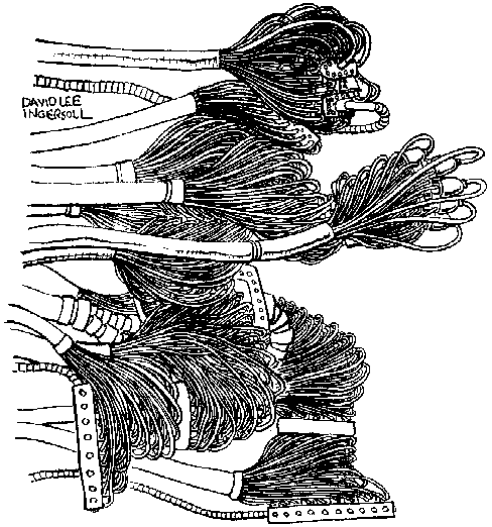
Virtual Reality & Physically-Based Simulation
Input Devices



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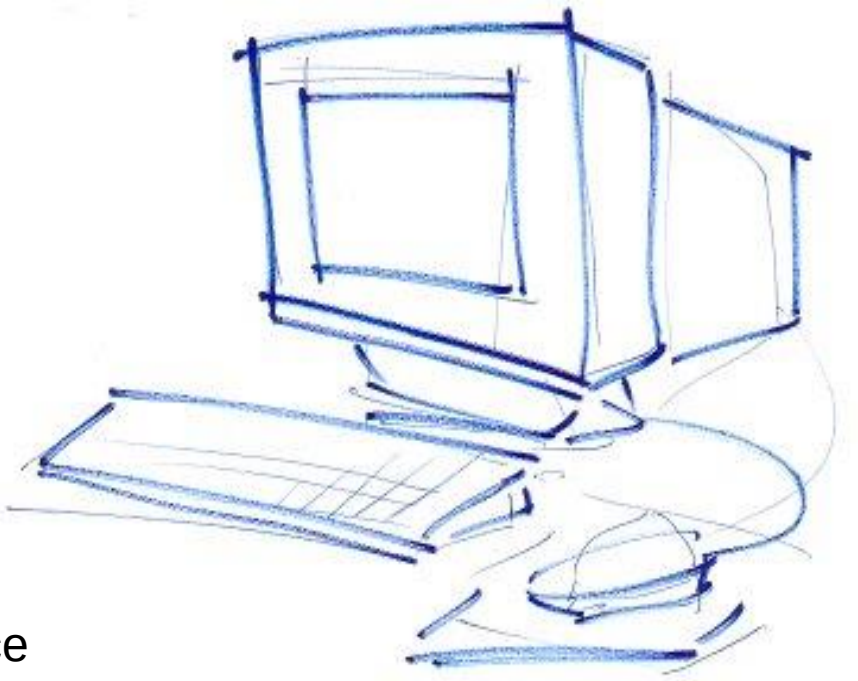
cgvr.cs.uni-bremen.de

The "Bill Buxton Test"

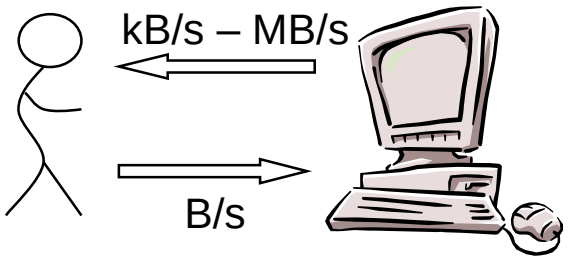
- Draw a computer within 15(!) seconds
- Ca. 80% of all people draw something like this:
  - Monitor
  - Keyboard
  - Mouse
- Remarkable:
  - No "computer" in the drawing!
  - Message: users don't see
    the system as a computer,
    they just see a device on its surface
    (i.e., they only see its I/O interface),
    and they just perceive some kind of I/O behavior



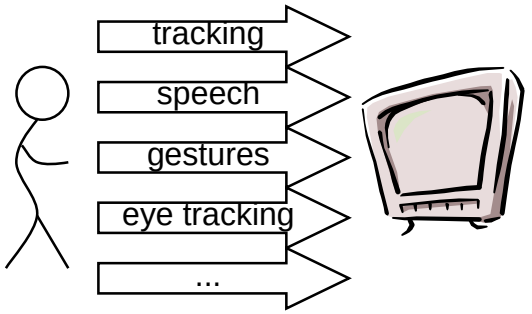
Extreme Examples of "*Intrusive*" I/O Devices

Why are Devices (until now) so Important in VR?

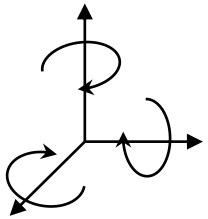
- The "playground" for many researches in VR
- Vision: *no* input devices at all!
- Bandwidth with conventional devices



- Multimodal input = input using different modalities, e.g., tracking and voice

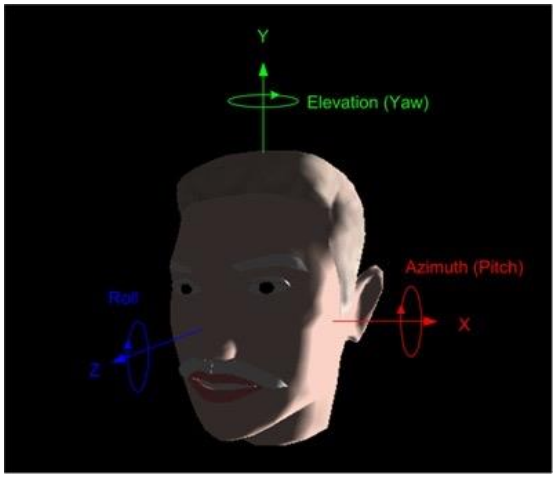


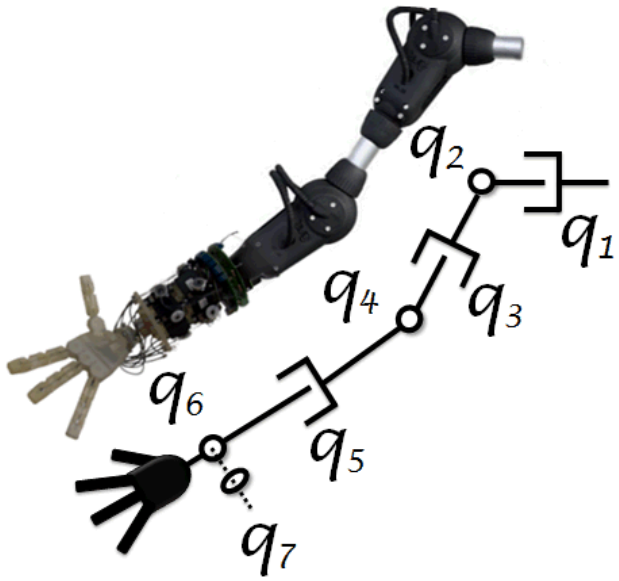
- Degrees of Freedom (DOFs) :=
  number of independent states of a system, or
  number of variables free to vary independently

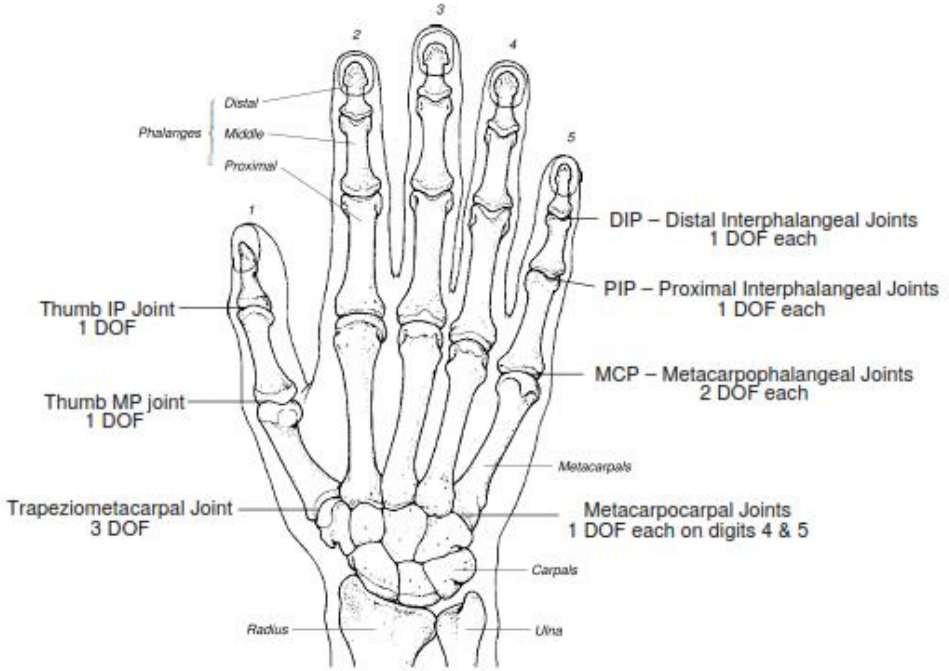


Quiz About DOFs

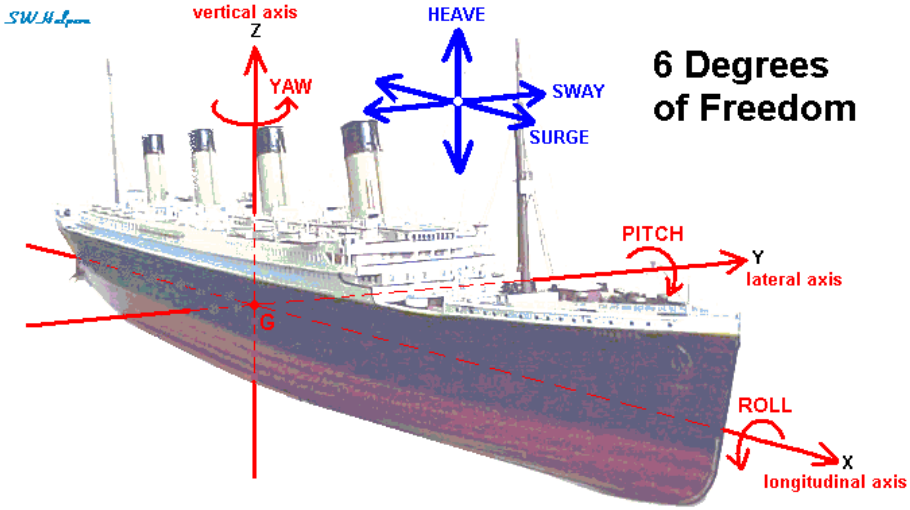
- How many DOFs does our wrist joint have?
- The head?
- One human arm?
- Our hand?



