Universidade de Aveiro
Departamento de Electrónica,
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Input Devices

Virtual and Augmented Reality 2021

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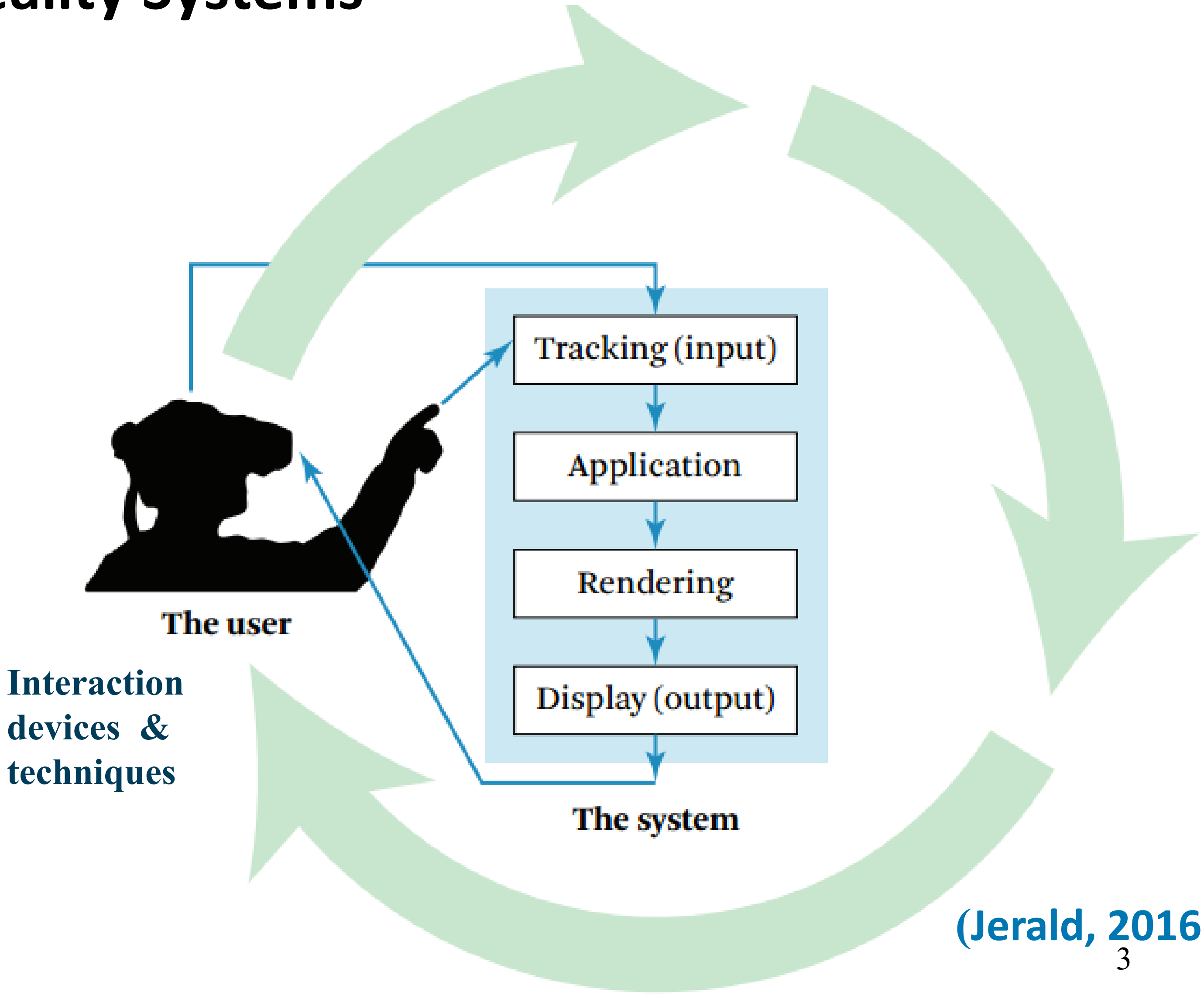
What is Virtual Reality?

"A high-end user interface that involves real-time simulation and **interaction** through multiple sensorial channels." (vision, sound, touch, …) (Burdea and Coiffet., 2003)

Virtual Reality Systems



(Jerald, 2016)

Crucial technologies for VR

- Visual displays
- Graphics rendering system
- **Tracking system**
- Database system
- **Interaction devices**
- Interaction techniques
- Sound and haptic displays (if possible…)

