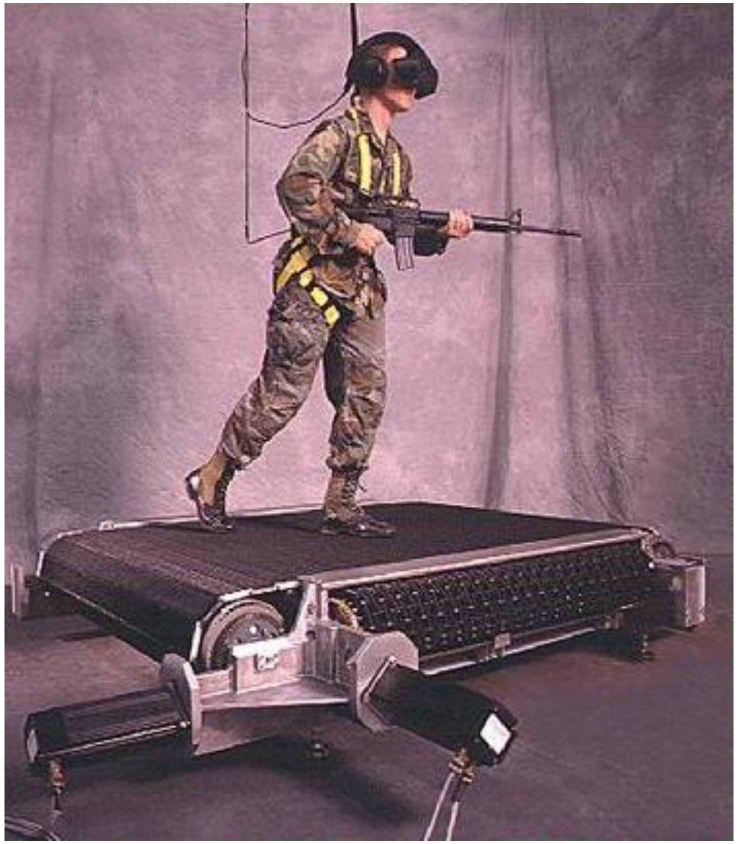


linear

Max Plank Institute, Tübingen

circular

2D planar treadmill platforms



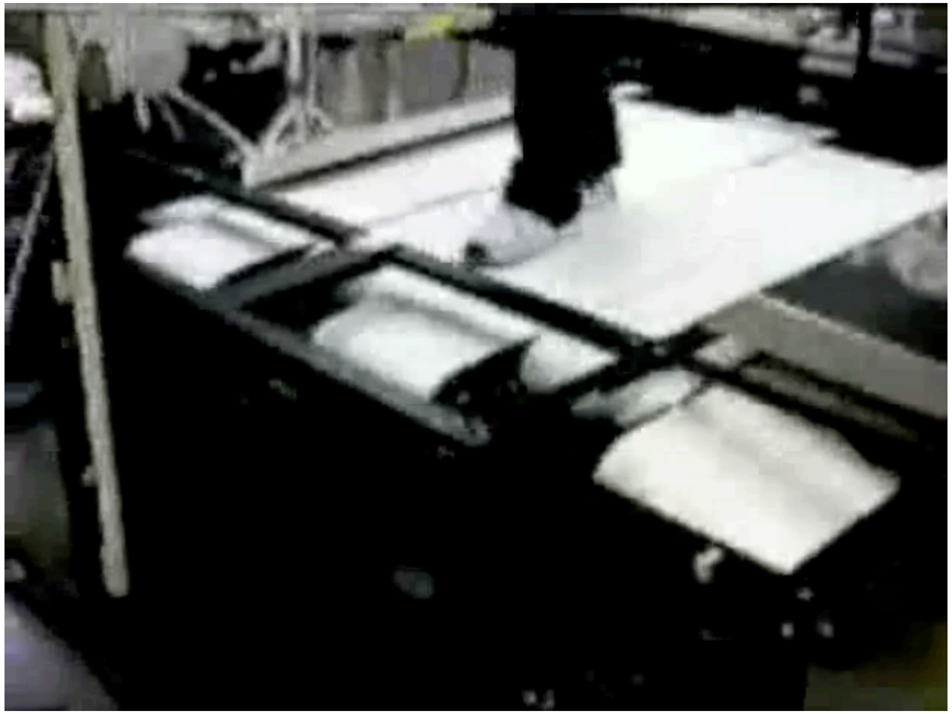
Omni-Directional
Treadmill (D. Carmein)

