Elective in Robotics

Haptic and Locomotion Interfaces

Prof. Alessandro De Luca

DIPARTIMENTO DI INFORMATICA
E SISTEMISTICA ANTONIO RUBERTI

SAPIENZA
UNIVERSITÀ DI ROMA

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*

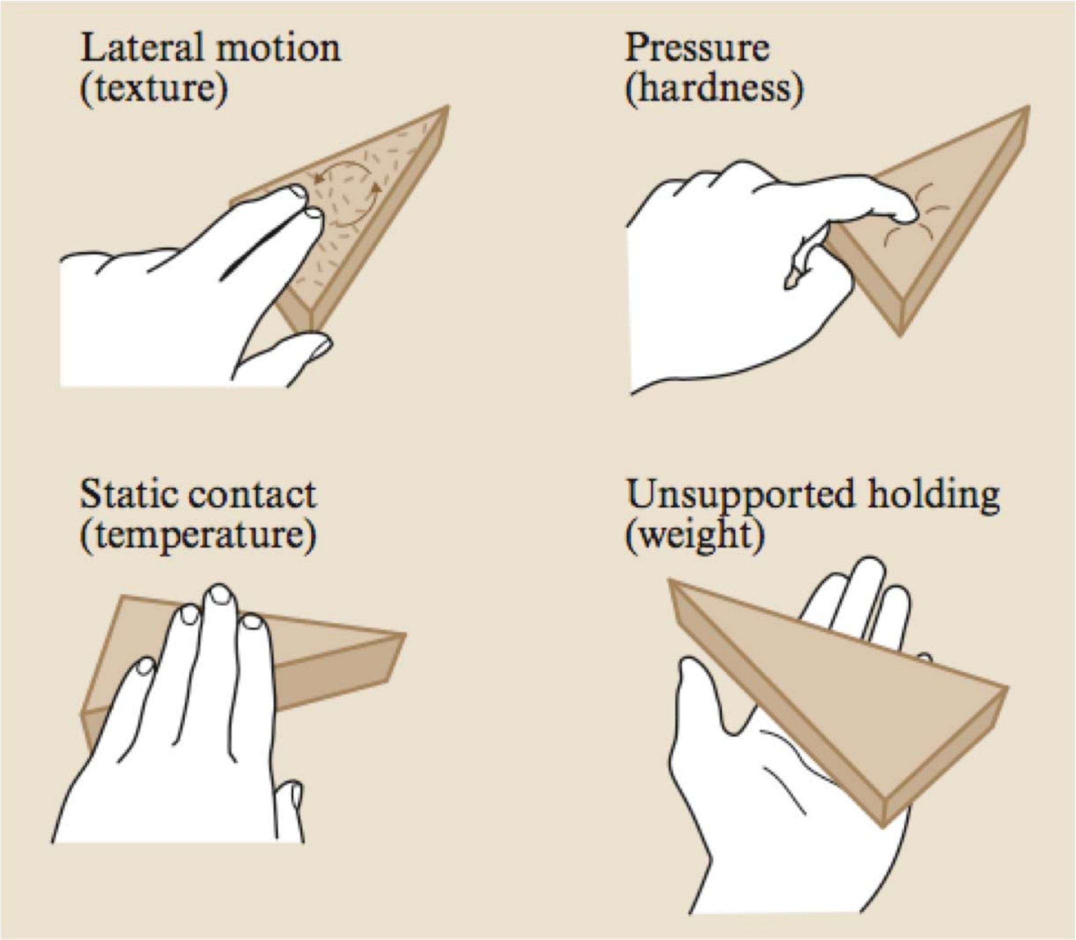
Locomotion interfaces refers to interfaces involving the human body/legs/feet and to natural or induced locomotion

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



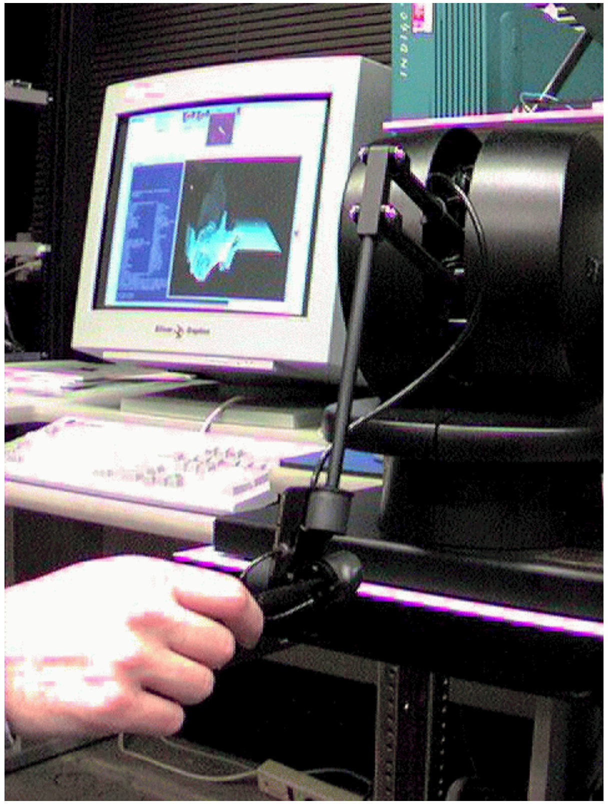
A force-exchange point of view

Haptic interfaces are robots that apply forces
to the 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

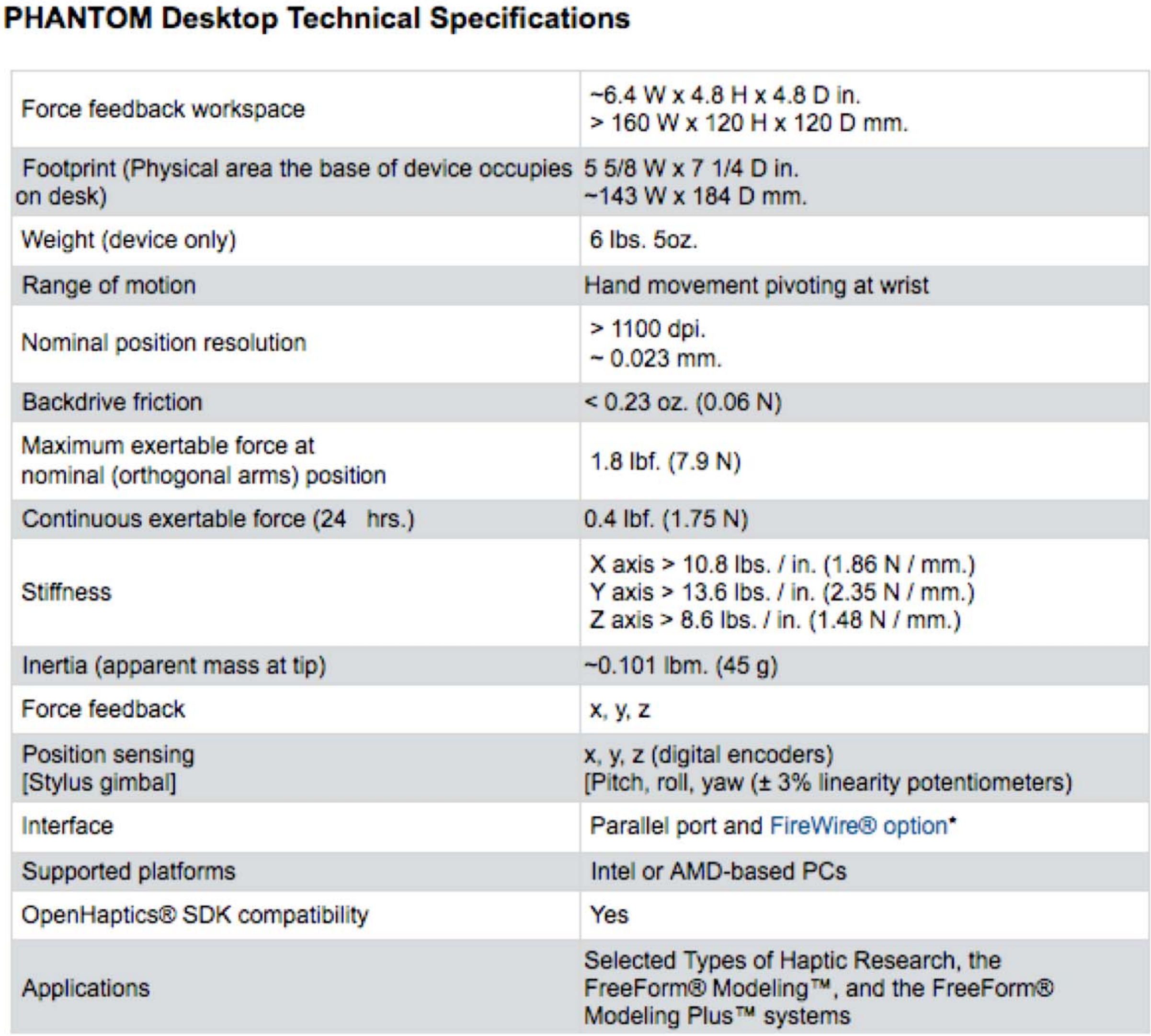
PHANTOM Desktop

PHANTOM Omni

(Sensable Technologies)