for AR

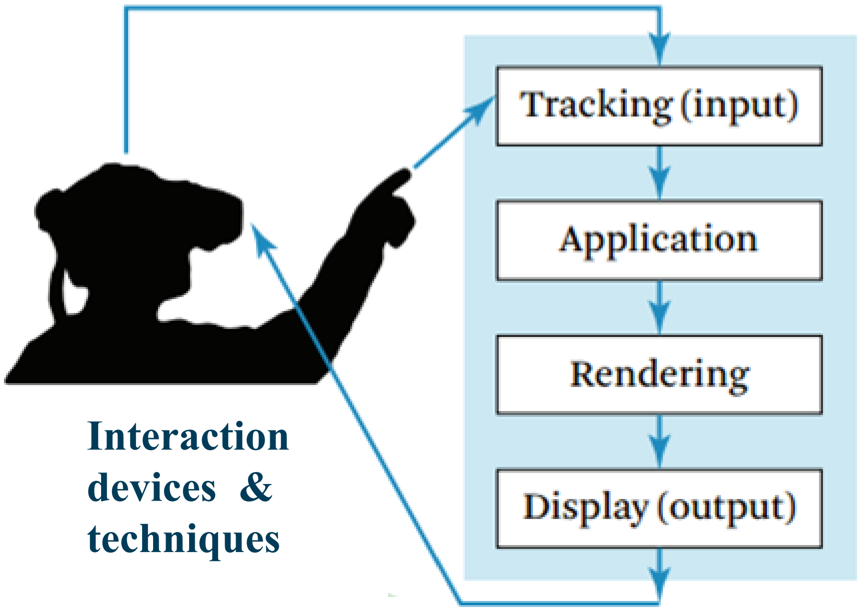
\+ Cameras and registering

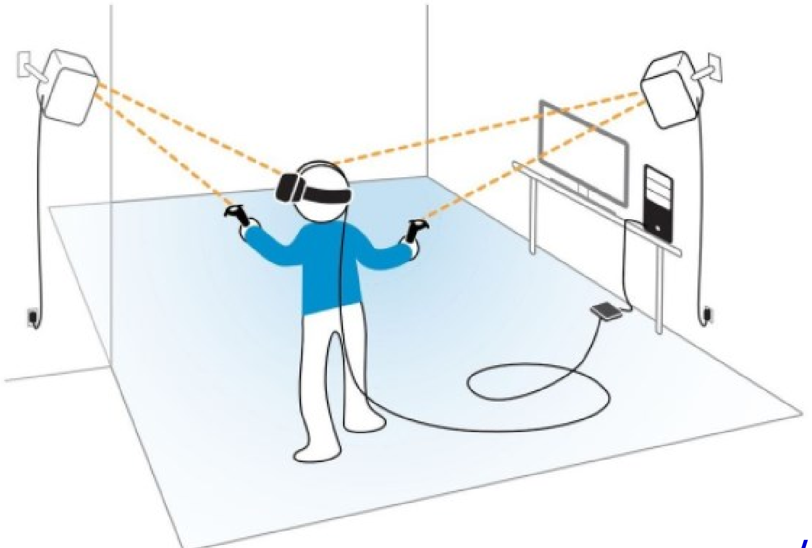
Input devices

- **Trackers**:
  - Magnetic (AC, DC)
  - Optical
  - Ultrasonic
  - Inertial,
  - Mechanical
  - Hybrid ...

- **Navigation and manipulation interfaces**:
  - Tracker-based
  - Controllers
  - 3D mice, ...

- **Gesture interfaces**:
  - Depth cameras
  - Gloves ...





https://www.vive.com/eu/

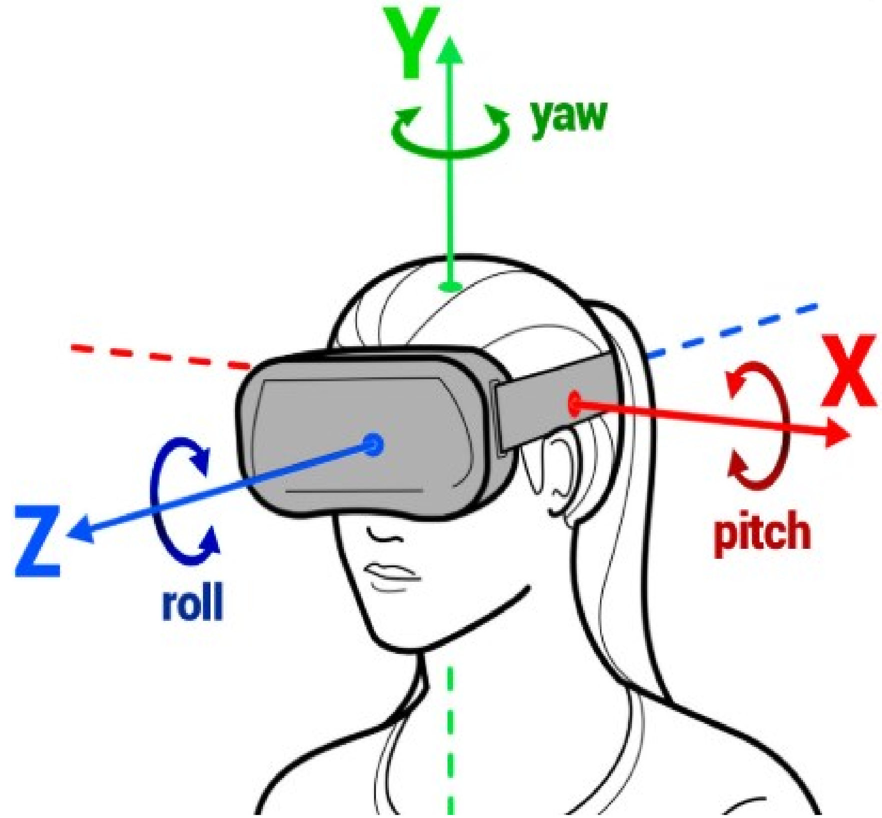
Tracker is a special purpose H/W to measure the real-time change in a 3D object position and orientation

Trackers measure the motion of "objects" (e.g. user head)
in a fixed system of coordinates.