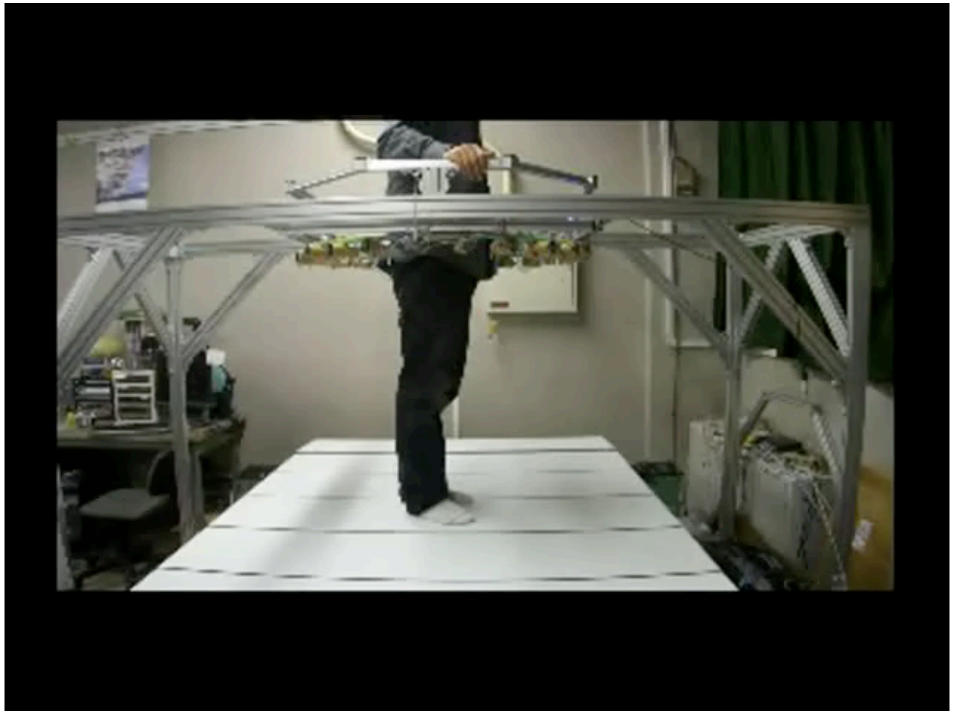
Iwata's Torus
Treadmill

Torus treadmill

video

video





new version (2011)

H. Iwata (University of Tsukuba)

Omni-Directional Treadmill (ODT)

video

May 2005

video

May 2006

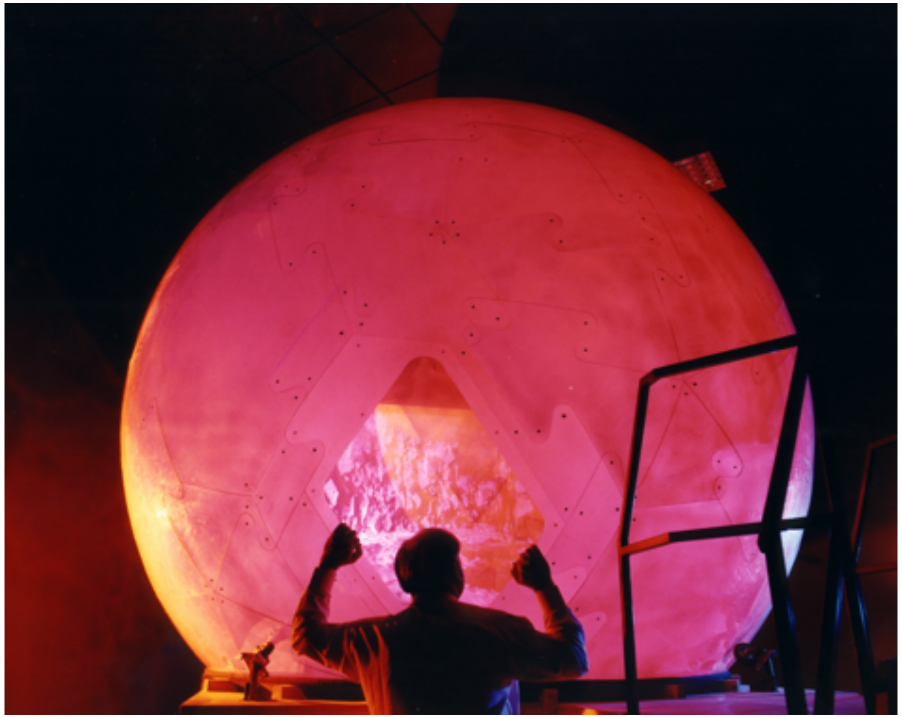
Virtual Space Devices, Inc. (David Carmein)