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

A VR application in surgery

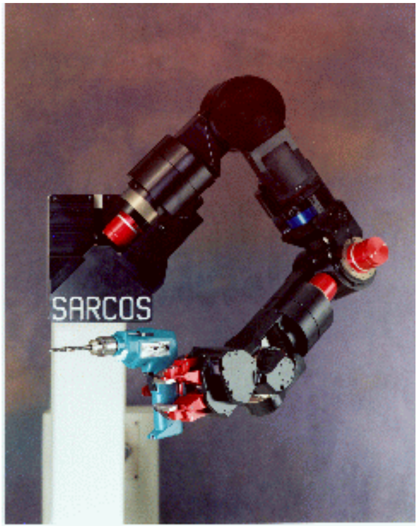
video

Immersive Touch

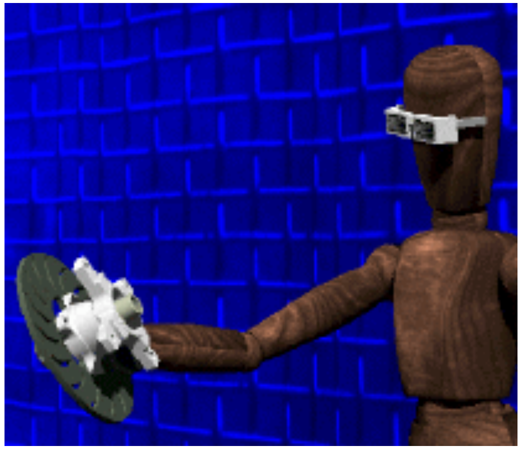
OMEGA 6D hand device

6D force feedback, Stewart platform
(Force Dimension)

Haptic interfaces:
Teleoperation and Virtual Reality

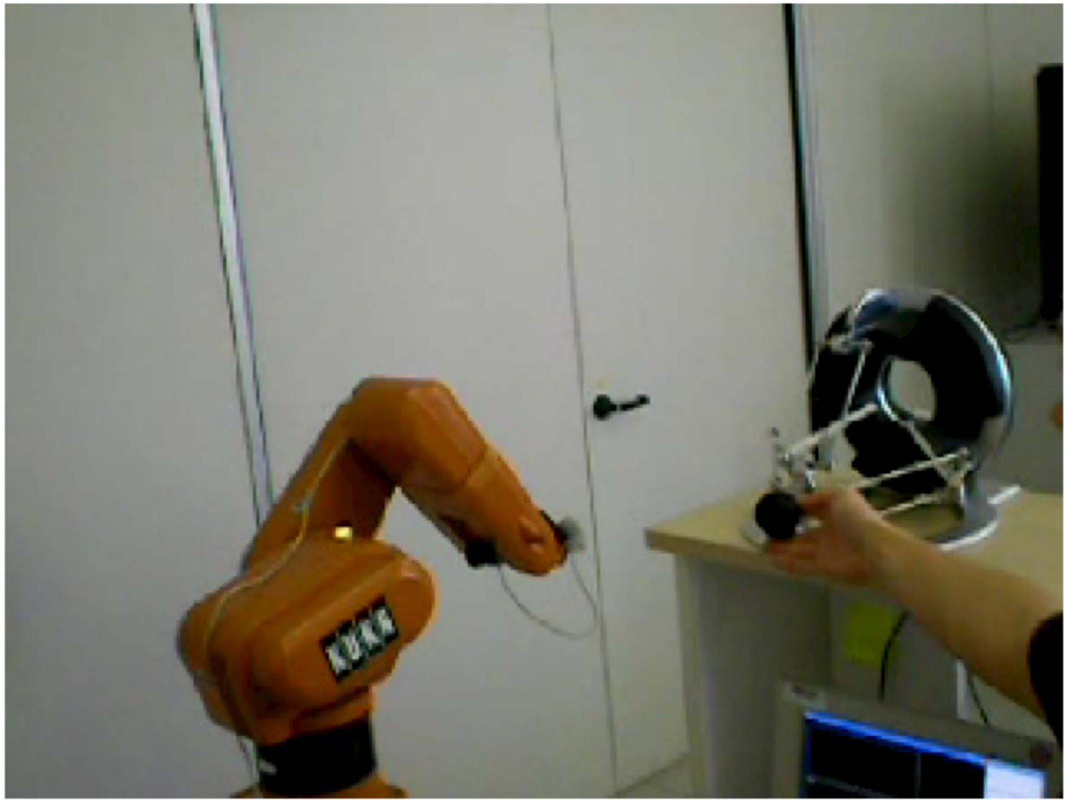


teleoperation
in the real world



an agent
in the virtual world

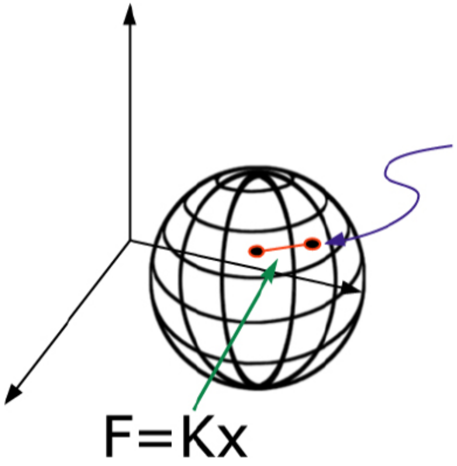
Teleoperation with an haptic interface

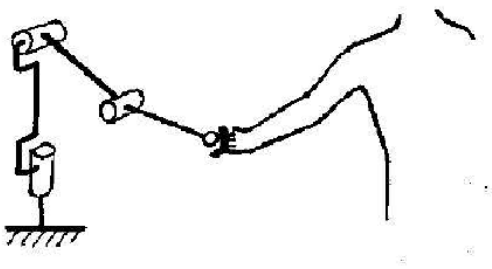


video

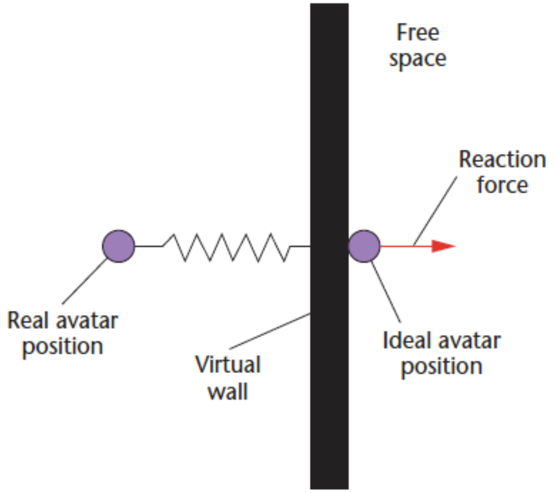
using an Omega device
(European project Robocast: http://131.175.32.10/Robocast)

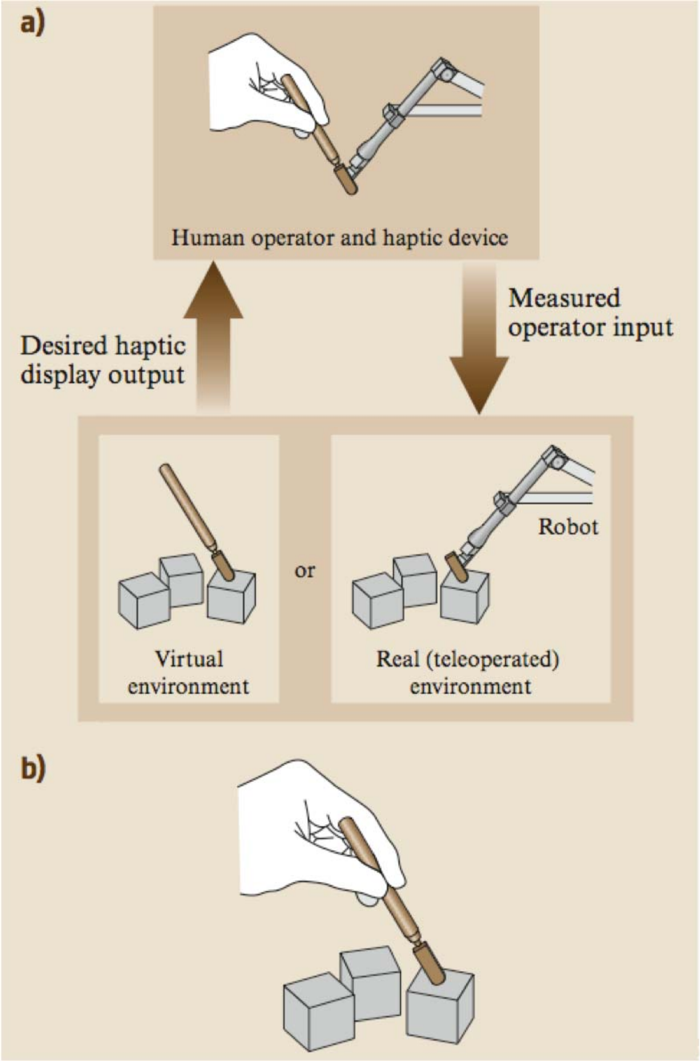
Force feedback from Virtual or Real world