(Virtual) objects have **6 degrees of freedom** (**D.O.F**s):

-three translations;

-three rotations.



(Burdea and Coiffet., 2003)

Roll – rotation around the zz axis

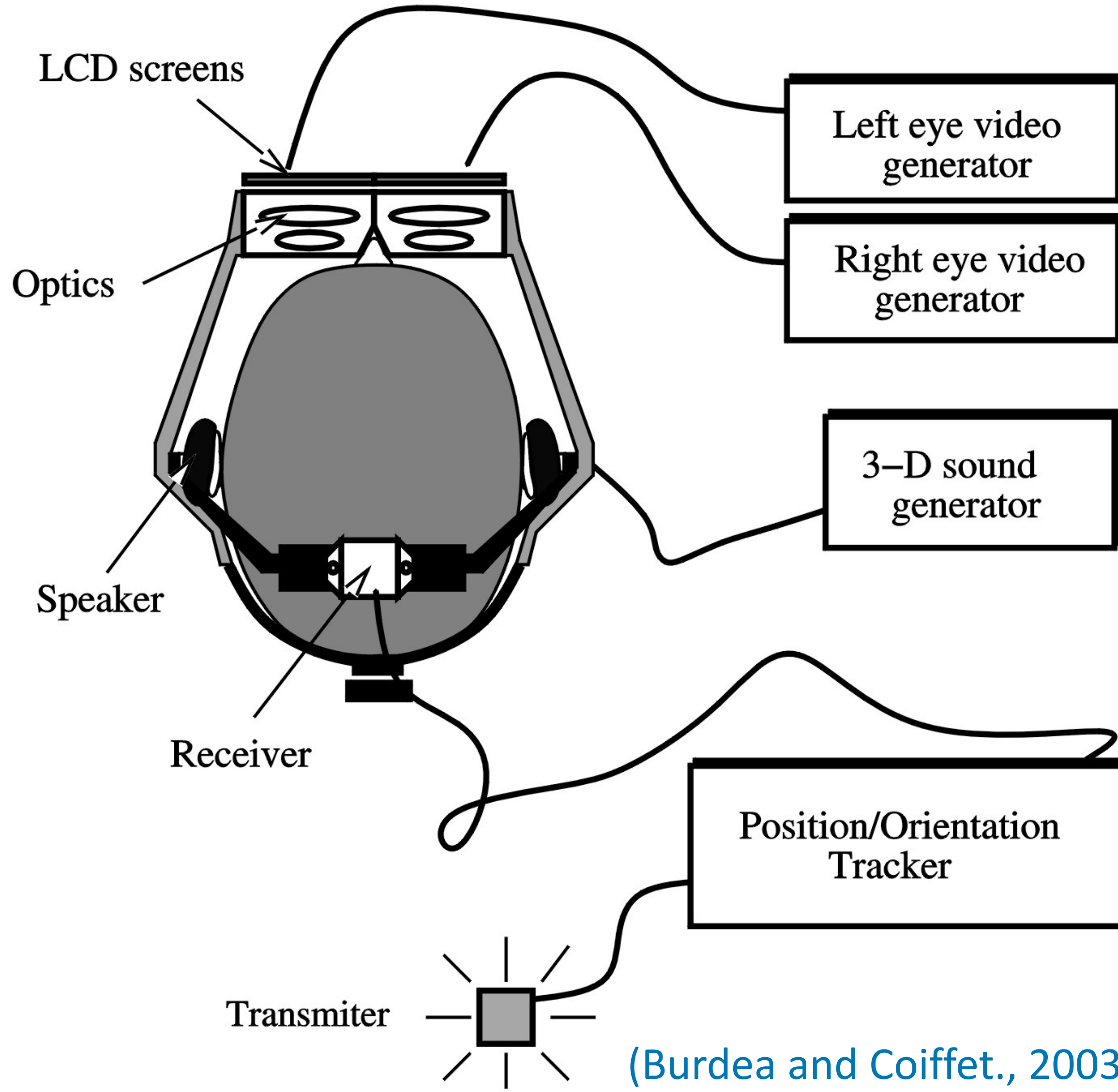
https://en.wikipedia.org/wiki/Aircraft_principal_axes

Note: you may find slightly different definitions…

Example: 3D magnetic sensor in a HMD

Without the head tracker
- the image
- the sound

cannot change to
match the head posture



Required tracking accuracy:
Image > sound

(Burdea and Coiffet., 2003)

What is usually tracked?

Body Tracking:

- Head
- Hand and fingers
- Torso
- Feet
- A group of people, ...

Indirect tracking:
Using physical objects
(props and platforms)

How?

Technologies:

- Electromagnetic
- Optical
- Ultrasonic
- Inertial
- Mechanical

- Hybrid ...