2D planar treadmill platforms

CyberWalk platform (the largest in the world!)

2D locomotion interfaces
without actuation

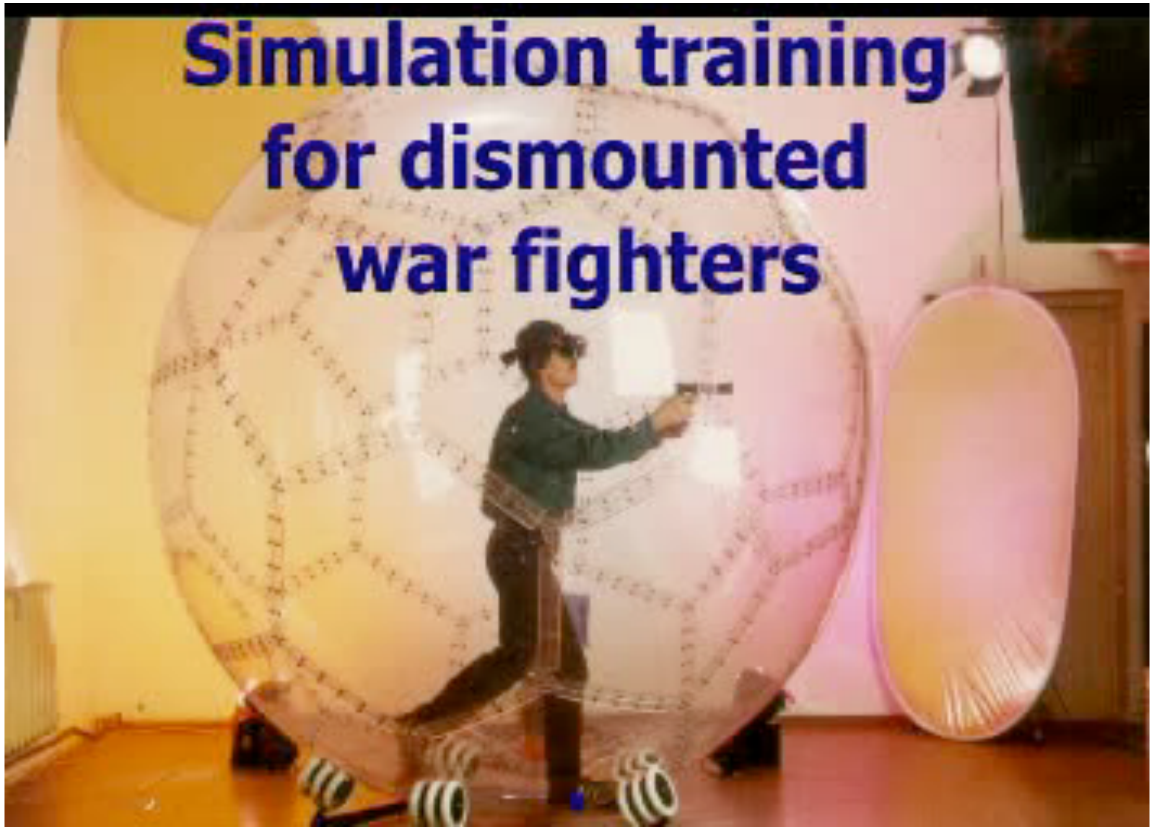
Virtusphere
(R. Latypov)