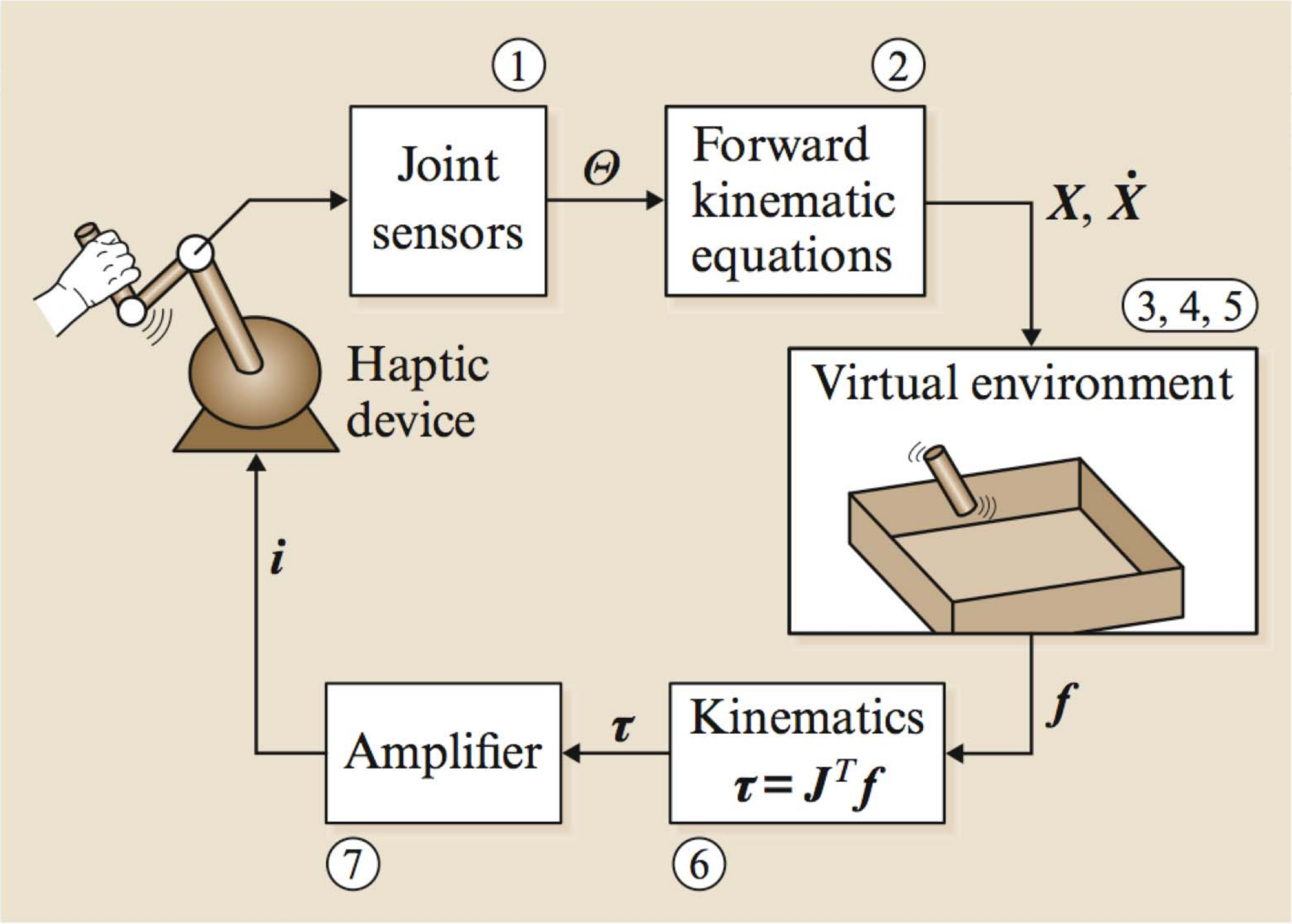
virtual environment compliance modeled with a spring/damper





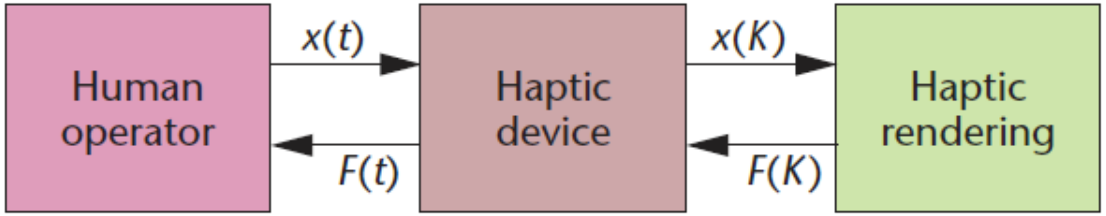
Haptic rendering control loop

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)



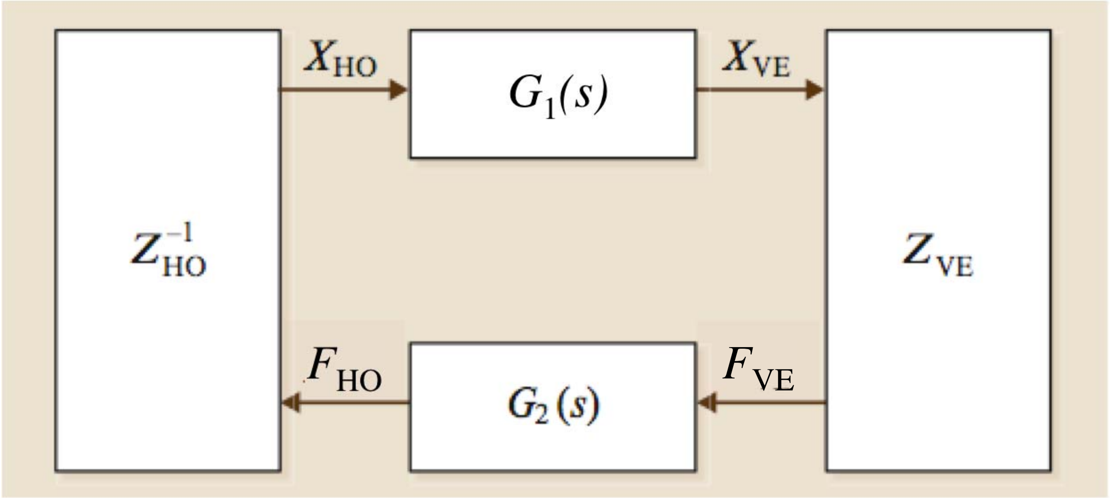
Haptic rendering control loop

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)

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

master coordination torque (applied by motors) → τ_m

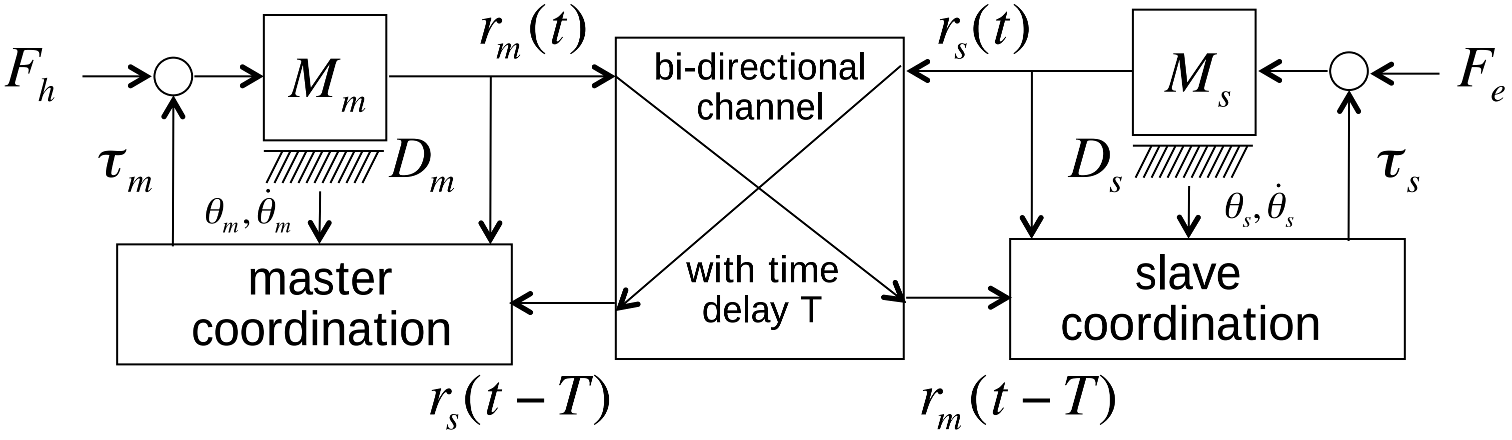
applied by human → F_h

slave
(environment side)