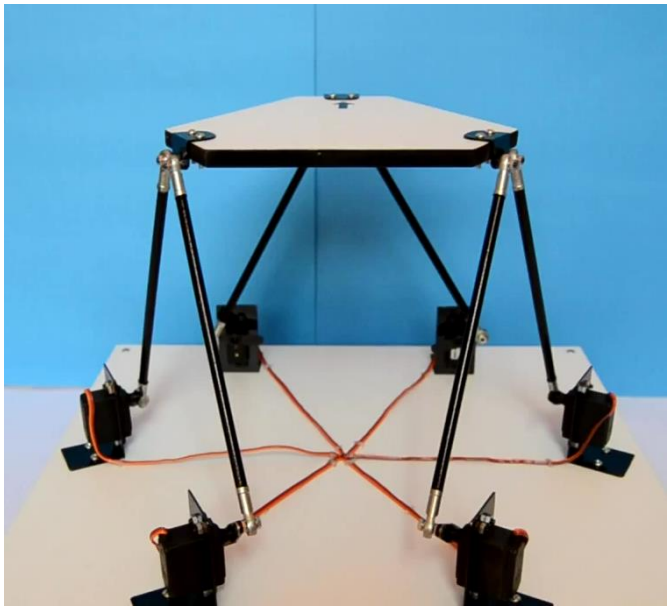




- A ship

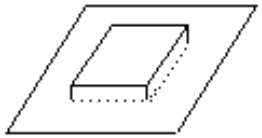
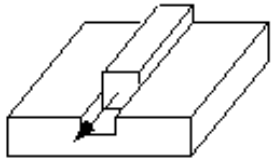
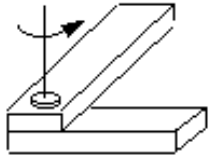
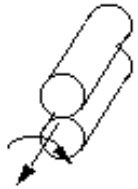
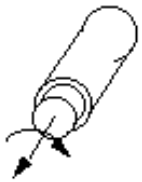
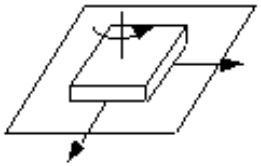
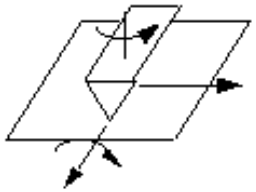
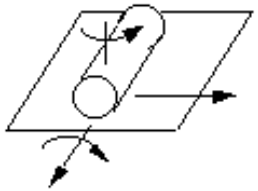
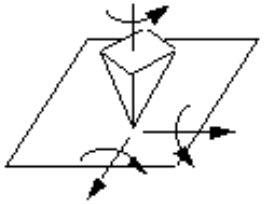
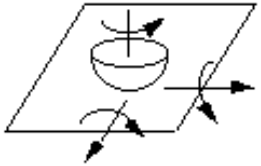
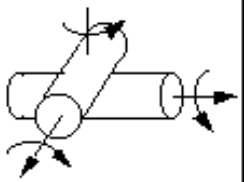


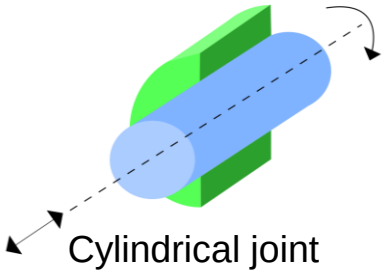
- The Stewart motion platform
  - How many independent DOFs?
  - How many dependent DOFs?

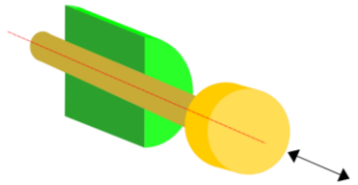


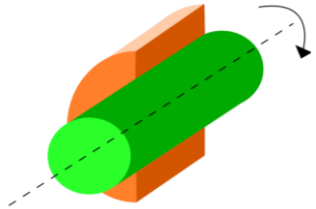
Video

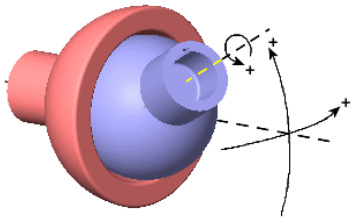
- The main kinematic joints/pairs

 Rigid (no motion)	 Prismatic	 Revolute	 Parallel Cylindrical
 Cylindrical	Spherical	 Planar	 Edge Slider
 Cylindrical Slider	 Point Slider	 Spherical Slider	 Crossed Cylinder

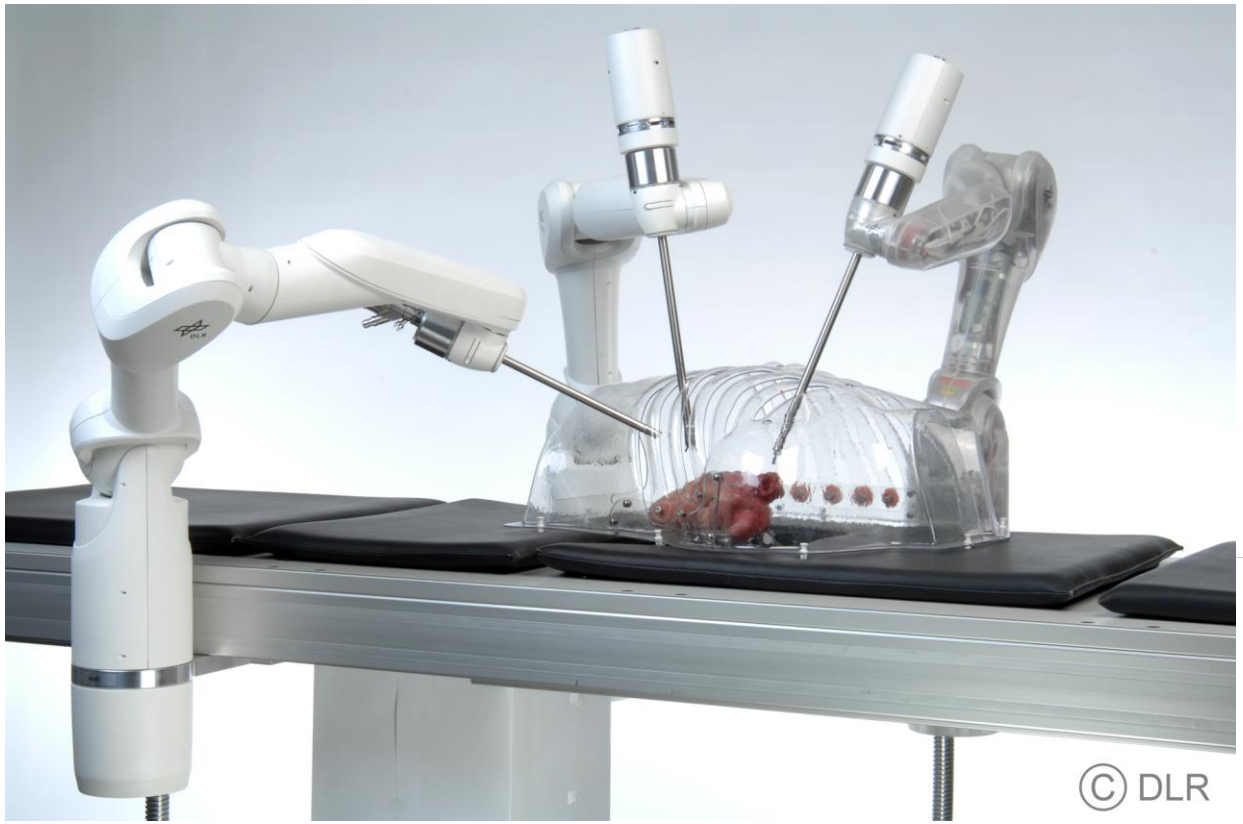

Cylindrical joint


Prismatic joint (slider)

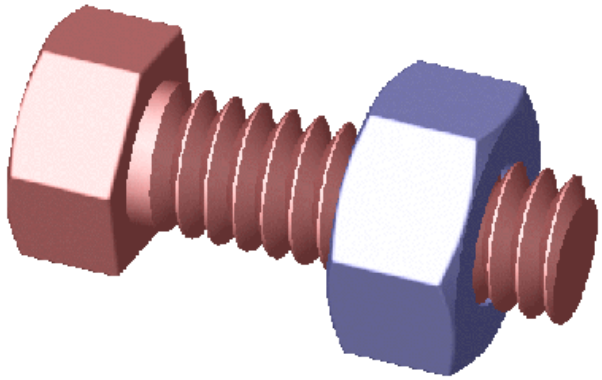

Revolute joint


Spherical joint

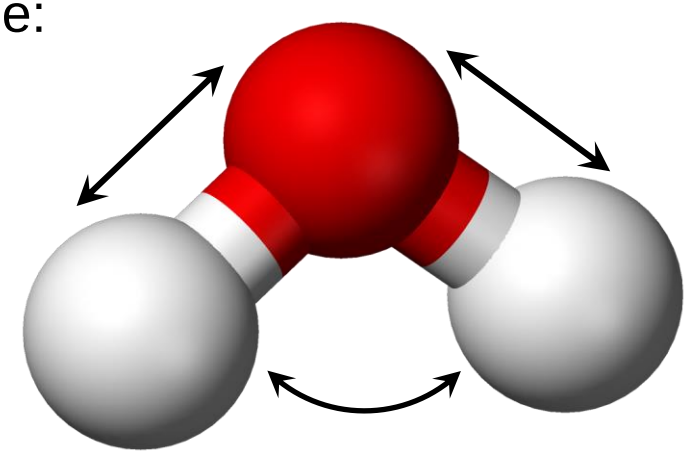
- How many independent DOFs in one robot arm of this surgery robot?