Cybersphere
(University of Warwick)

both are non-actuated devices, with curved walking surface

Virtual Sphere



video

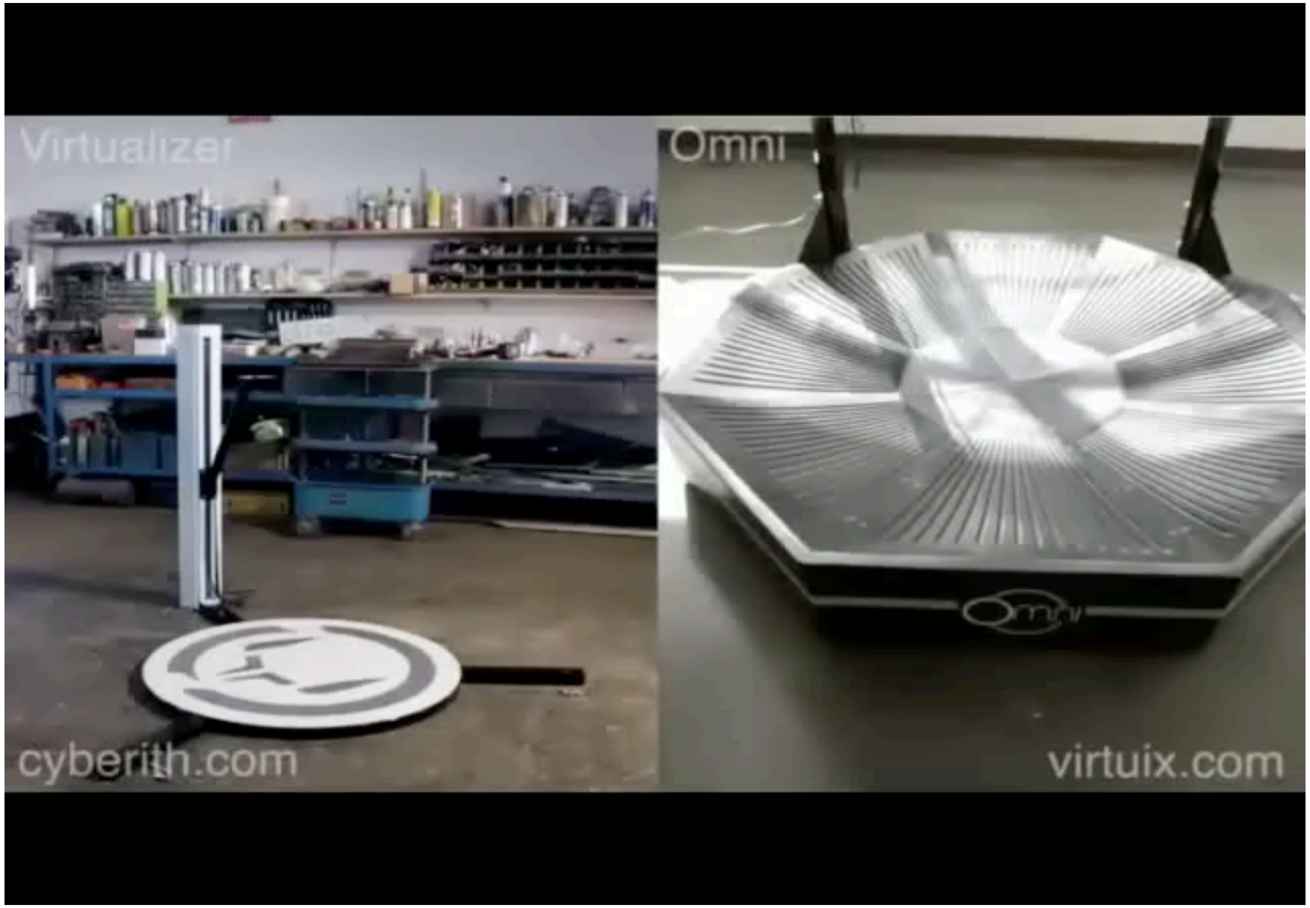
http://www.virtusphere.com

Cyberith Virtualizer

video

arrived in June 2016 at the DIAG Robotics Lab

Cyberith Virtualizer vs. Virtuix Omni



video

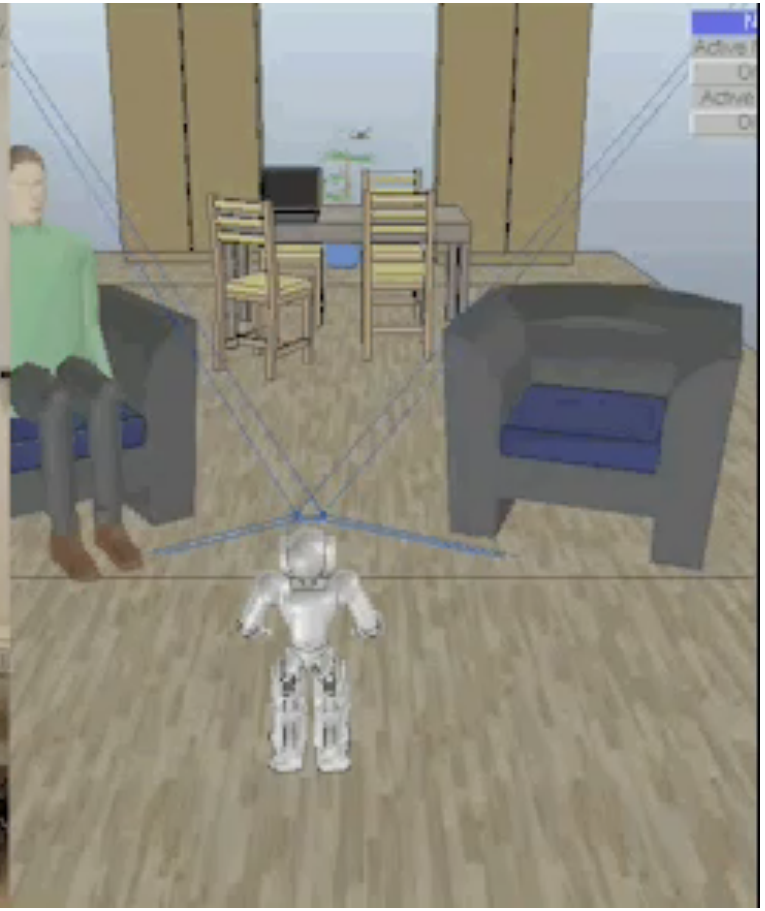
similar compact locomotion platforms (sensed, but not actuated)