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

slave coordination torque (applied by motors) → τ_s

reaction torque by environment → F_e



master coordination

bi-directional channel

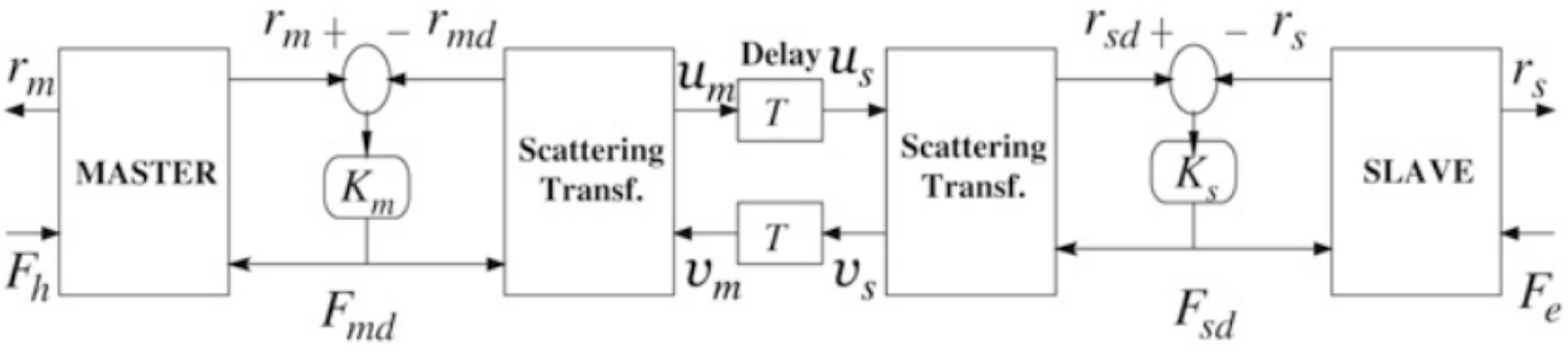
with time delay T

slave coordination

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

Telemanipulation (1-dof) control loop - 2

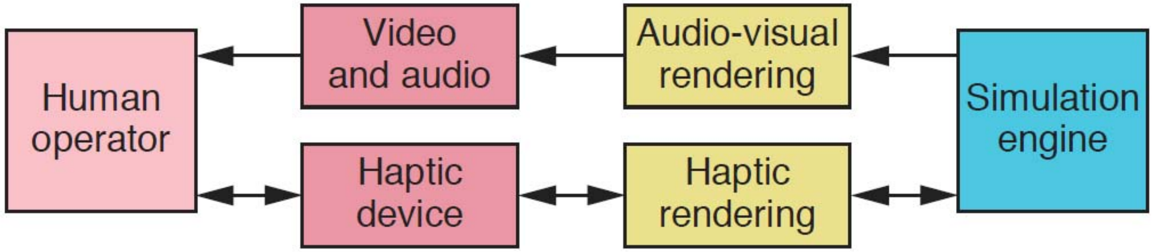
to preserve passivity of the closed-loop in the presence of delay T, scattering transformations are often introduced

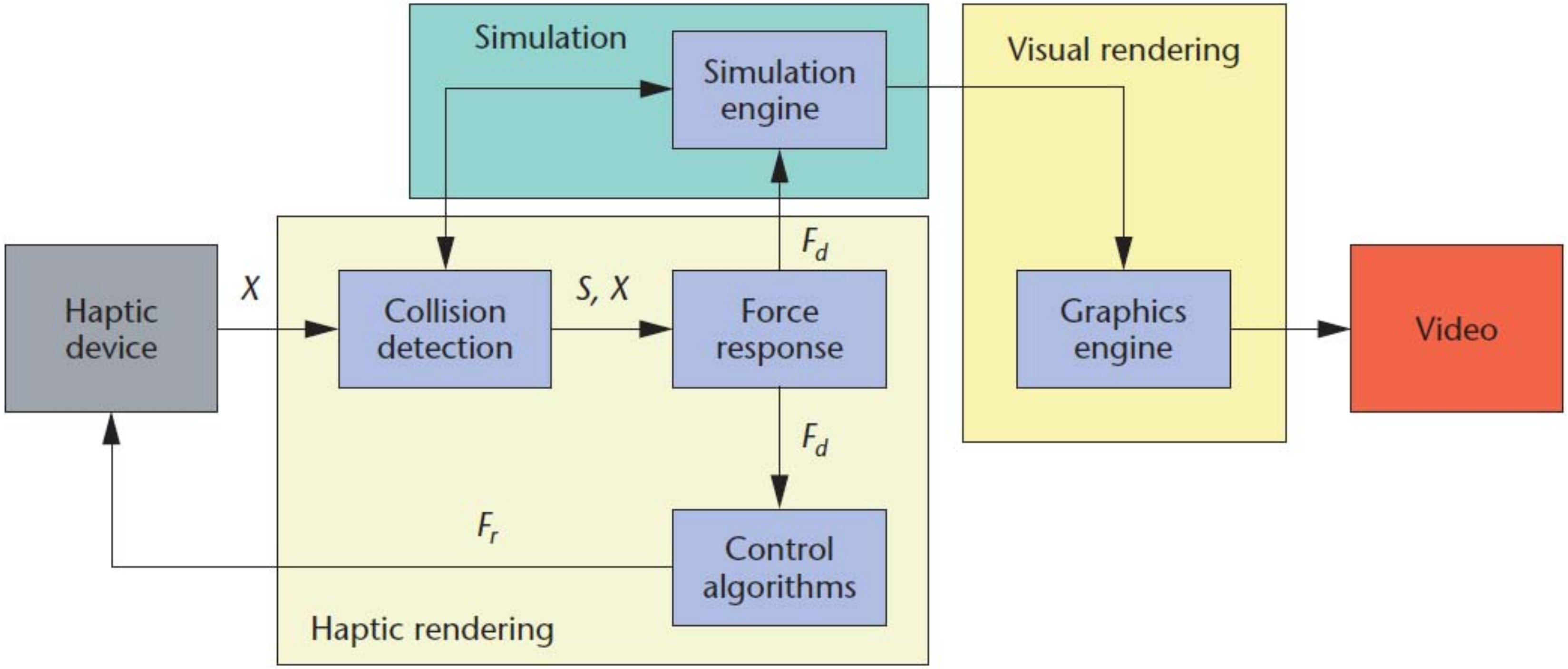


scattering variables u_m, v_s (and their delayed versions) are suitable combinations of local torque and position/velocity variables

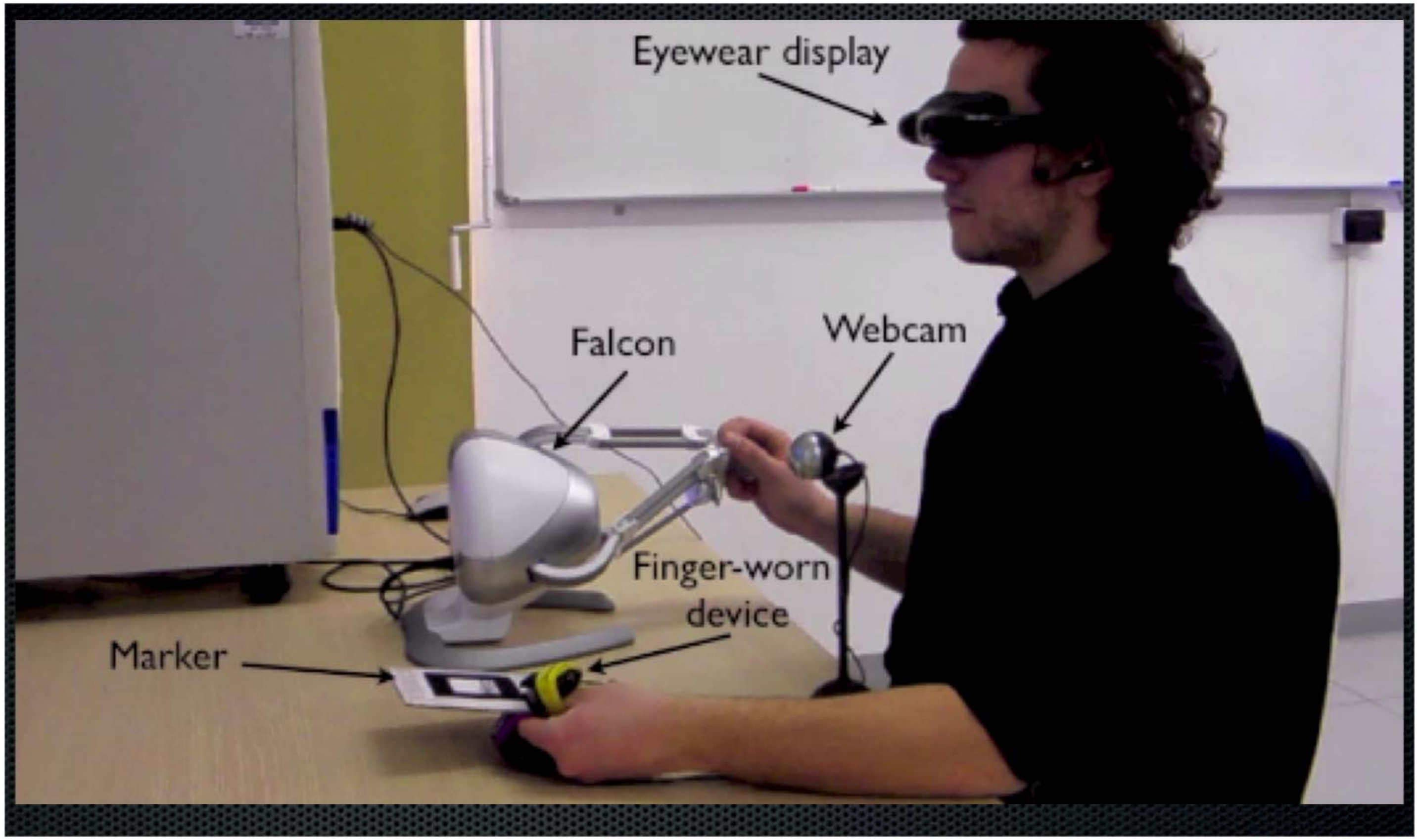
(see, e.g., Chopra, Spong, Lozano:
“Synchronization of bilateral teleoperators with time delay,” Automatica, 2008)