- The screw joint:
  - Joint with coupled rotational and translational degrees of freedom
  - One independent DOF, two(!) dependent DOFs



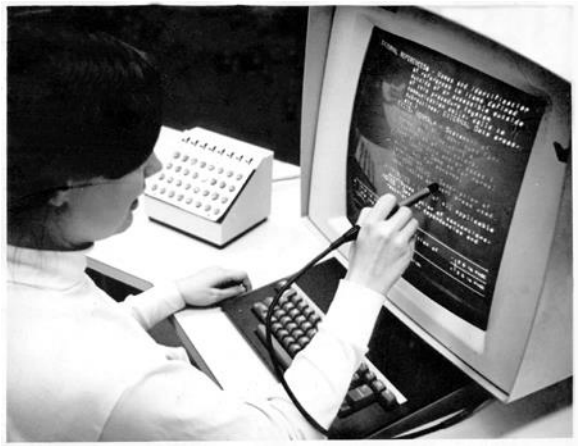
- The internal DOF's of a water molecule:



A fish about
to have
no degrees
of freedom
!!

Classical Input Devices

- Mouse:
  - Precise, inexpensive
  - Only 2D, input of orientations is cumbersome
- Drawing tablet:
  - Precise, very well suited for ... drawing
  - 2D, input of orientations is virtually impossible
- Light pen (early version of touch/tablet screen)



The Virtual Trackball

- Interaction task: rotate an object around an arbitrary axis
- Interaction device: classic 2D mouse
  - Would be trivial with real trackball
- Problem: how to enter orientations with a mouse?

The Interactions Metaphor

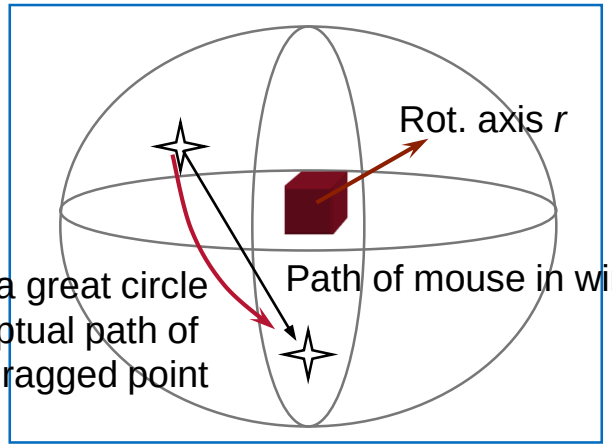
- Idea:
  - Conceptually, put a (virtual) sphere around the object
  - The sphere can rotate only abouts ist center
  - With the mouse, you drag points on the surface of the sphere
- Given: 2D points start = (x_1,y_1), end = (x_2,y_2)
- Wanted: rotation axis r
- Computation:
  1. Derive 3D points

$$\mathbf{p}_i = (x_i, y_i, z_i)$$

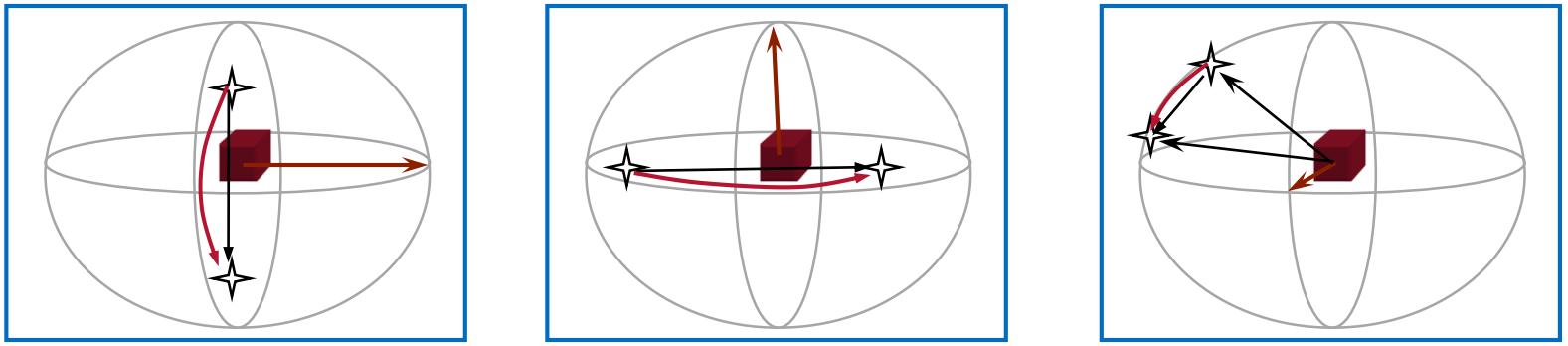
$$z_i = \sqrt{1-(x_i^2 + y_i^2)}$$

  2. Rotation axis

$$\mathbf{r} = \mathbf{p}_1 \times \mathbf{p}_2$$



- If p_1 = first mouse click, p_2 = current mouse pos. → not intuitive
- If p_1 = mouse pos. As of last frame, p_2 = current mouse pos. → intuitive, but rotation exactly about z-axis impossible



- Improvements / variants:
  - "Spinning trackball": "re-grabbing" the sphere is less often necessary
  - "Snapping": allows precise rotation around world/object coord. axes
  - In case p_2 leaves the ellipse → could use different 3D surface that can be attached continuously to sphere (e.g., hyperboloid)

Remarks

- Rotation axis r is given in the camera coordinate frame!
  - You need it in the world frame or object frame
    - Depending on whether the rotation is to be applied to the object before or after all other transformations
- Warning: with variant 2 ("incremental trackball"), a lot of small rotations need to be accumulated! (one per frame) ⟶ consider numerical robustness and drift

Desktop Devices

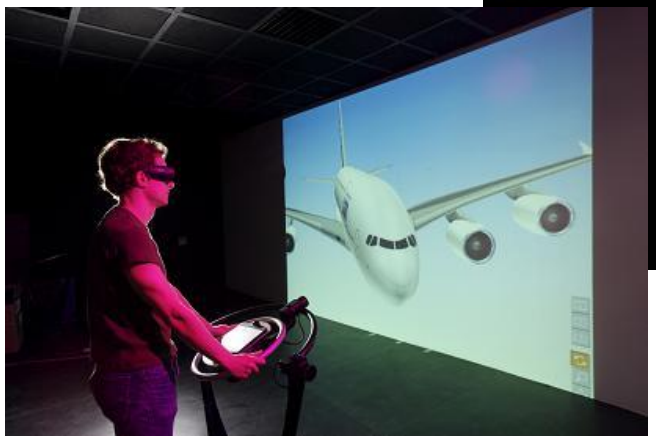
- Spacemouse:
  - 6 DOFs
  - Suitable for CAD, viewpoint navigation in general, rotation of the whole scene

- Steering wheel
  - With force feedback

- Others ? ...

Beyound Desktop: CAT — Control Action Table

- 6 DOF, plus tablet
  - Gimbals for rotation
  - Spacemouse -like "push" sensors for translation



Project "IPARLA", INRIA, France

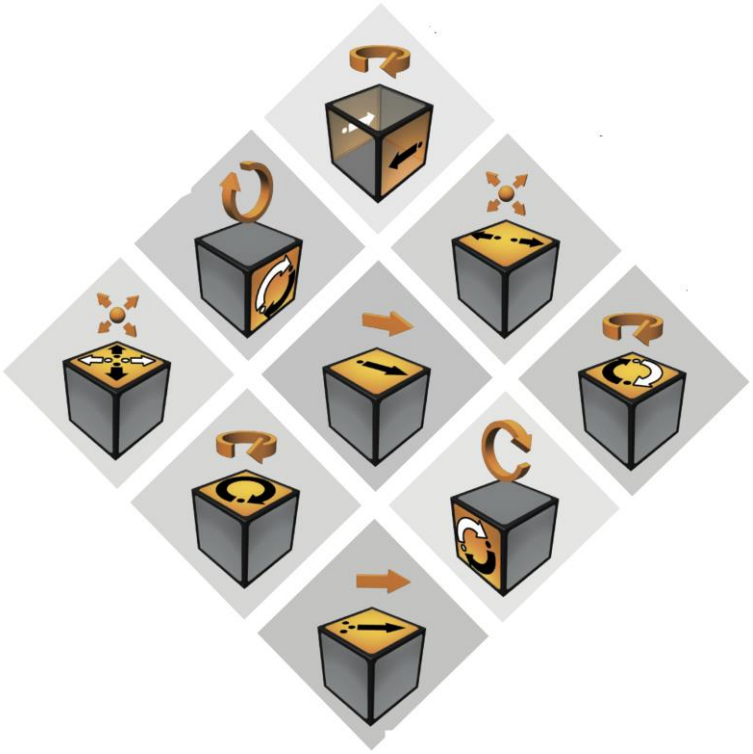
Isotonic vs Isometric Sensing

- Isotonic = "same muscle tension during contraction of the muscle"
- Isometric = "same muscle length although muscles contract"

- Definition isotonic sensing device:
  The user can move the device (or just that DoF) all the way without changing muscle tone.
- Examples:
  - The rotational DoF's of the CAT
  - The tracking sensors of a tracking device
- Definition isometric sensing device:
  The device (or just that DoF) does not move when the user pushes/pulls the device, no matter how hard she pushes/pulls.
- Examples:
  - The translational DoF's of the CAT
  - The spacemouse (not purely isometric)

Cubtile

- 5 multi-touch surfaces arranged in a cube
- Bonus: very neat illumination ☺



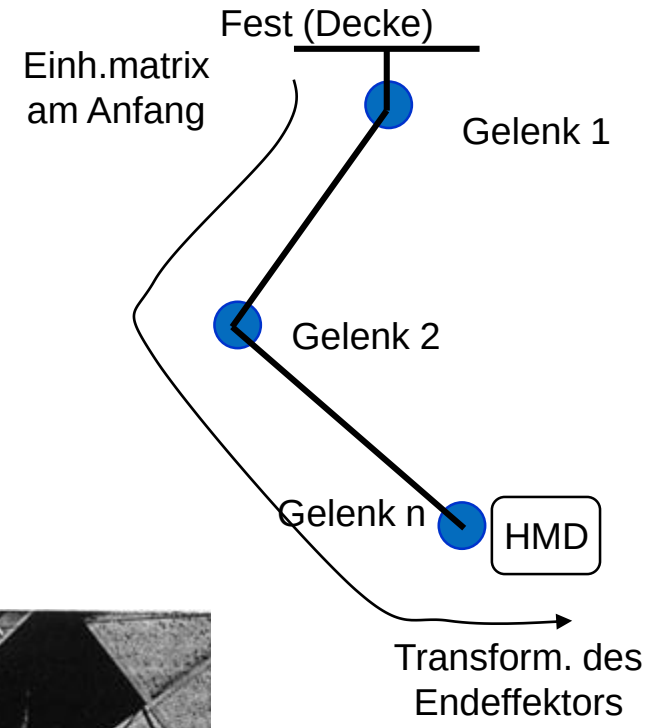
Tracking the User

- Task: determine "where is X of the users?"
  - X = head, hand, eyes, feet, whole body, ...
- Requirements:
  - *Non-intrusive*
  - High precision (1 mm)
  - Low latency (1 msec)
  - High *update rate* (100 Hz)
  - Works in all environments and conditions
  - Large working volume
- Doesn't exist (yet?)!