to be used with other HMI/VR devices (Oculus RIFT, Kinect, video games, ...)

Cyberith platform and remote control
(telepresence)

video

Oculus Rift HMD

video



passive but
sensorized!

NAO humanoid (virtual in VREP, real in the lab)

Infinadeck

video

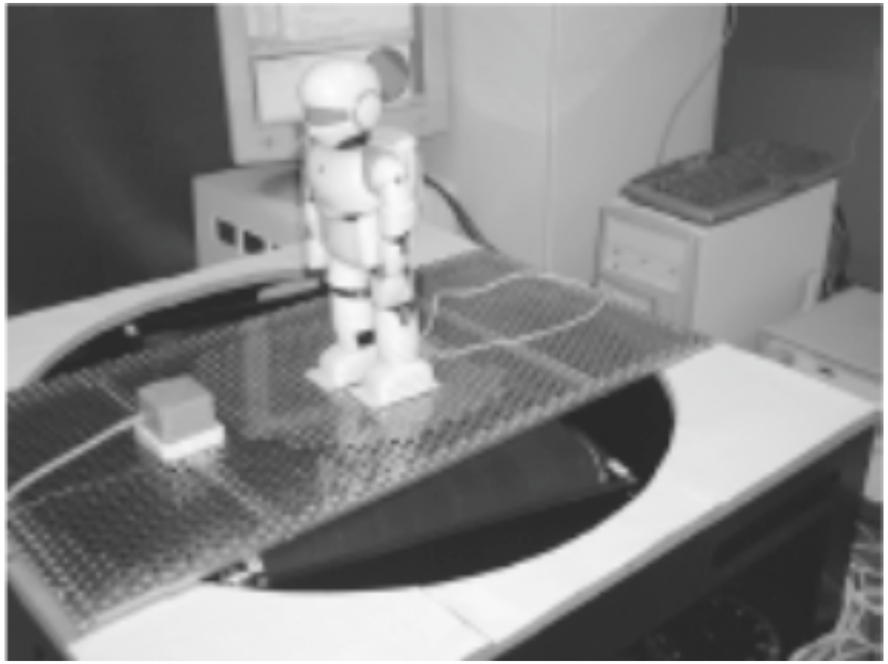
compact actuated omnidirectional locomotion platform (with body sustain)