Haptic/visual rendering architecture





Haptic rendering and augmented reality



video

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

Mobile haptic devices - 1

+

=

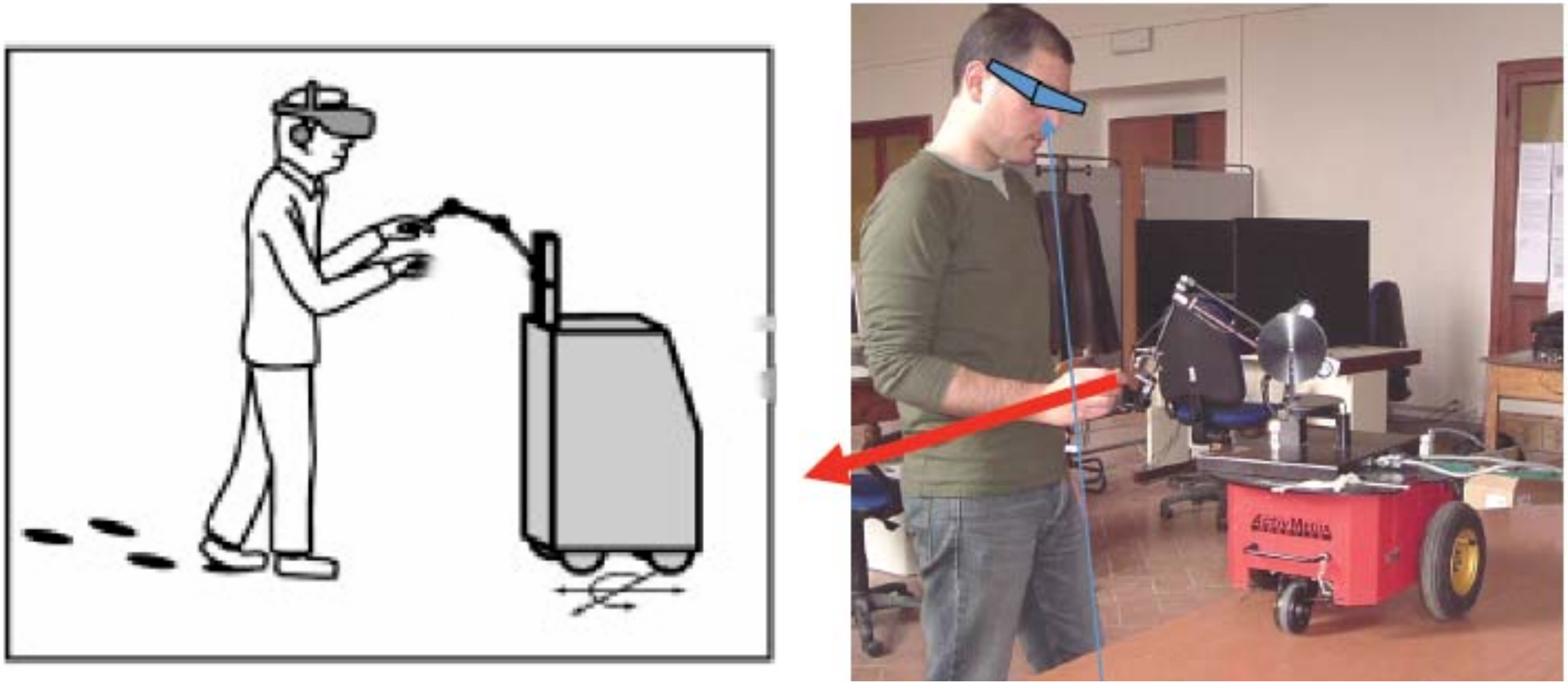
- Force controlled
- Limited workspace
- Fast dynamics

- Position controlled
- Unlimited workspace
- Slow dynamics

Unlimited workspace

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

Mobile haptic devices - 2



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

- see video on YouTube

  http://www.youtube.com/watch?v=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 attachment to ICRA'10 paper

A Novel Framework for Closed-Loop Robotic Motion Simulation – **Part II: Motion Cueing Design and Experimental Validation**

P. Robuffo Giordano, C. Masone, J. Tesch, M. Breidt, L. Pollini, and H. H. Bülthoff

Max Planck Institute for
Biological Cybernetics
Tübingen

Dipartimento di
Informatica e Sistemistica
Università di Roma "La Sapienza"

Dipartimento di
Sistemi Elettrici e Automazione
Università di Pisa

video

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

Other robots that apply forces to humans

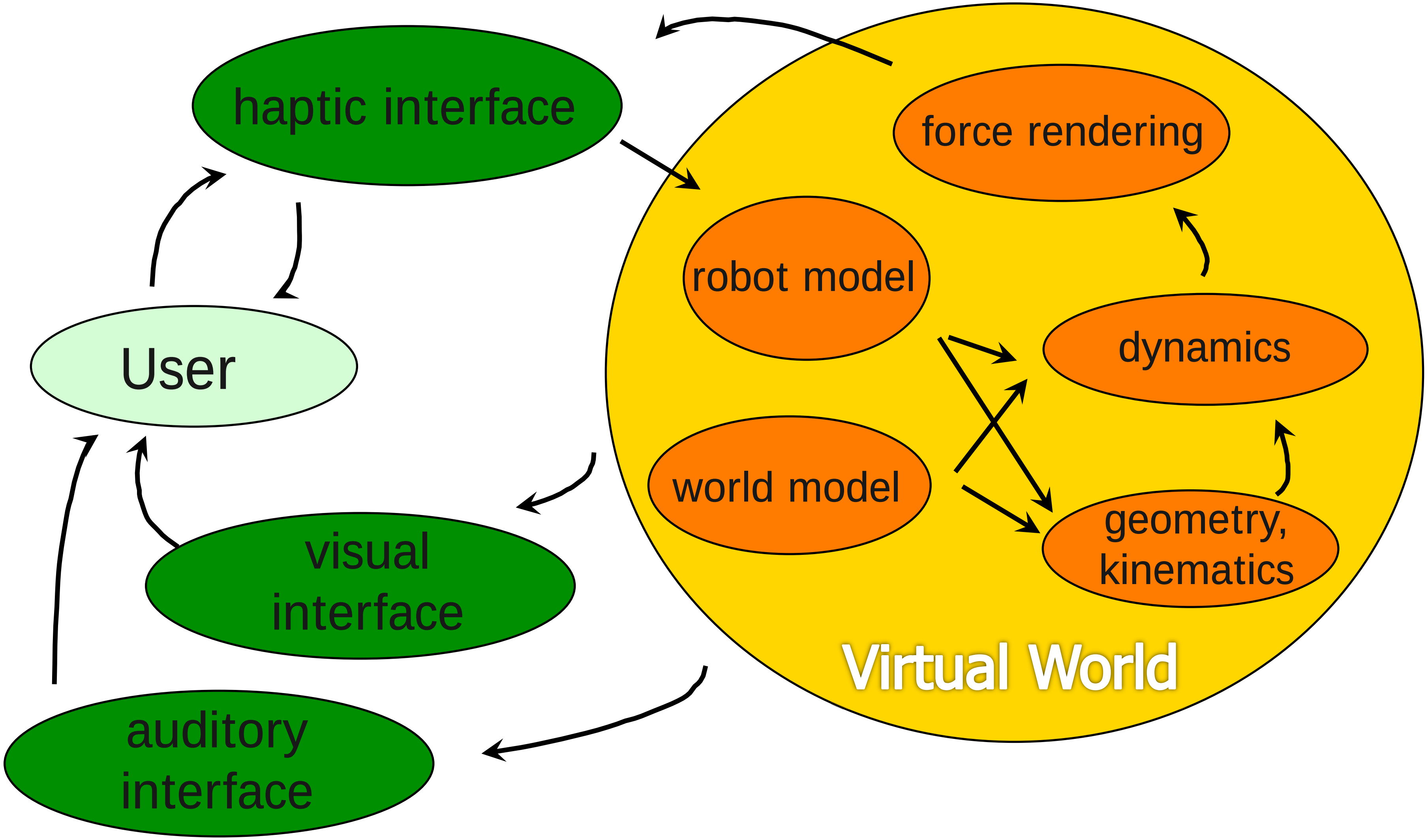
a thin line separates similar robotic devices