Tracker characteristics:

- Measurement rate – Readings/sec
- Sensing latency
- Sensor noise and drift
- Measurement accuracy
- Measurement repeatability
- Resolution
- Tethered or wireless
- Work envelope
- Sensing degradation
- …

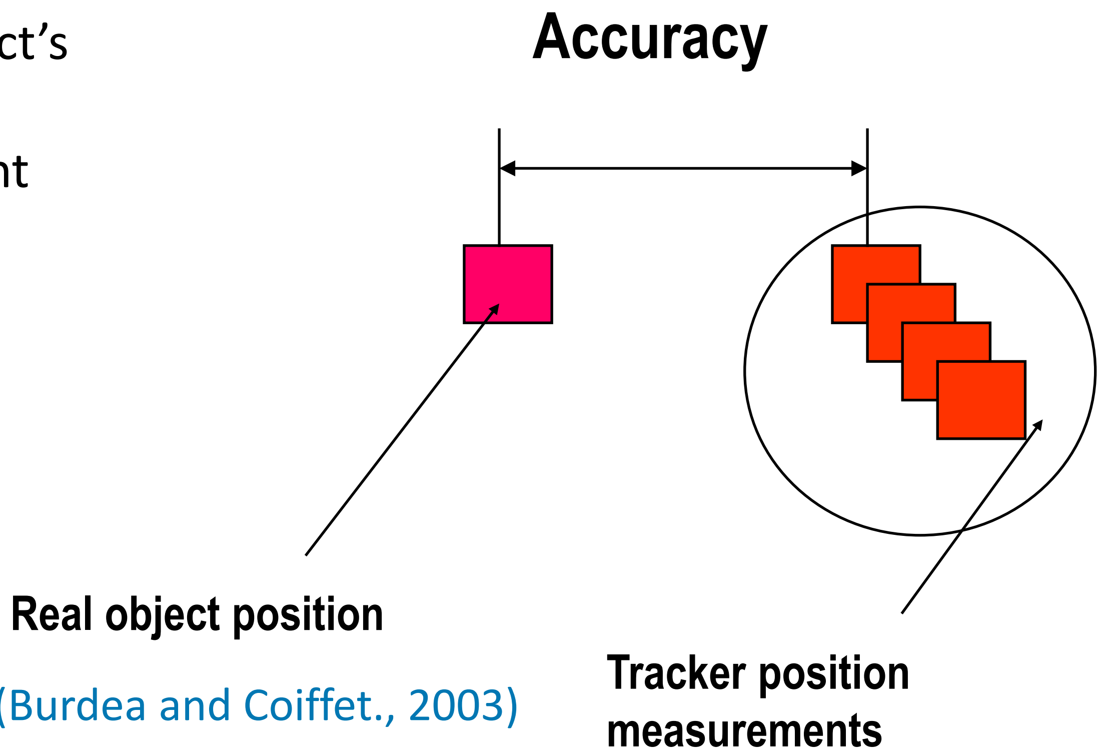
Tracker performance parameters:

- Accuracy
- Jitter
- Drift
- Latency
- Tracker update rate

Tracker performance parameters should be analyzed to match a solution for sensorial channel and budget of an application!

Tracker characteristics

Accuracy:
Difference between the object's actual 3D position and that reported by the measurement



(Burdea and Coiffet., 2003)

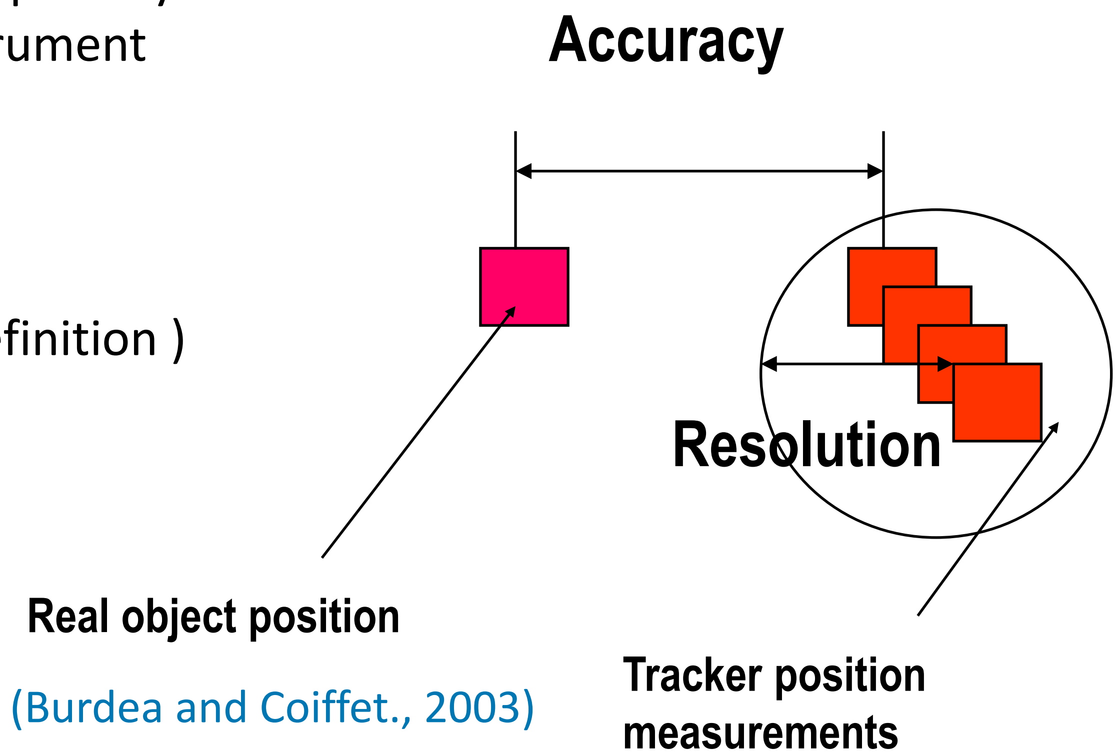
Tracker characteristics

Resolution:

"the smallest amount of the quantity being measured that the instrument will detect."