presented at the Consumer Electronic Show in Las Vegas (CES 2016)

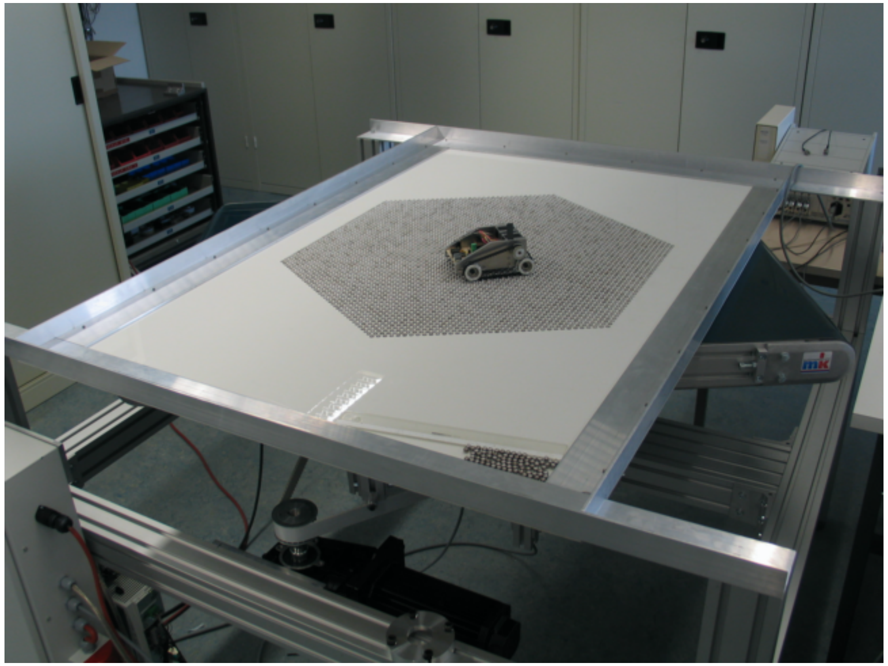
video

...in a CAVE environment

Other 2D locomotion interfaces



BAT Ball Array Treadmill
(Kogakuin University)