- 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



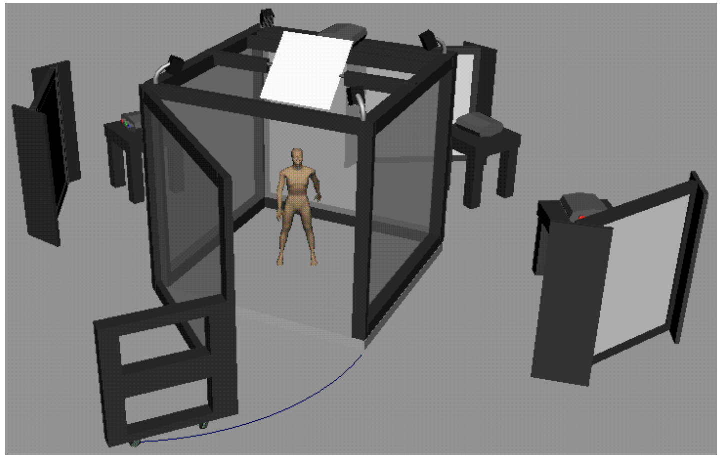
Relevant aspects for haptics & VR

- 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

- 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)
  - cyclic proportional control is typically used (gait)
  - user expends energy to move through VE
  - sensorimotor integration for geometry
  - human power enhancers for locomotion

CAVE and HMD



Cave Automatic Virtual Environment (ELV, Univ Illinois Chicago)

eMagin Z800

Head Mounted Display (with tracker)

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

- pedaling devices
- walking-in-place systems
- programmable foot platforms
- treadmills
- moving bases
- …

Pedaling devices

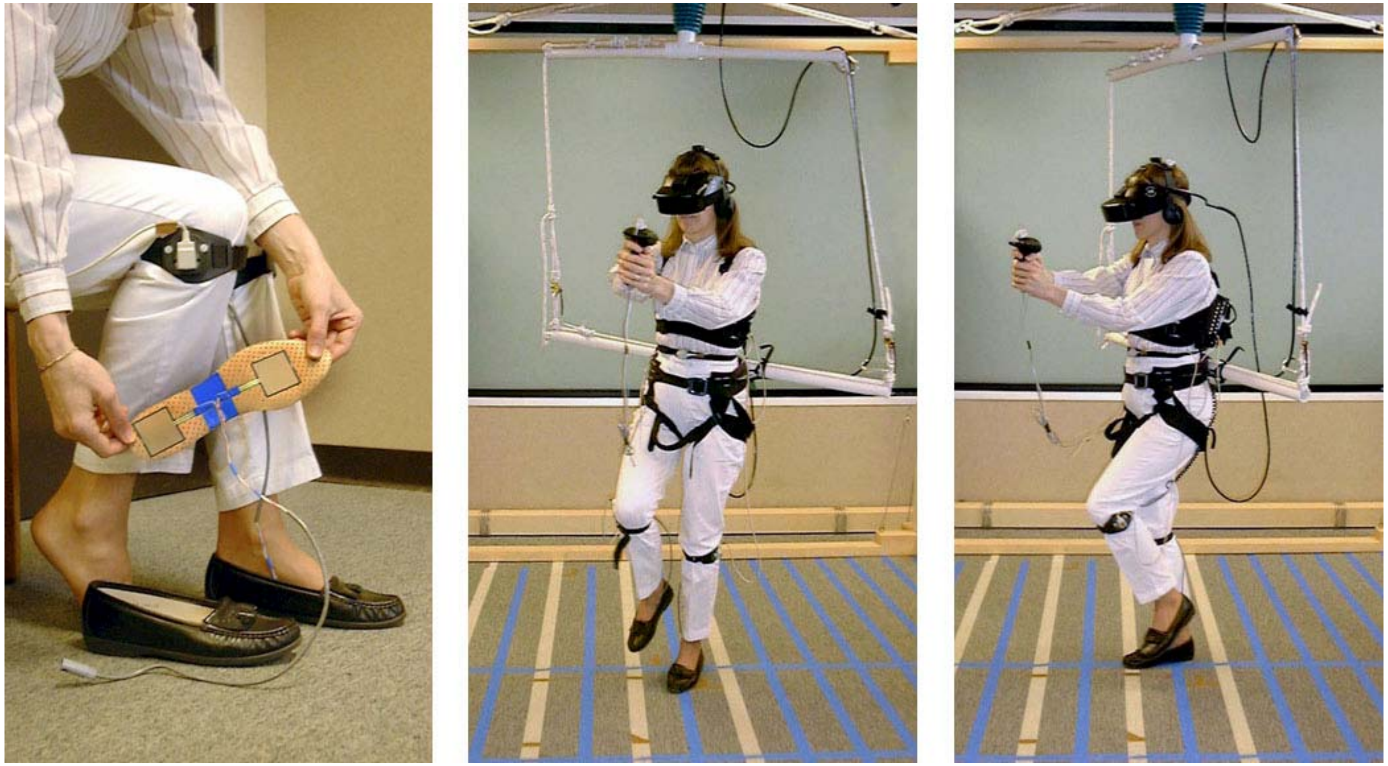
Tectrix VR bicycle
(Georgia Tech)

Sarcos Uniport

Room-size environments

Room instrumentation

Walking-in-place systems



Templeman’s Gaiter system
(US Navy Research Lab)

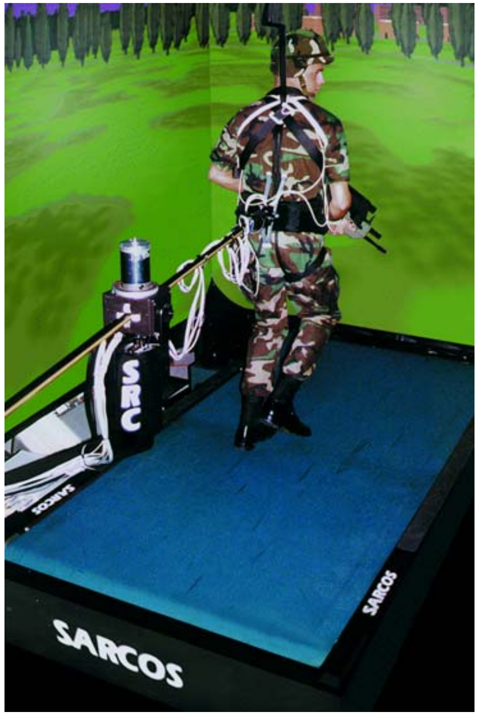
Programmable foot platforms

Sarcos Biport

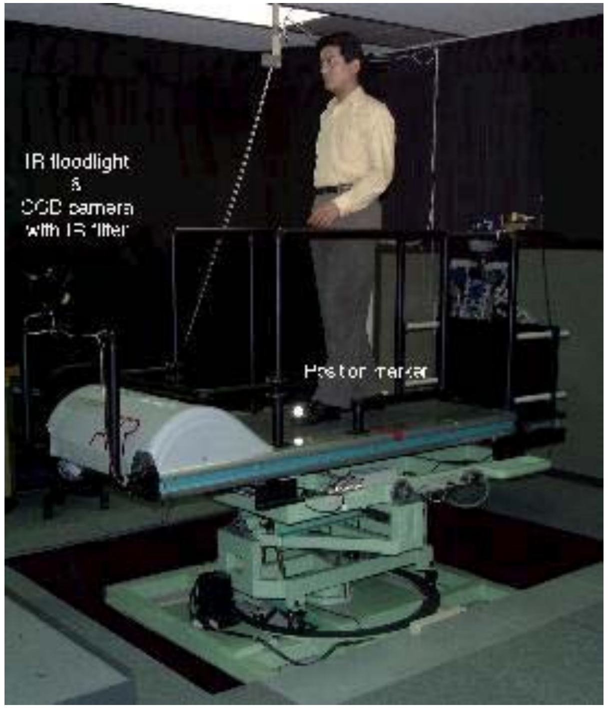
Iwata’s GaitMaster

cyclic walking in 3D

1D linear treadmill platforms



Sarcos Treadport



ATR ATLAS

ATR GSS
(ground surface
simulator)