- Technologies for tracking:
  - Mechanical
  - Electro-magnetic
  - Acustic (ultra sound)
  - Optical
  - Computer vision-based
  - Inertia sensors
  - Laser
  - GPS
  - Hybrids

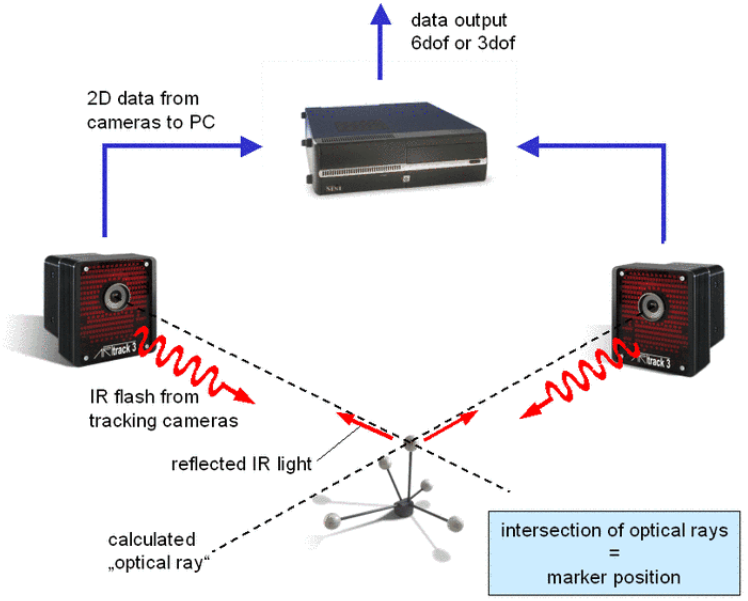
Mechanical

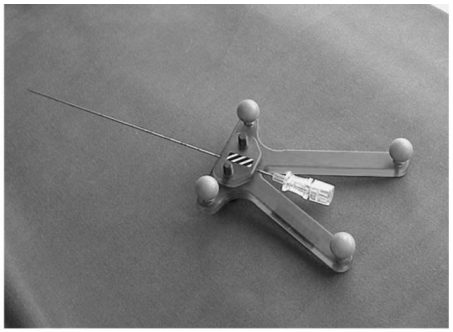
- Advantages:
  - Precision
  - Low Latency
  - No distortion by metal in environment
- Disadvantages:
  - Uncomfortable
  - Working volume
  - "Dead" zones
  - Intrusion
  - Calibration
  - Inertia b/c of mass

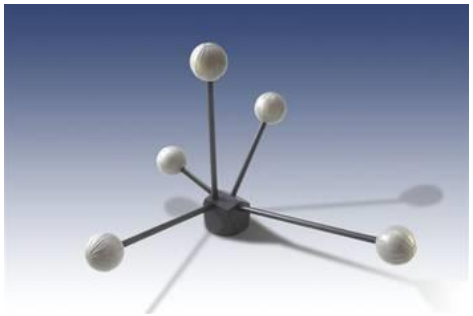


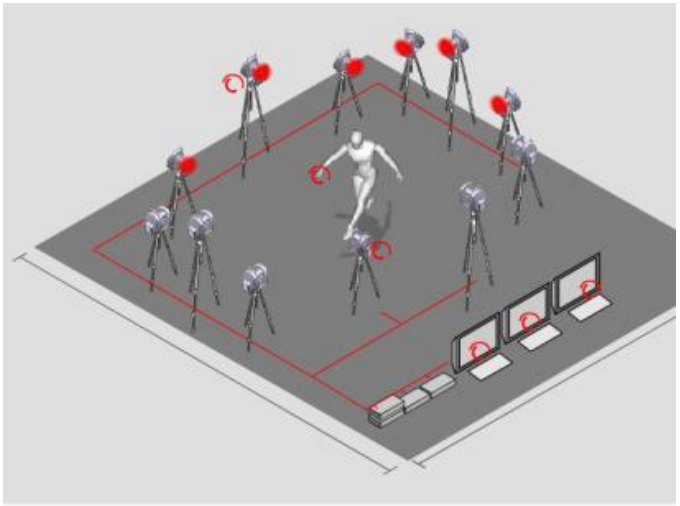
Optical Tracking

- Idea: track highly reflective markers using IR cameras
- 1 marker → position
  - By way of triangulation
- ≥3 markers (a "*rigid body*") → position and orientation
- Standard technology for body tracking in animation studios and for game dvelopment
  - Motion capturing (MoCap)



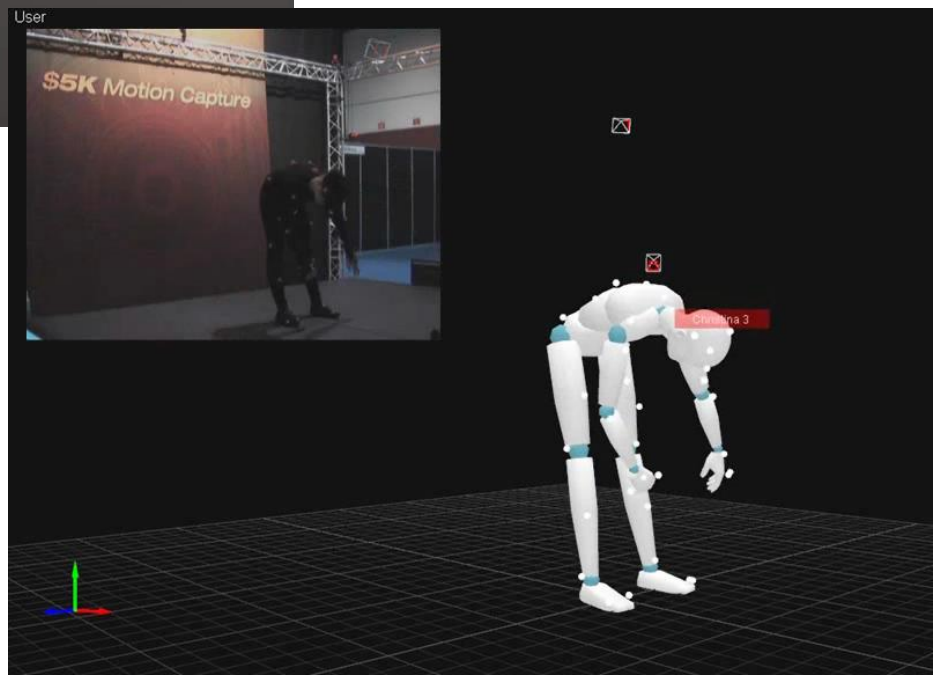




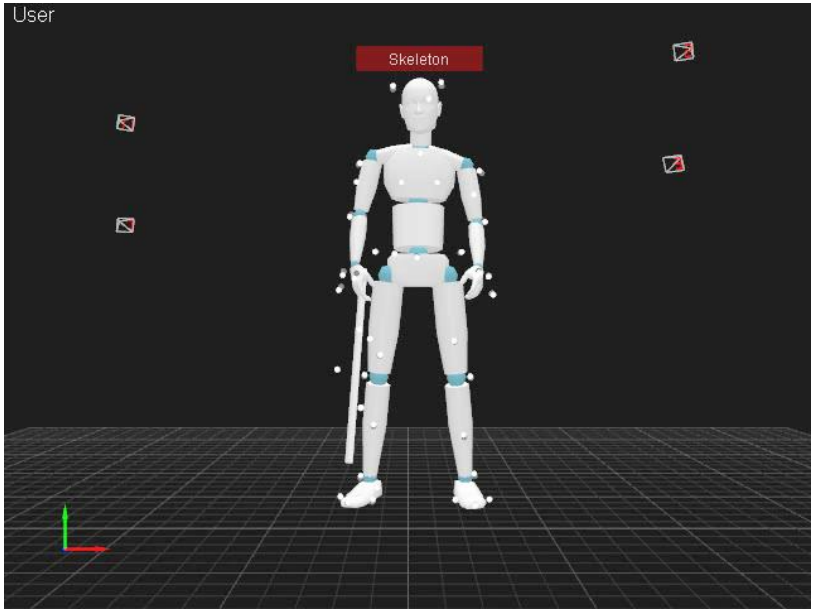


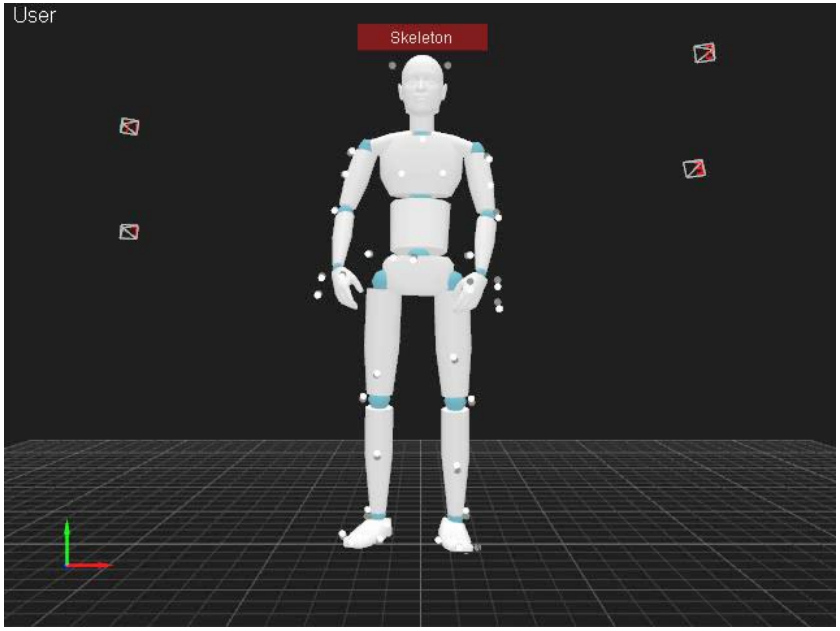
- Advantages:
  - Free movement for users / actors
  - Large working volume
  - High *sampling rate* (typically 120-250 Hz)
  - *Facial animation* is possible, too
- Disadvantages:
  - *Line-of-sight* needed (mitigation: lots of cameras)
  - Price ($40,000 – $140,000)
    - New systems cost only about $6,000