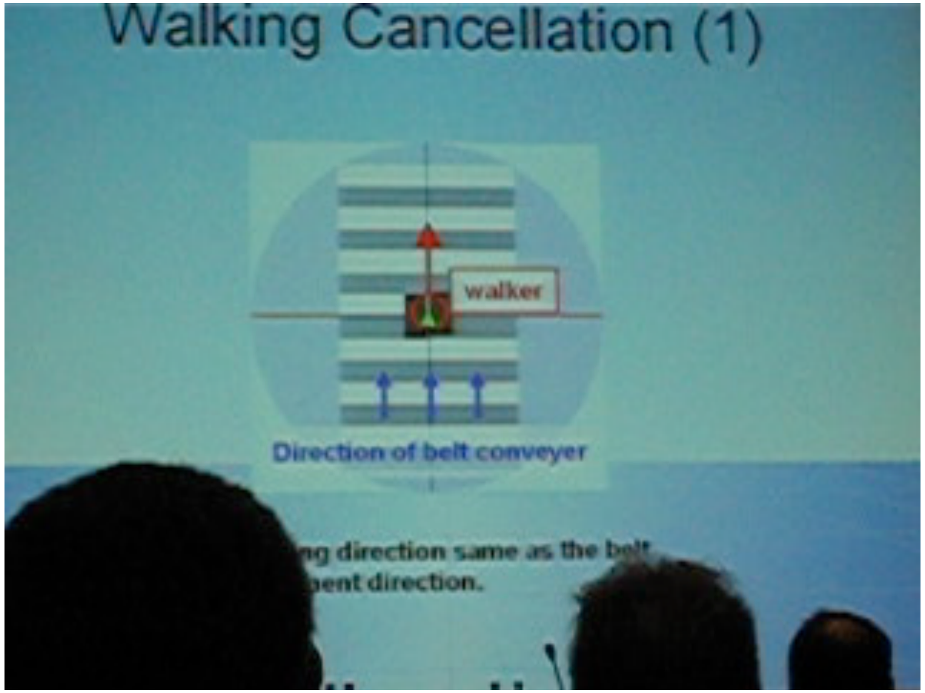


CyberCarpet

nonlinear couplings between rotation and translation

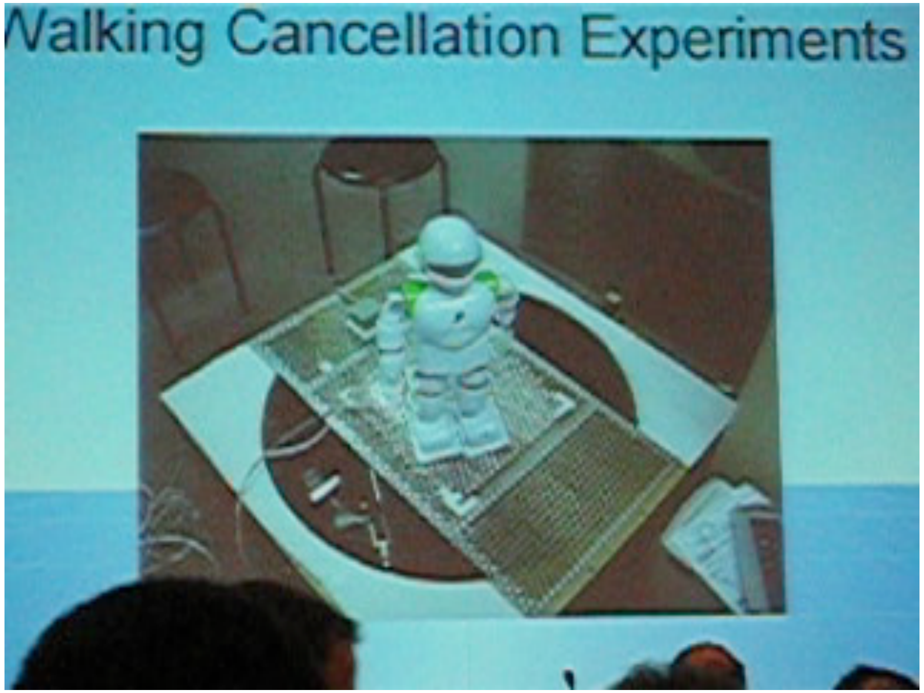
BAT Ball Array Treadmill

video



Simulation

video



Experiment

N. Akira (KU), W. Kohei (KU), K. Masato (Fujitsu Social Science Lab), S. Ryo (KU), I. Minoru (KU)
IEEE Virtual Reality Conference (VR 2005), Bonn