Sarcos Treadport video

video

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

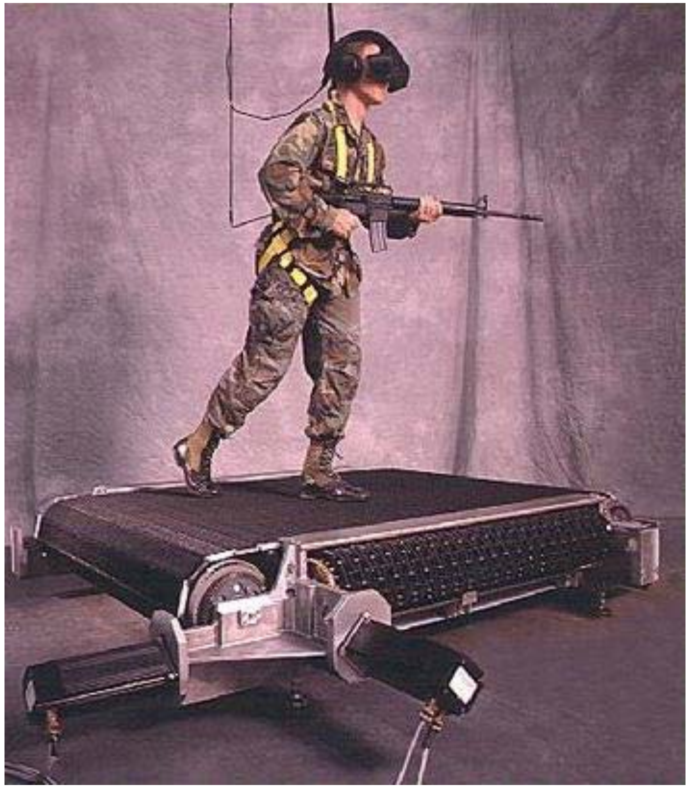
1D treadmill platforms

linear

circular

Max Plank Institute, Tübingen

2D planar treadmill platforms



Omni-Directional Treadmill (D. Carmein)

Iwata's Torus Treadmill

Torus treadmill clip

video

H. Iwata (University of Tsukuba)

Omni-Directional Treadmill (ODT)

video

Virtual Space Devices, Inc.
Omni-Directional Treadmill
May 2005

May 2005

video

May 2006

http://www.vsd.bz
(Virtual Space Devices, Inc.)

2D planar treadmill platforms

CyberWalk platform (the largest in the world!)

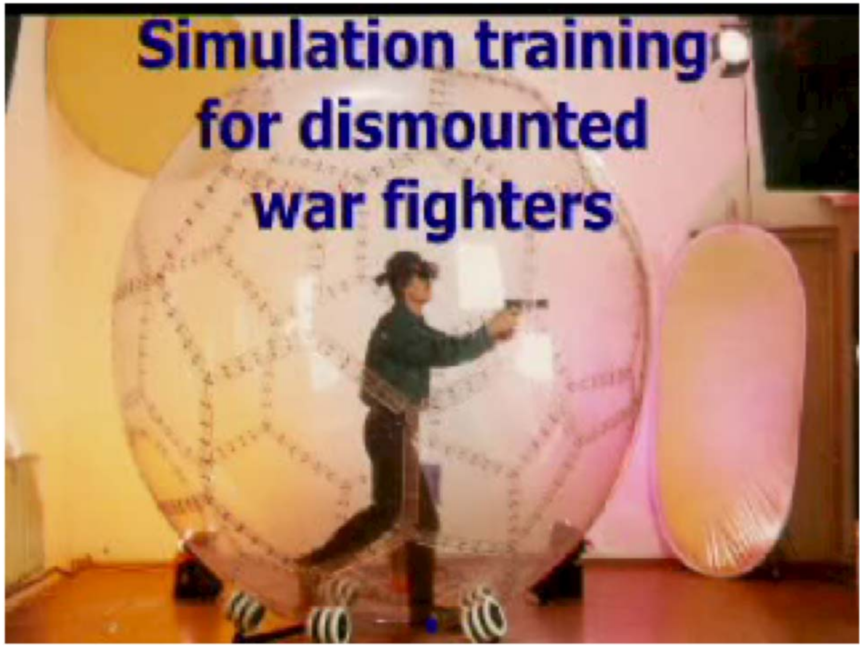
2D passive locomotion interfaces

Virtusphere
(R. Latypov)

Cybersphere
(University of Warwick)

both are passive devices, with curved walking surface

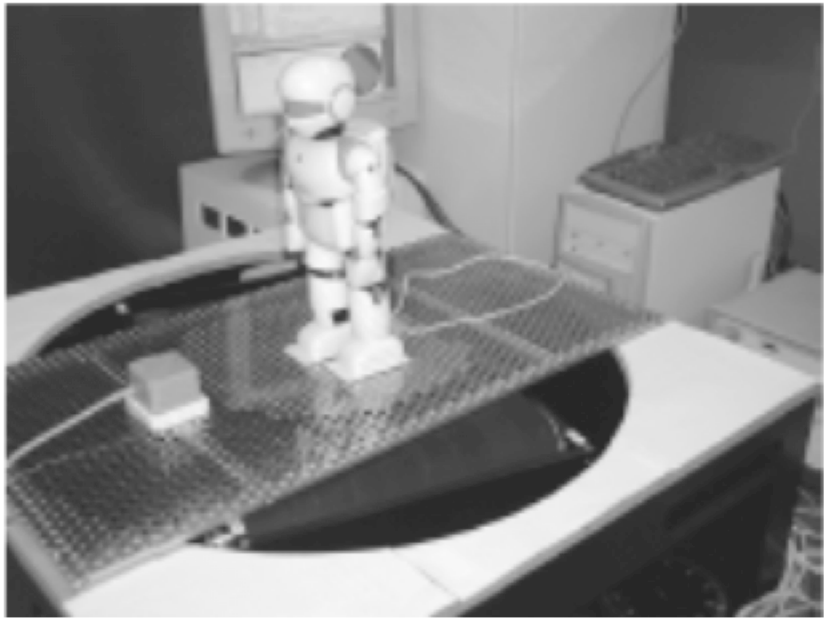
Virtual Sphere



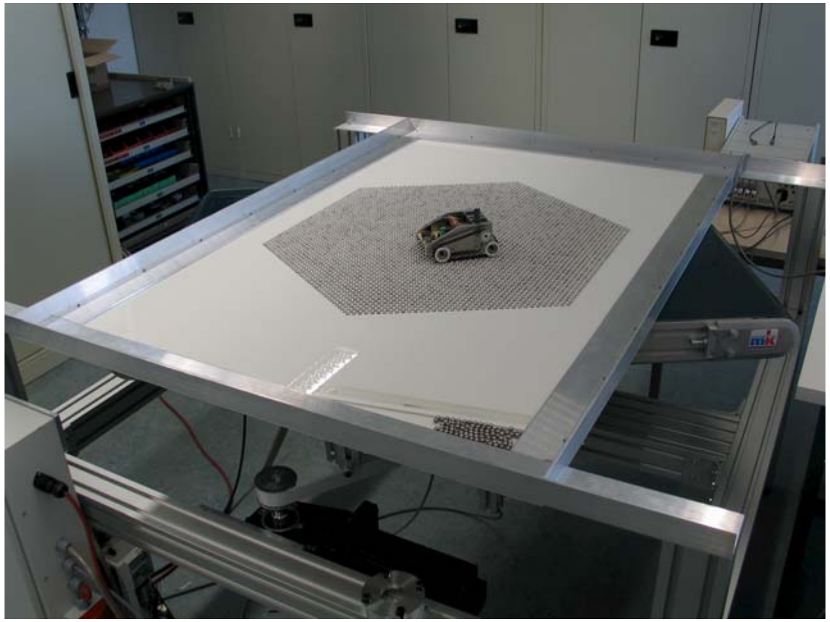
video

http://www.virtusphere.com

Other 2D locomotion interfaces



BAT Ball Array Treadmill
(Kogakuin University)