Fluid Images



NaturalPoint (OptiTrack)


User
Skeleton


User
Skeleton

Optical Tracking "*Inside Out*"

- Camera on the head of the user, array of markers (e.g., pulsed LEDs) on the ceiling
- Advantages:
  - Only 1 camera needed
  - Fast (up to 1 msec, 1000 Hz)
  - Precise (1/10 mm)
- Disadvantages:
  - How to track a user's hand?
  - Time- and hardware-consuming installation
- Example: UNC's "HiBall"

  http://www.cs.unc.edu/~tracker/

Eye Tracking

- Where are the user's eyes?
  → eye tracking
- In which direction does the user look?
  → eye gaze tracking
- Applications:
  - Head tracking
  - Controlling LODs
  - Autostereo monitors
- Problems:
  - Precision
  - Sometimes additional hardware is needed

Acoustic Tracking

- Similar to sonar:
  - 1 ultra sound source
  - 3 receivers (for 3 DOFs)
  - Travel time → position
- Advantages:
  - Very inexpensive
- Disadvantages:
  - Echos
  - *Line-of-sight* prerequisite
  - 3 transmitters needed for 6 DOFs
  - Small range
  - Precision: speed of sound depends on air temperature, humidity, etc.

Inertia Sensors

- Measures acceleration in one direction
- Advantages:
  - No transmitter necessary
  - Very small sensors
- Disavantages:
  - Drift
- Often combined with other tracking technologies to compensate for drift, e.g., ultra sound

Laser Tracker

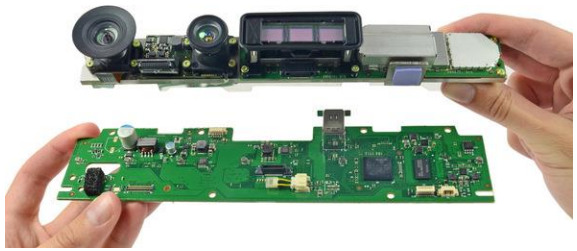
- Measures just distance / position
- So far being used only in manufacturing industries (CNC machines)

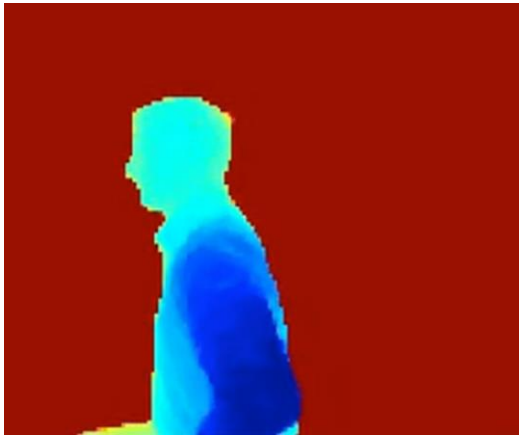
Electromagnetic Tracking

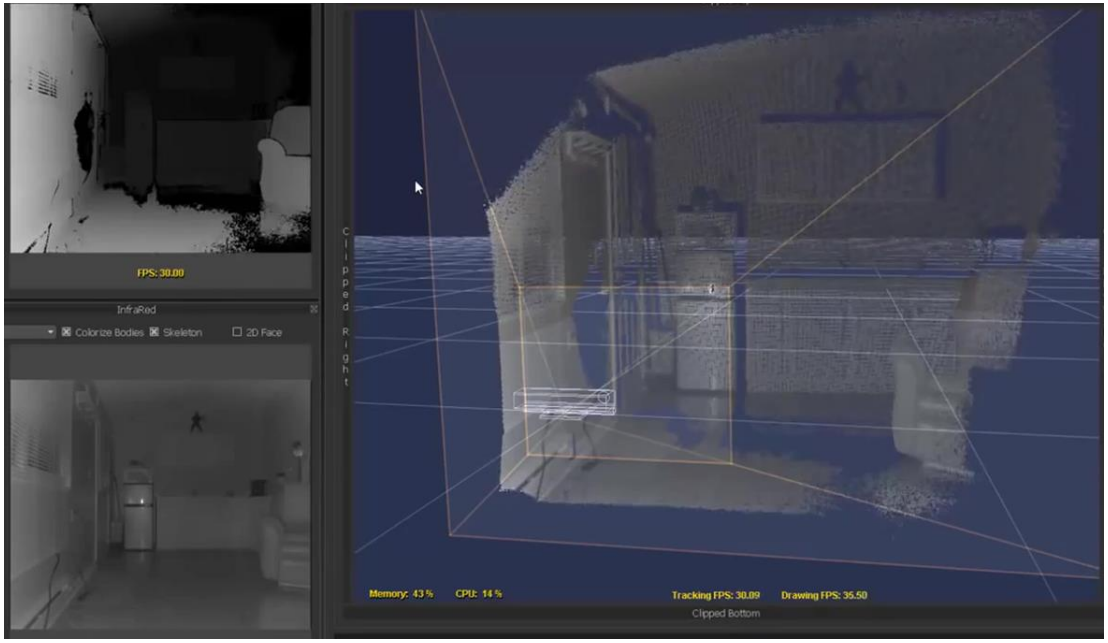
- Transmitter =
  - 3 orthogonal coils (using 3 different frequencies)
  - Emit 3 orthogonal electromagnetic fields
- Sensor = receiver =
  - 3 orthogonal coils, too
  - Receive 9 signals in total
- Phase shifts between transmitted and receive signal → distance
- Strength of the 9 different signals → orientation
- Advantages:
  - Small sensors; Working volume = 3 m (or more)
- Disadvantages:
  - Tethering (cables)
  - Metal in environment has severe impact in field distortions
  - Noise

Depth Sensors / Range Image Sensors

- Kinect is the most prominent sensor



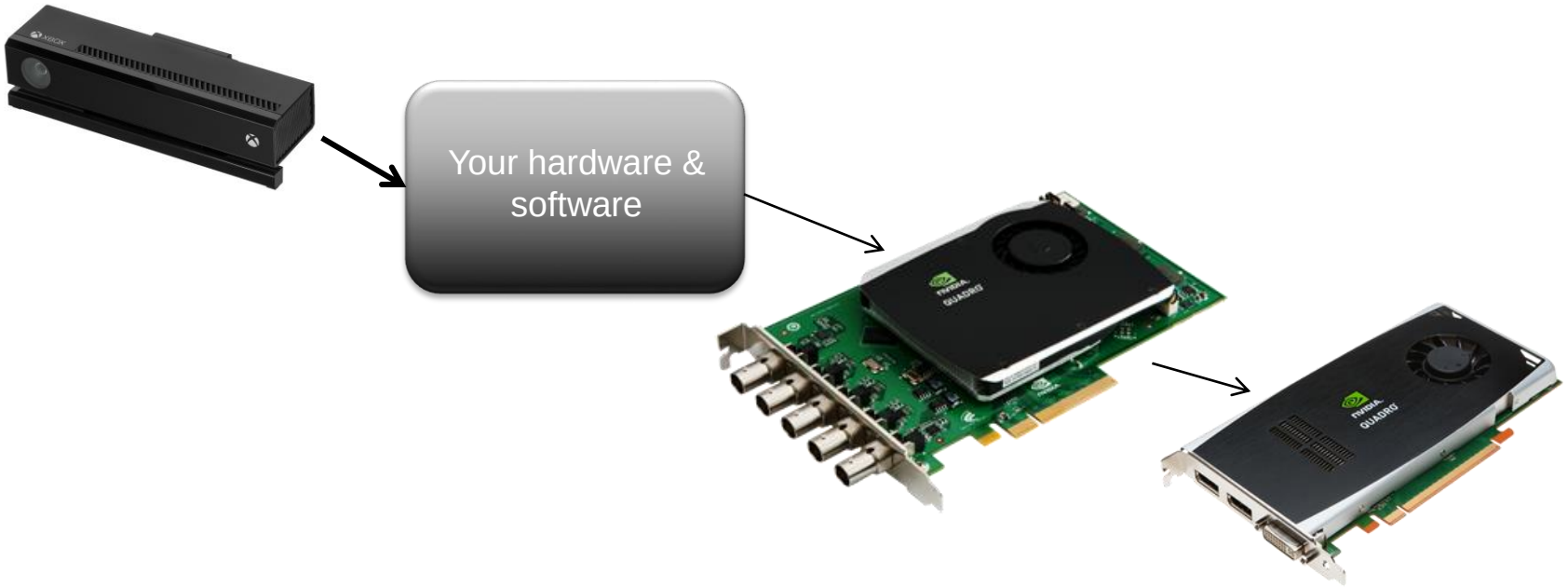




- Lead to new category of user interfaces: NUI = Natural User Interface
  - But this vision existed from the beginning of VR

Bachelor / Master Thesis

- Build hardware in order to connect a Kinect directly to a GPU
- There is a card that can capture of SD-, HD-, 3G-SDI video footage, in real time, directly to the GPU memory
- So, "only" need to turn the Kinect output into an SD/HD stream



Characteristics of Tracking Systems in Gerenal

1. # DOFs
2. Precision, drift, replicability
3. Update rate, latency
4. Noise
5. Additional buttons
6. E*ase-of-use*, *tethering* (=cables) – *unintrusiveness*!
7. Working volume
8. Price

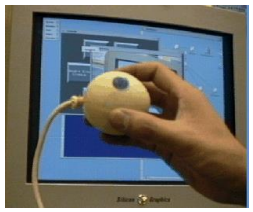
3D Pointers / Stylus

- Analogue to 2D mouse
- Hardware = tracker with buttons
  - Sometimes with additional joystick, etc.
- Names: *flying mouse*, *flying joystick*, *wand* (= Stab), *bone*, *fly-stick*, etc...
- Advantage: physical object induces a strong feeling of presence while grasping a virtual object

Zhai and Milgram's Directness Continuum for Input Devices

Isomorphic input — Directness / Indirectness — "Magic tools"

	Position control			Velocity control	Higher order control (e.g., accel.)
	Absolute		Clutch ("Nachfassen")		
	1:1	scaled			
2-DOF example	*Touch screen*	*Drawing tablet*	*Mouse*	*Joystick*	?
6-DOF example	*Tracking the user*	*Finger-ball*	*Cyber-glove*	*Spacemouse*	?