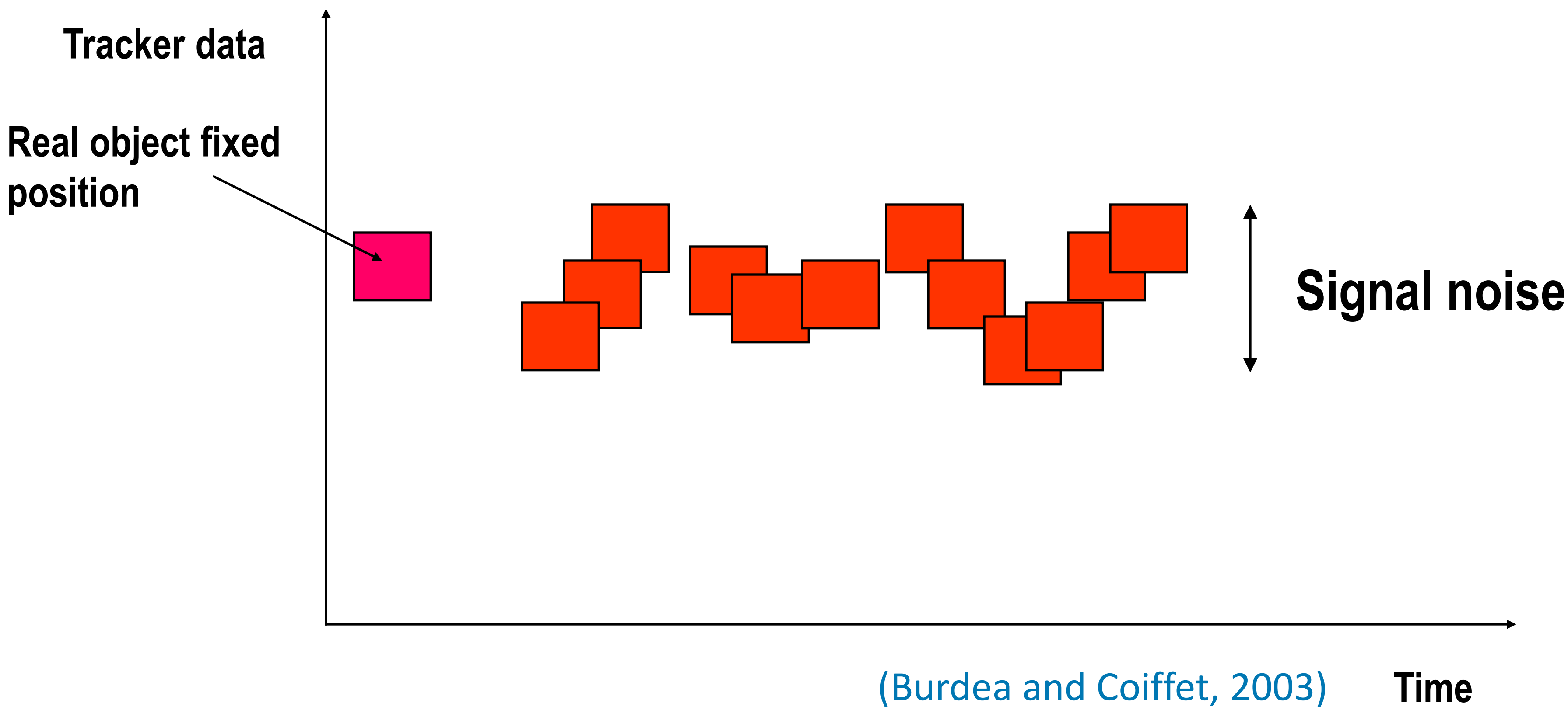
(used by Ascension)

(Polhemus uses a different definition)