Moving bases for locomotion

CirculaFloor

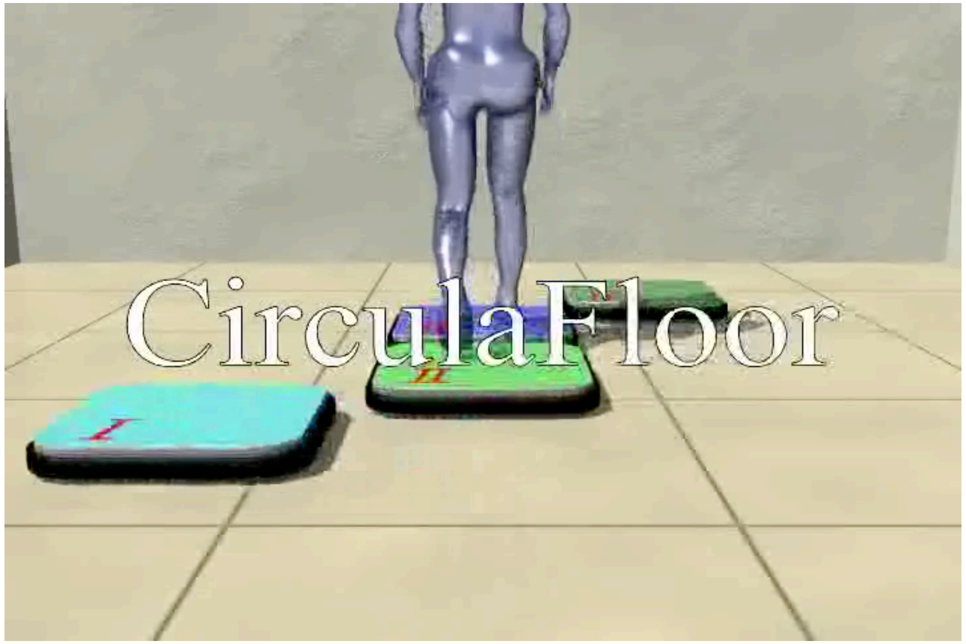
Powered Shoes

VR Lab, University of Tsukuba (Hiroo Iwata)

general objective is to cancel walker's motion...

CirculaFloor

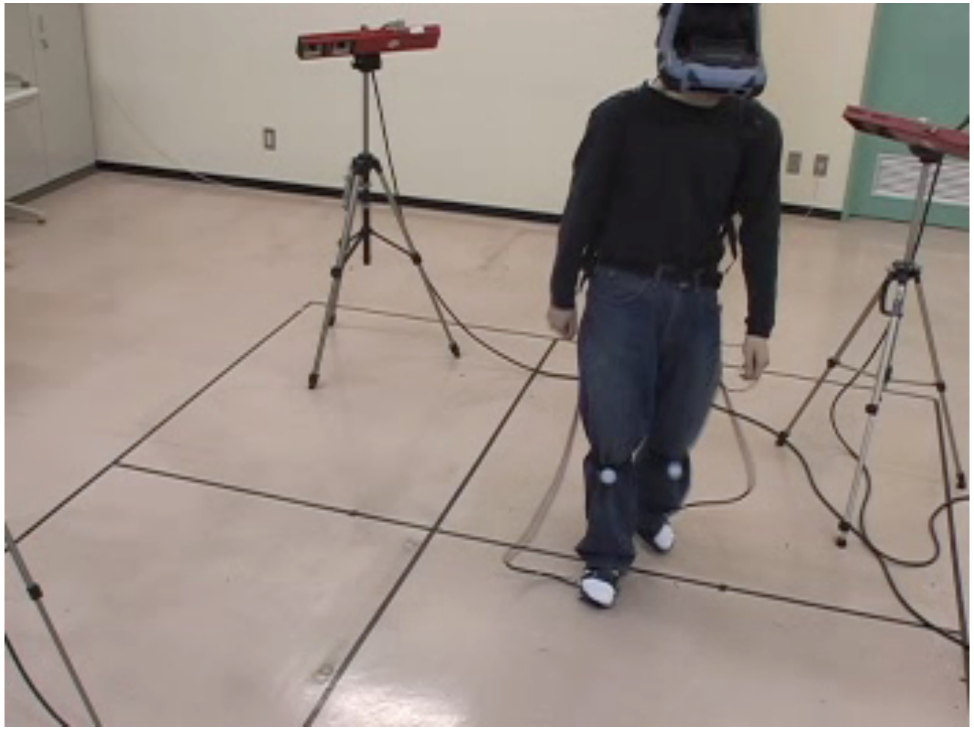
video



video

University of Tsukuba
ACM SIGGRAPH 2004 Conference, Los Angeles

Powered Shoes



video

University of Tsukuba
ACM SIGGRAPH 2006 Conference, Boston

Other commercial motion interfaces ...

Nintendo Wii Fitness

Microsoft Kinect

what are their apparent limitations? and advantages?

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