Position Control vs. Rate/Velocity Control

- Spacemouse video showing rate control

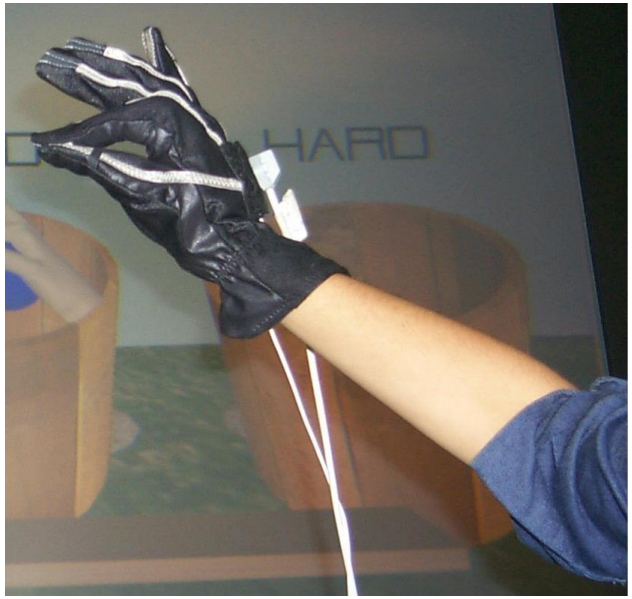
- Seamless switch from position control to rate control: "Human-Scale Passive Haptic Feedback for Augmenting Interaction and Perception in Virtual Environments" - Merwan Achibet, Adrien Girard, Maud Marchal, Anatole Lécuyer, Anthony Talvas, IEEE VR 2015

The Dataglove

- "Tracks" fingers of human hand = measures angles of joints
- One of the very eary VR devices
- Different numbers of sensors:
  - 12 = 4 (thumb) + 4x2 (2 sensors per finger)
  - 22 = 4 (thumb) + 4x3 (3 sensors per finger) + 3 sensors between fingers + 1 sensor on back of hand (Handrücken)
- Sensor technologies:
  - Glass fibers (not very robust)
  - Bimetallic strips
- Disadvantages:
  - Low precision
  - Glove by and itself (not really accepted)

Variants

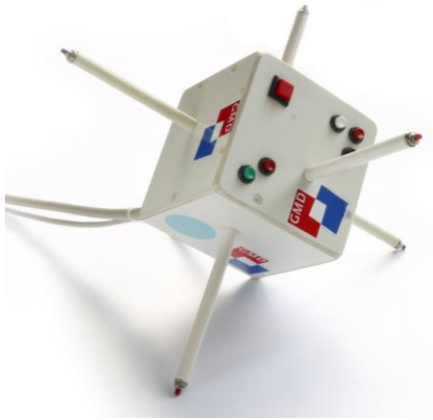
- Pinch glove:
  - No tracking, just detects contact between finger tips → each finger acts like a button
- Usefuly only using 2 tracked pinch gloves; with, though, pretty clever navigation and manipulations can be performed:
  - Grasping and moving
  - Scaling (using *handles* à la Inventor)
  - Will be presented later ...
- Disadvantage: a virtual hand cannot be rendered

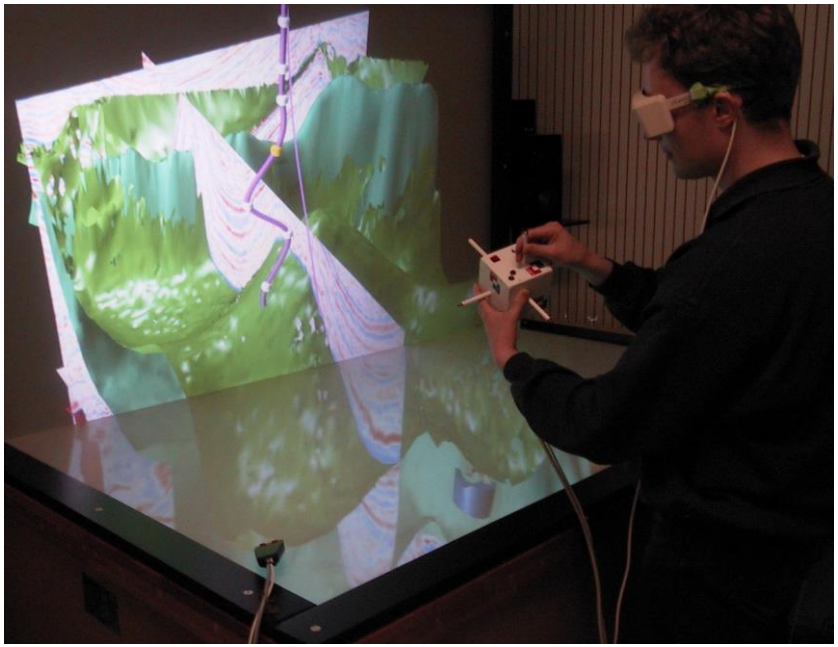


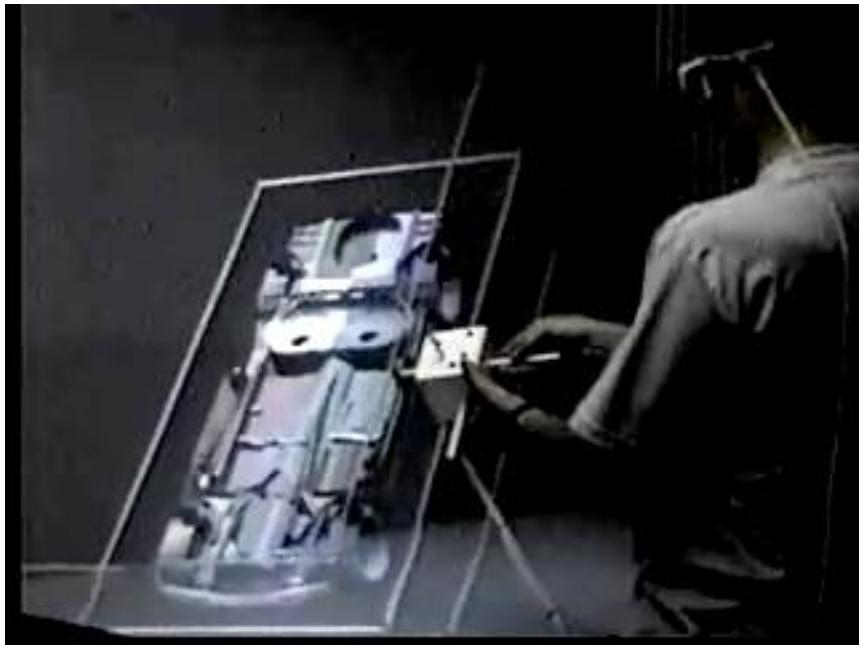
- The P5 from Virtual Realities (www.vrealities.com):

Other High-Dimensional Input Devices

- Cubic Mouse:
  - Number of DOFs = 9





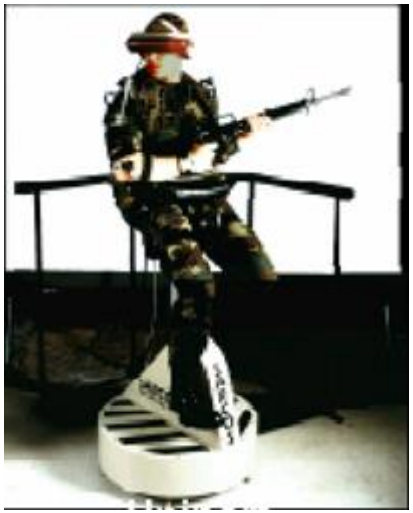


3D Range Sensors

- First device: Microsoft Kinect
- Deliver depth image (range image)
- Lead to so-called natural user interaction (NUI)

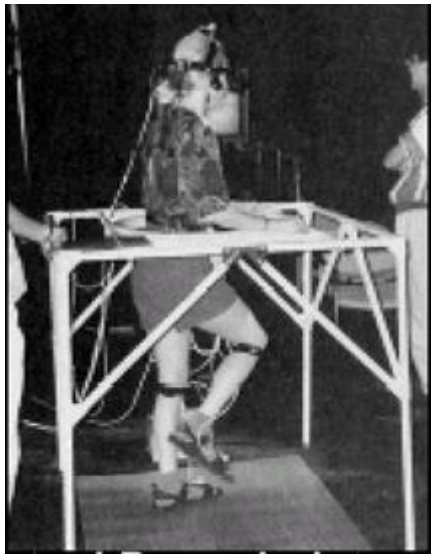
Photo (CC-BY-SA-NC) Kyle McDonald; used by permission