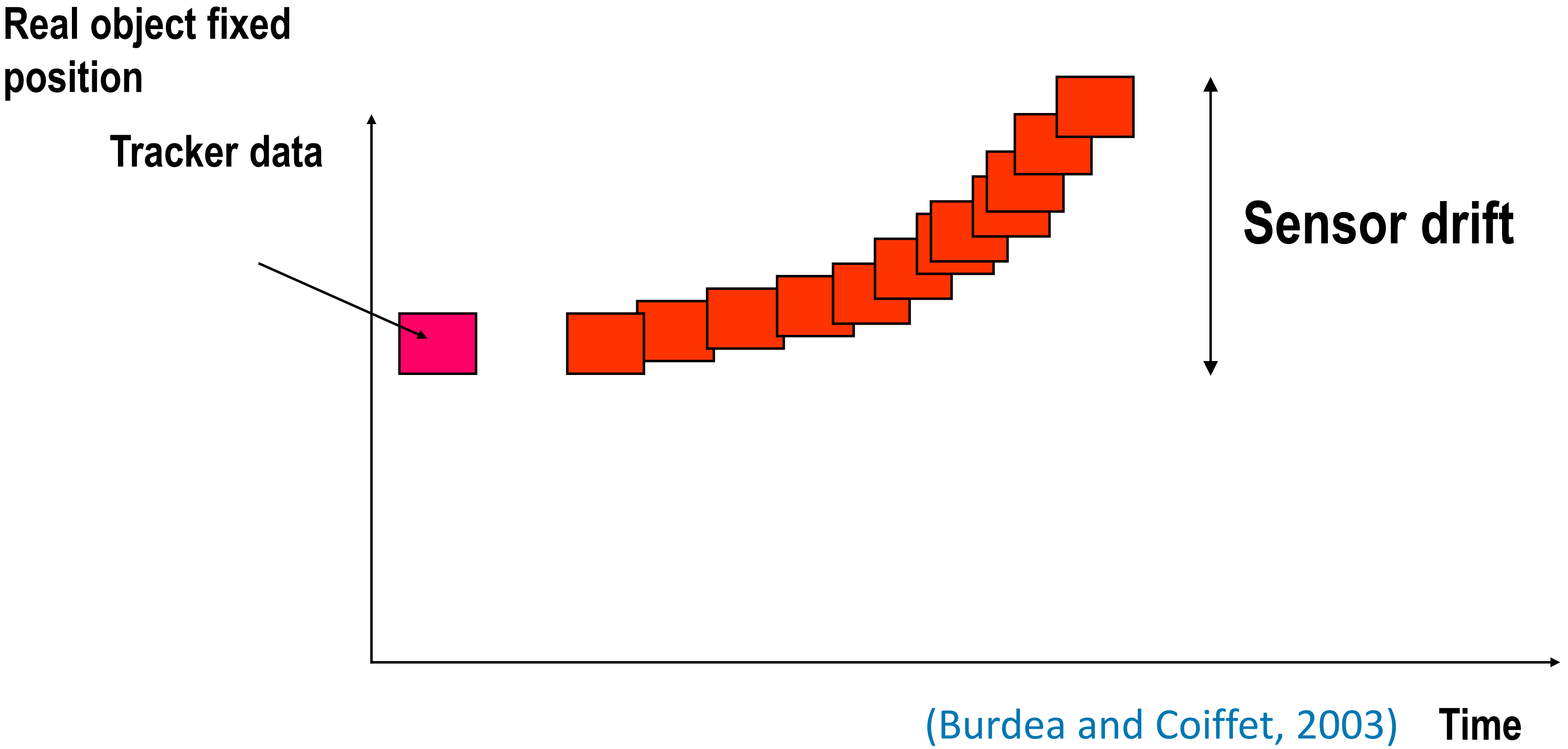
(Burdea and Coiffet., 2003)

Jitter:
Change in tracker output when
the tracked object is stationary



(Burdea and Coiffet, 2003)

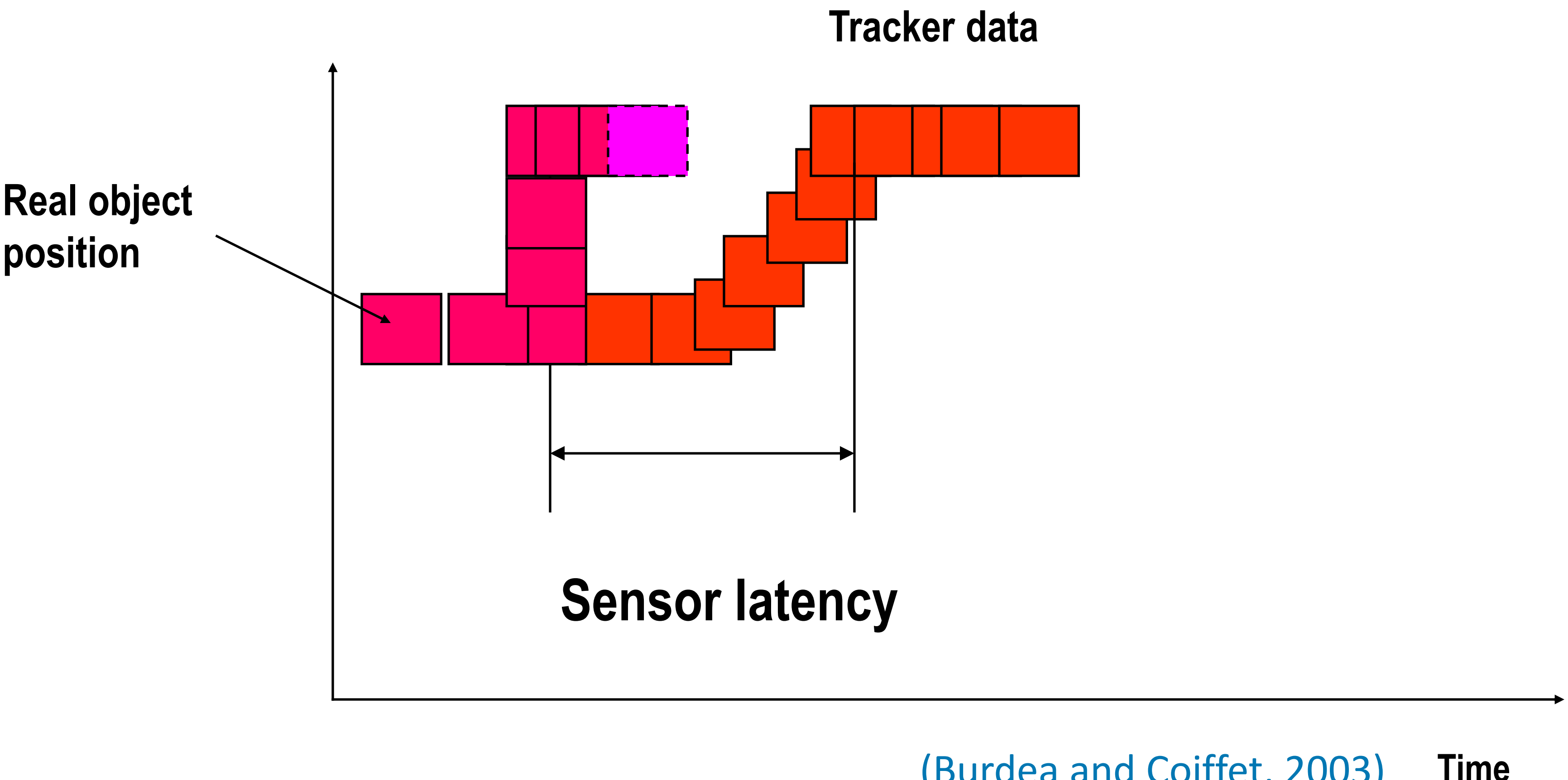
Drift: Steady increase in tracker error with time