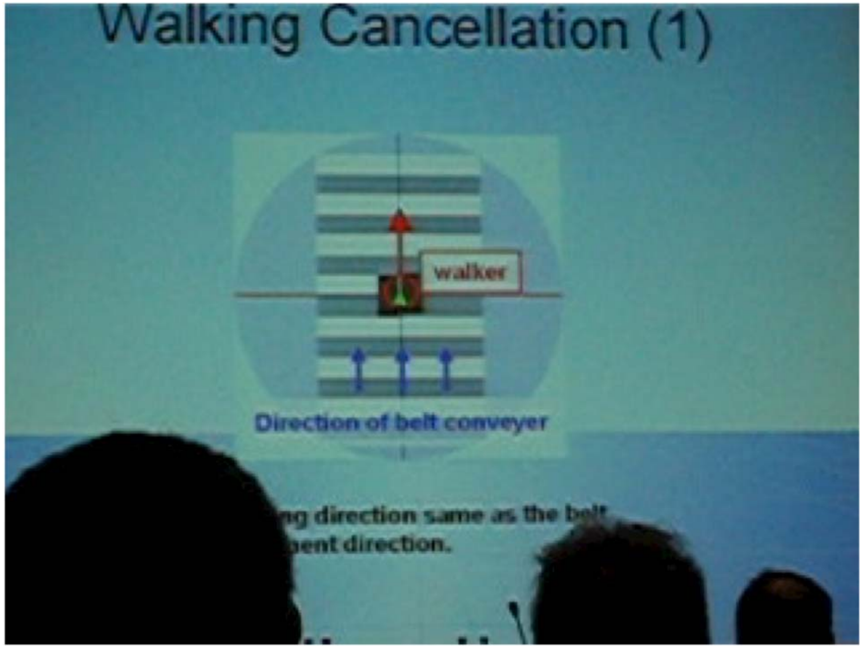


CyberCarpet

nonlinear couplings between rotation and translation

BAT Ball Array Treadmill

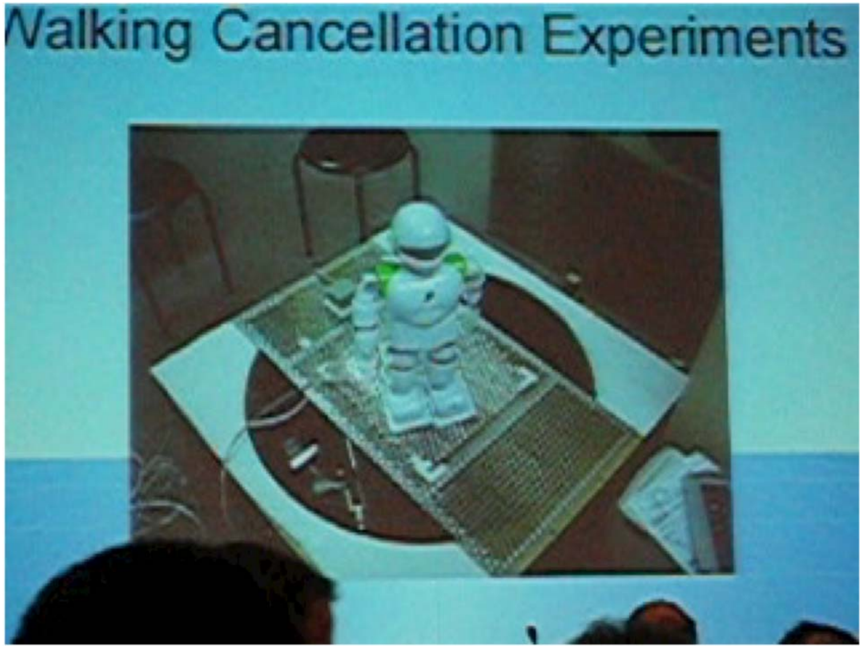
video



Walking Cancellation (1)

Simulation

video

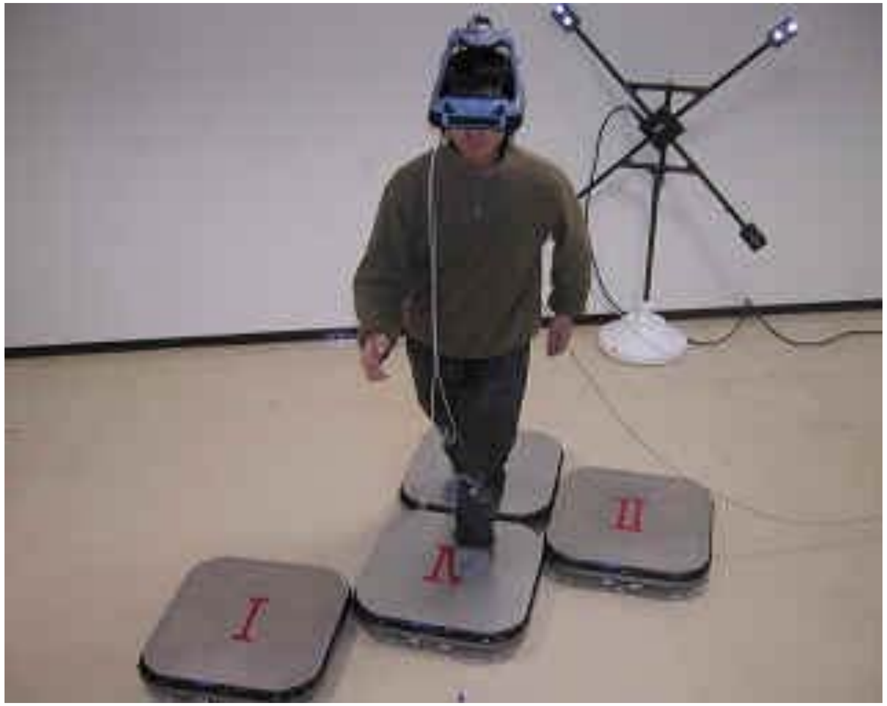


Walking Cancellation Experiments

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

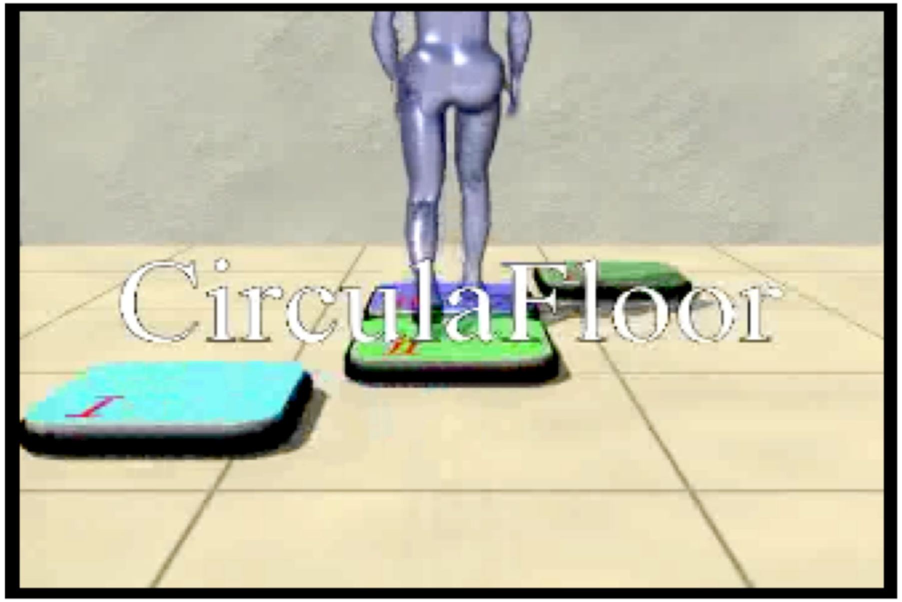
CirculaFloor

in SIGGRAPH2004

Hiroo Iwata, Hiroyuki Fukushima,
Haruo Noma and Hiroaki Yano

University of Tsukuba
ATR Media Information Research Labs

video



University of Tsukuba
ACM SIGGRAPH 2004 Conference, Los Angeles

Powered Shoes

video

University of Tsukuba
ACM SIGGRAPH 2006 Conference, Boston

Commercial motion interfaces …

Nintendo Wii Fitness

Microsoft Kinect

what are their apparent limitations? and advantages?

Bibliography - 1

- B. Hannaford, A.M. Okamura, “Haptics”, *Springer Handbook of Robotics* (O. Khatib, B. Siciliano, Eds.), Springer, 2008
- K. Salisbury , F. Conti, F. Barbagli, “Haptic rendering: Introductory concepts,” *IEEE Computer Graphics and Applications*, vol. 24, pp. 24-32, 2004
- J.M. Hollerbach, “Locomotion interfaces,” in *Handbook of Virtual Environments Technology* (K.M. Stanney, Ed.), pp. 239-254, Lawrence Erlbaum Associates, 2002
- H. Iwata, “Locomotion interface for virtual environments,” *9th Int. Symp. on Robotics Research*, pp. 275-282, 2000
- R. Mills, J.M. Hollerbach, and W.B.Thompson, “The biomechanical fidelity of slope simulation on the Sarcos Treadport using whole-body force feedback,” *Experimental Robotics VII (ISER'00)*, pp. 437-446, Springer, 2001
- H. Iwata, H. Yano, and F. Nakaizumi, “Gait Master: A versatile locomotion interface for uneven virtual terrain,” *IEEE Virtual Reality Conf.*, pp. 131-137, 2001

Bibliography - 2

- H. Noma and T. Miyasato, “Design for locomotion interface in a large scale virtual environment ATLAS: ATR locomotion interface for active self motion,” *7th Annual Symp. on Haptic Interface for Virtual Environments and Teleoperated Systems,* pp. 111-118, 1998
- R. Darken, W. Cockayne, and D. Carmein, “The Omnidirectional Treadmill: A locomotion device for virtual worlds,” in *Proc. Symp. User Interface Software and Technology*, pp. 213-221, 1997
- H. Iwata, “The Torus Treadmill: Realizing locomotion in VEs,” *IEEE Computer Graphics and Applications*, vol. 9, pp. 30-35, 1999
- K.J. Fernandes, V. Raja, and J. Eyre, “Cybersphere: The fully immersive” spherical projection system," *Communications of the ACM*, vol. 46(9), pp. 141-146, 2003
- A. Nagamori, K. Wakabayashi, and M. Ito, “The Ball Array Treadmill: A locomotion interface for virtual worlds,2 *Work. on New Directions in 3D User Interfaces (at IEEE VR 2005)*, Bonn, D, 2005
- H. Iwata, H. Yano, H. Fukushima, and H. Noma, “CirculaFloor,” *IEEE Computer Graphics and Applications*, vol. 25, pp. 64-67, 2005