Locomotion Devices



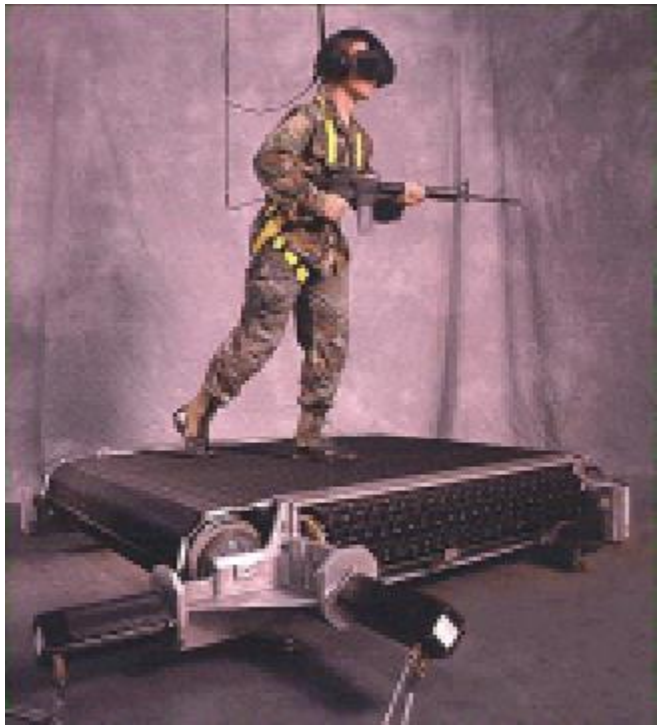
Sarcos, Utah

Sarcos

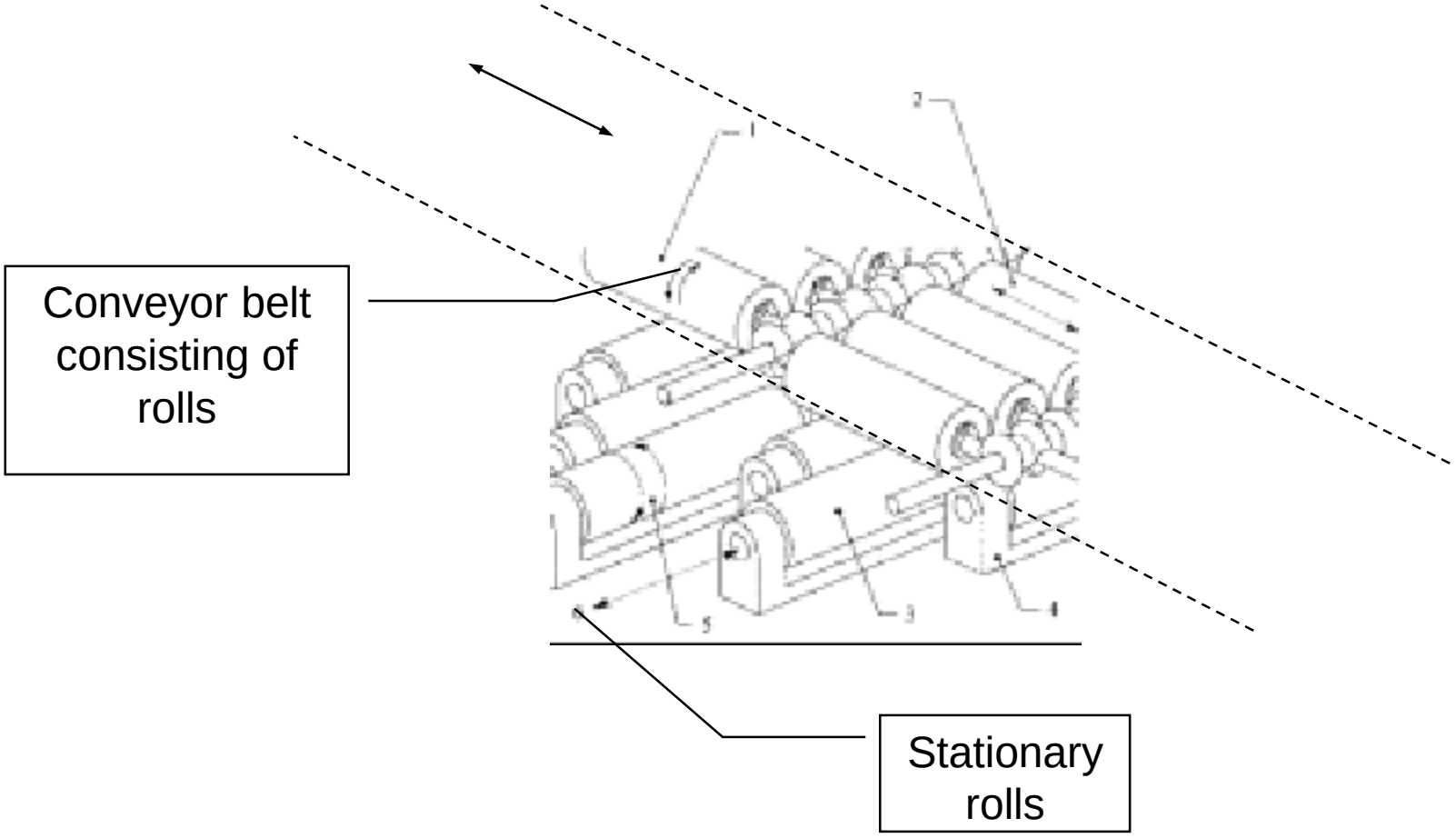


Uni Tsukuba, Japan

- *Omni-directional treadmill* (omni-direktionale Tretmühle)

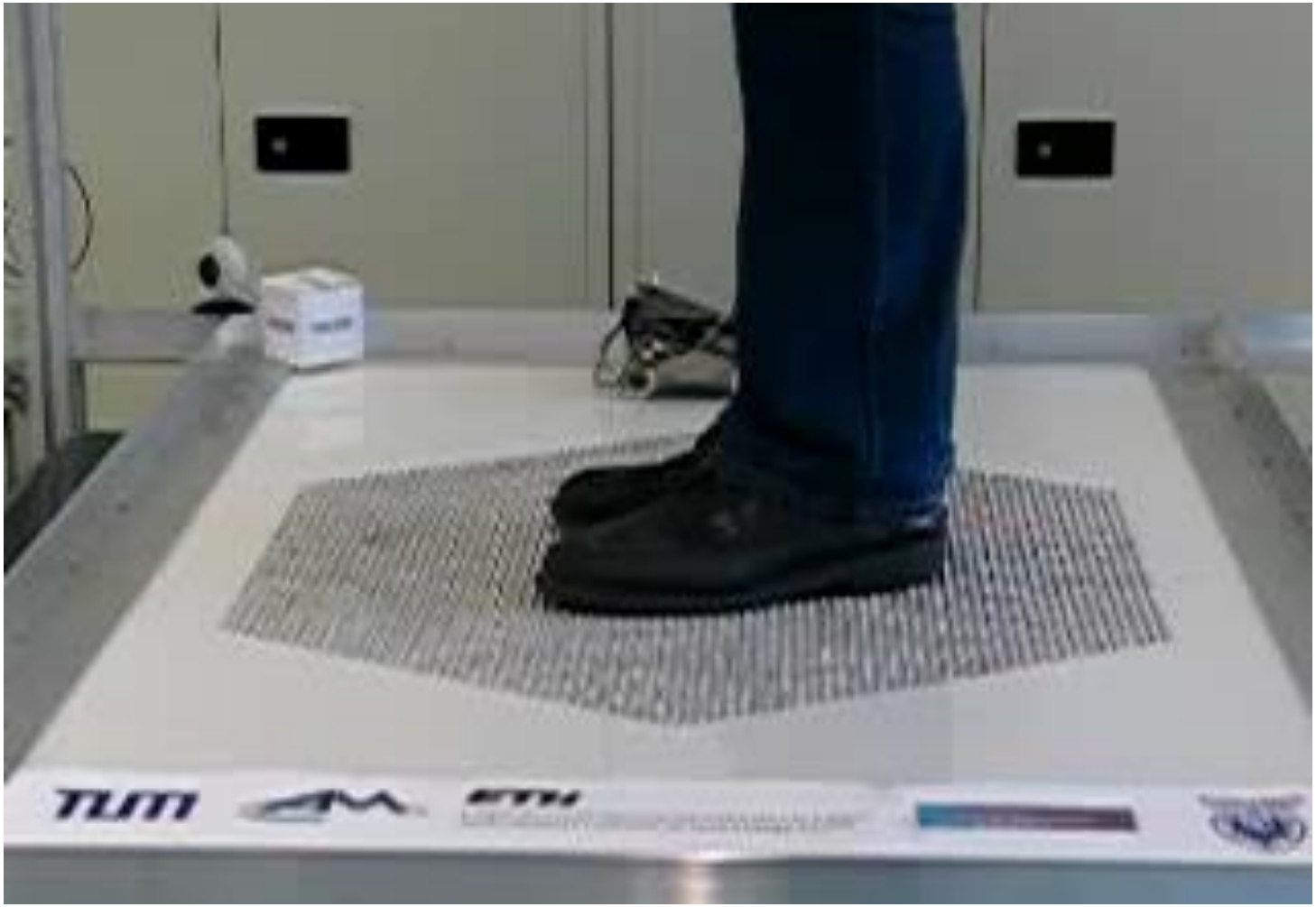


Virtual Space Devices, Inc.