(Burdea and Coiffet, 2003)

Latency:

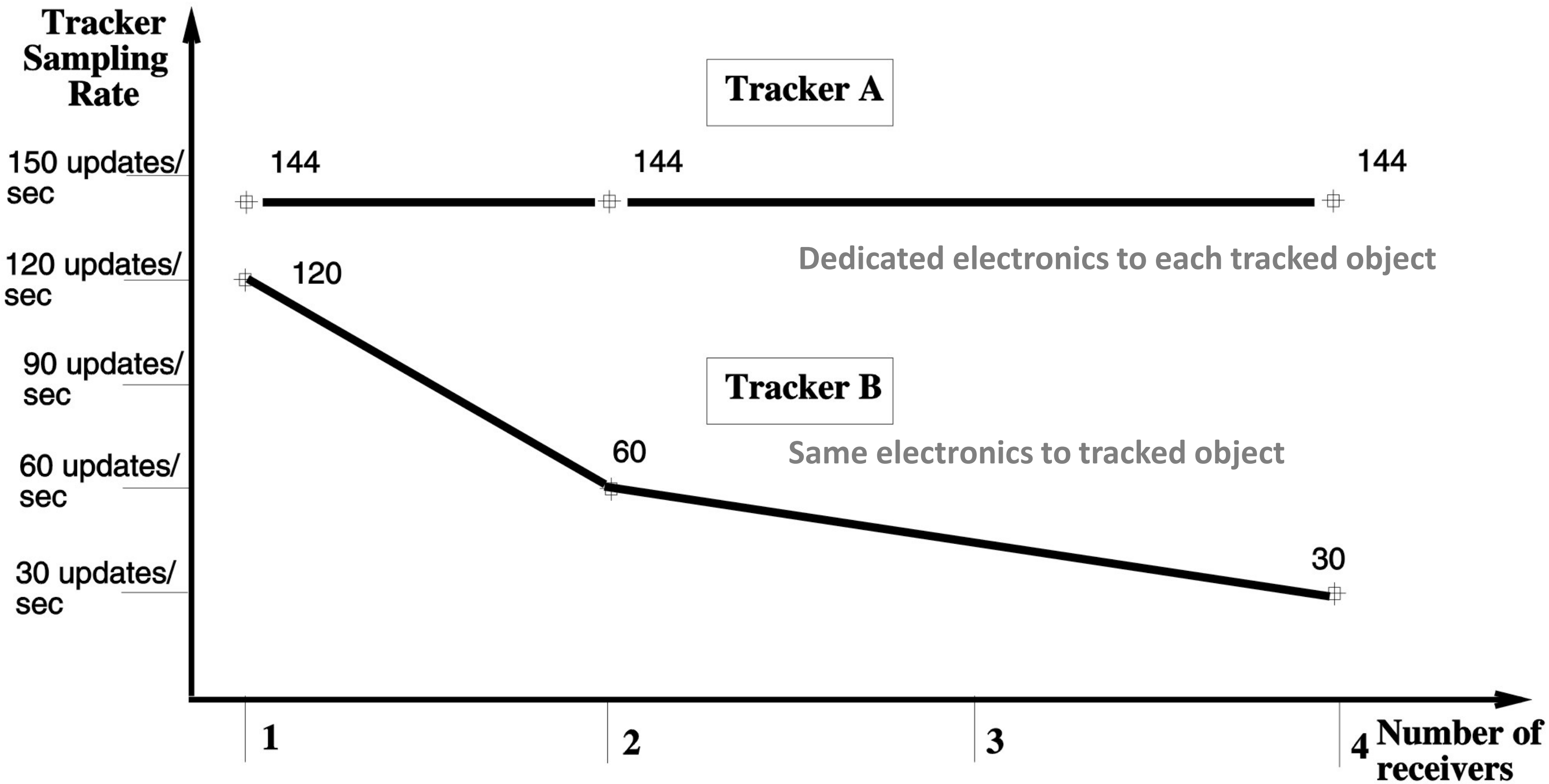
Time delay between action and result: time between the change in object position/orientation and the time the sensor detects this change