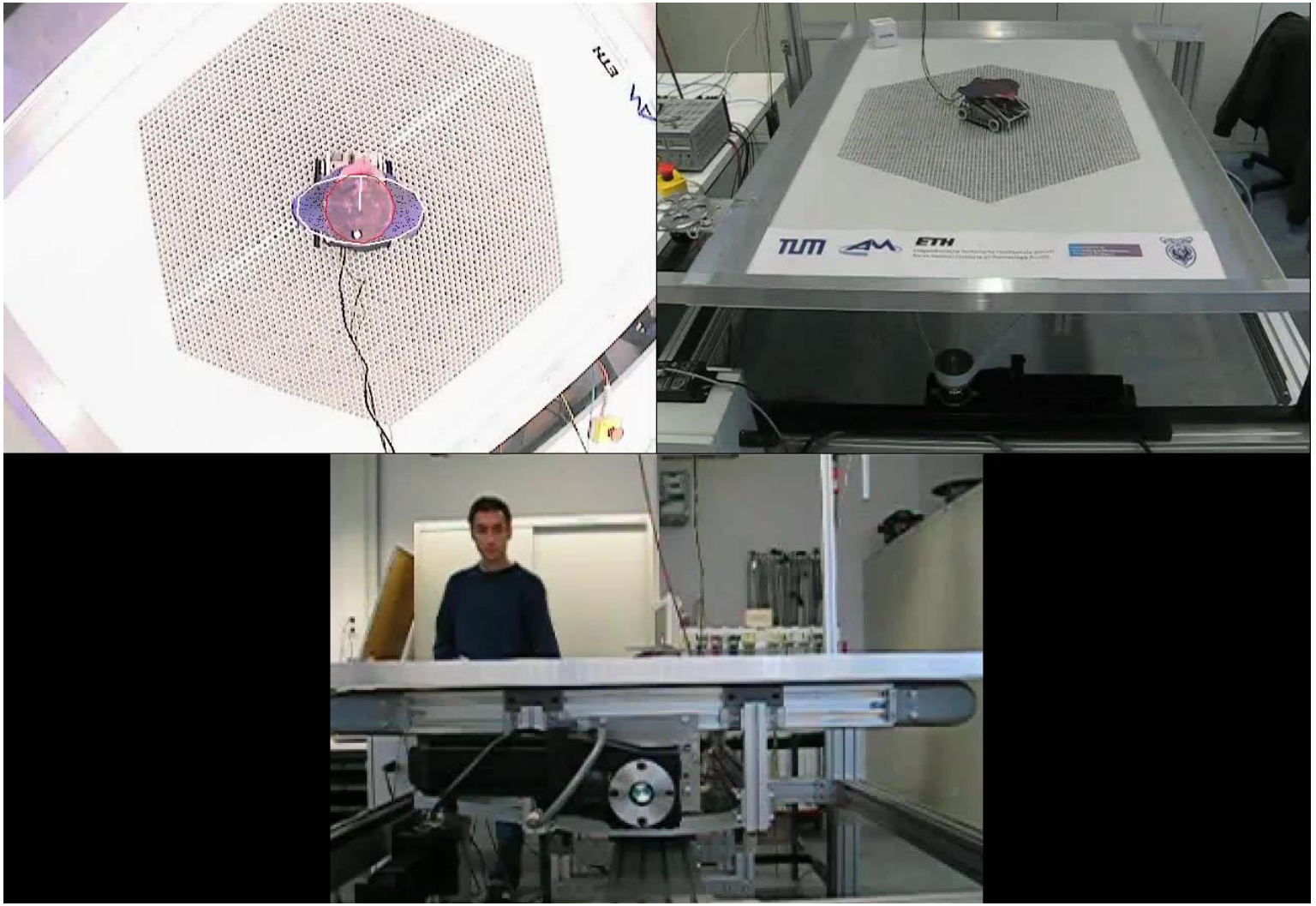

Conveyor belt consisting of rolls
Stationary rolls

Cyberwalk omni-directional treadmill, 2005-2008
TU München

Mode of operation of the Cyberwalk omni-directional treadmill



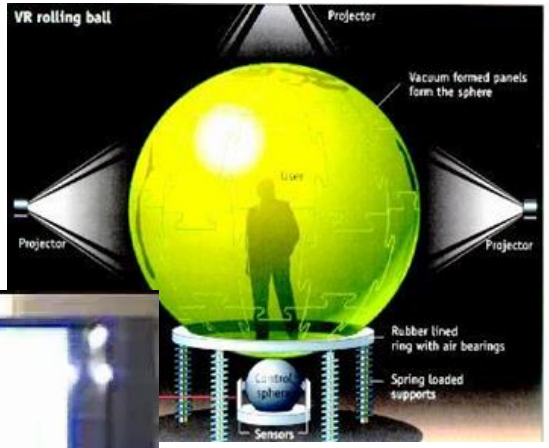
CyberCarpet
Martin Schwaiger, Dr. Thomas Thümmel, TU München



CyberCarpet's mode of operation

- Possible applications:
  - Research on behavior & cognition, brain research
  - Sports medicine
  - Training of soldiers and security staff
  - Fun parks (?)
  - Architecture:
    - Visualization and realistic exploration of architectural designs
    - Test of escape routes
  - Tests on humanoid robots

VirtuSphere



Frühe Studie

www.virtusphere.com

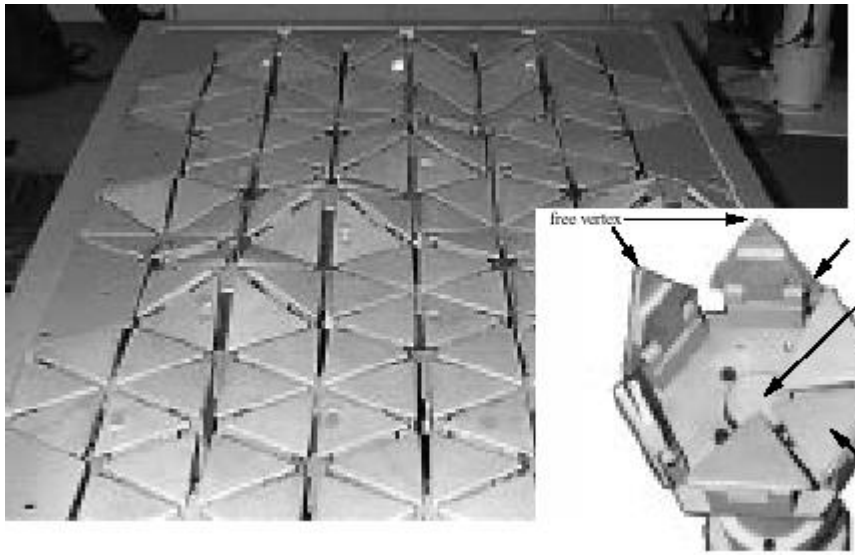
SPIEGEL ONLINE

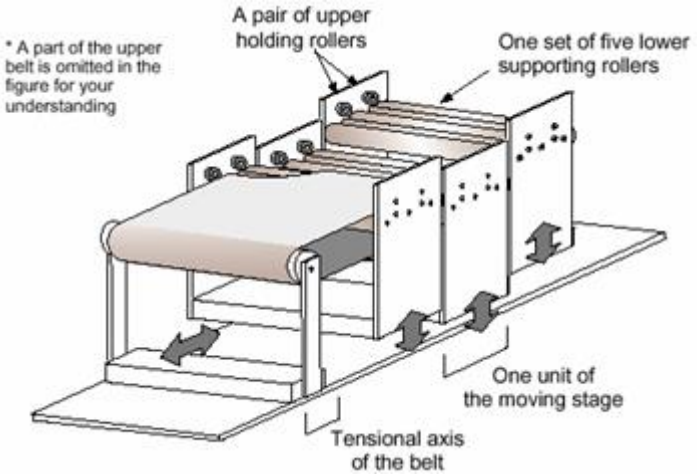
Virtuix: Omnidirectional treadmill for the home [2013]

Cyberith Virtualizer

CirculaFloor, 2006

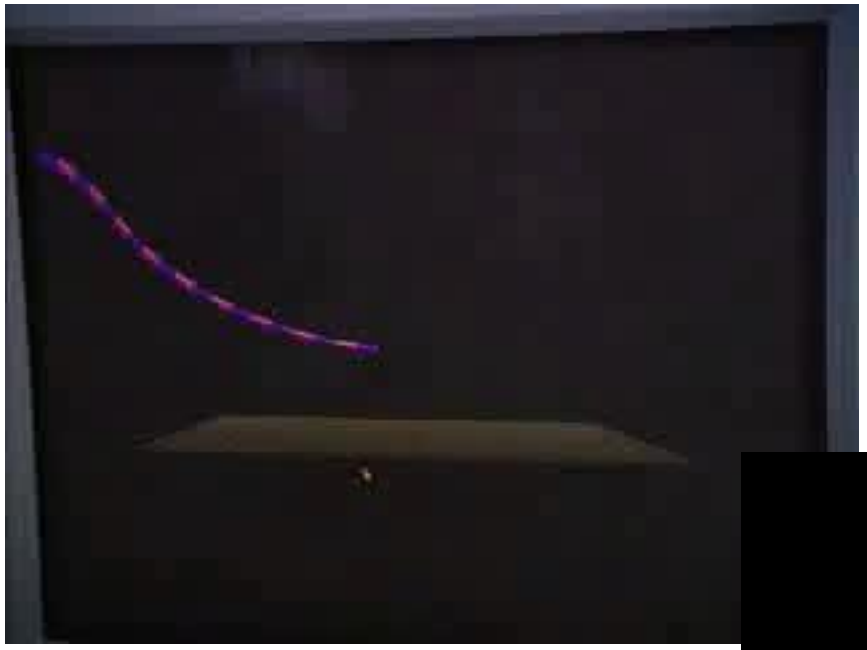
Simulation of Ground for Real Walking





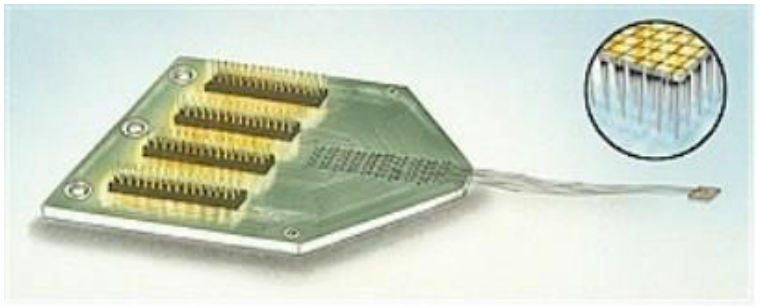
Other Locomotion Devices

Unconventional Input Devices



The Shape tape

Virtual Keyboard

Brain Computer Interfaces

- Idea: control the machine by your brain only (no intermediary devices)
  - So far: EEG
  - SciFi: implant