(Burdea and Coiffet, 2003)

Tracker update rate:
Number of measurements (samples) that the tracker reports every second

If the same tracker electronics is used to measure several objects, the sampling rate suffers due to multiplexing



(Burdea and Coiffet, 2003)

Most used trackers:

- Magnetic
- Ultrasonic
- Optical
- Inertial
- …

Magnetic Trackers

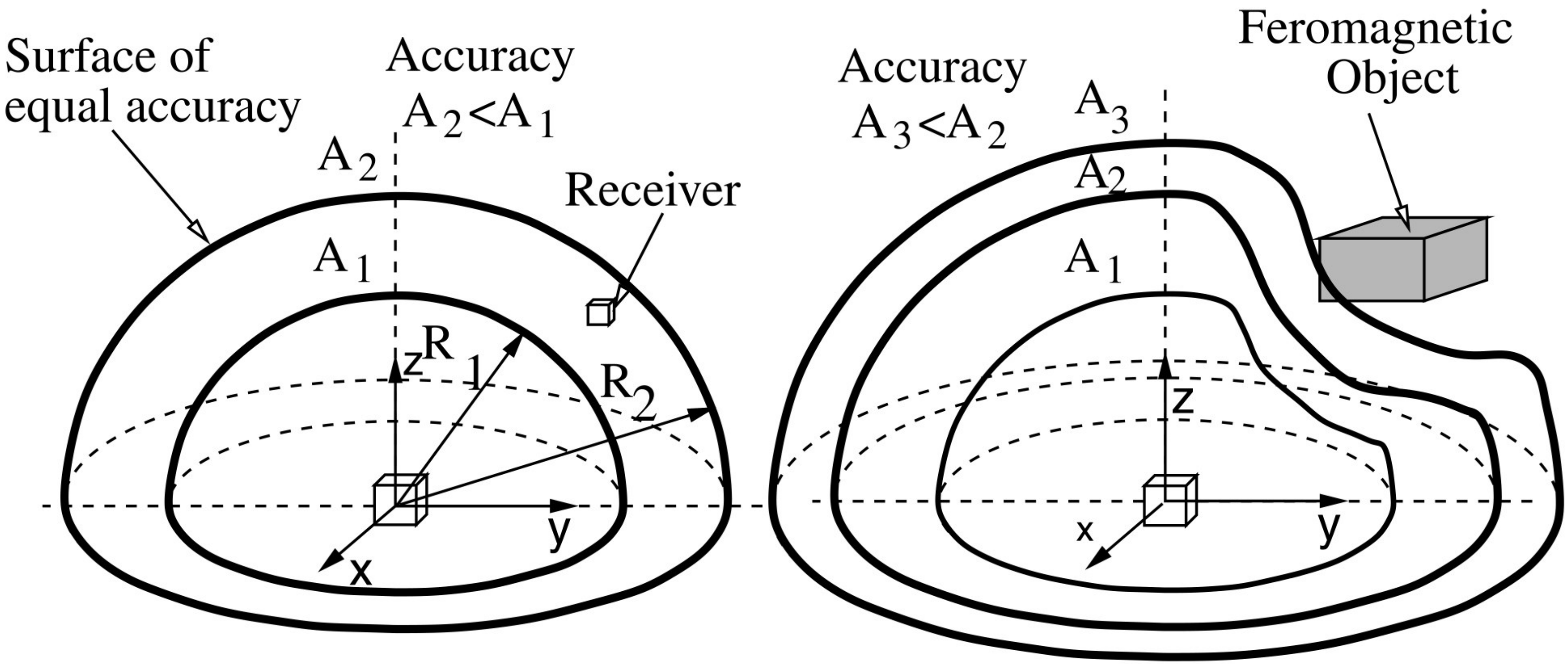
A magnetic tracker is a non-contact position measurement device that uses a magnetic field produced by a stationary **TRANSMITTER** to determine the real-time position of a moving **RECEIVER** element

may be AC
DC

Magnetic Trackers

- Use low-frequency **magnetic fields to measure position**
- Fields are produced by a fixed source
- Size of source grows with the tracker work envelope
- The **receiver is attached to the tracked object** and has three perpendicular antennas
- Distance is inferred from the voltages induced in the antennas – **needs calibration**…

Magnetic tracker accuracy degradation due to ferromagnetic objects in the environment



a) (Burdea and Coiffet, 2003) b)

Comparison of AC and DC magnetic trackers

- **DC trackers are immune to non-ferromagnetic metals**

  (brass, aluminum and stainless steel)

- **Both DC and AC trackers are affected by the presence of ferromagnetic metals**

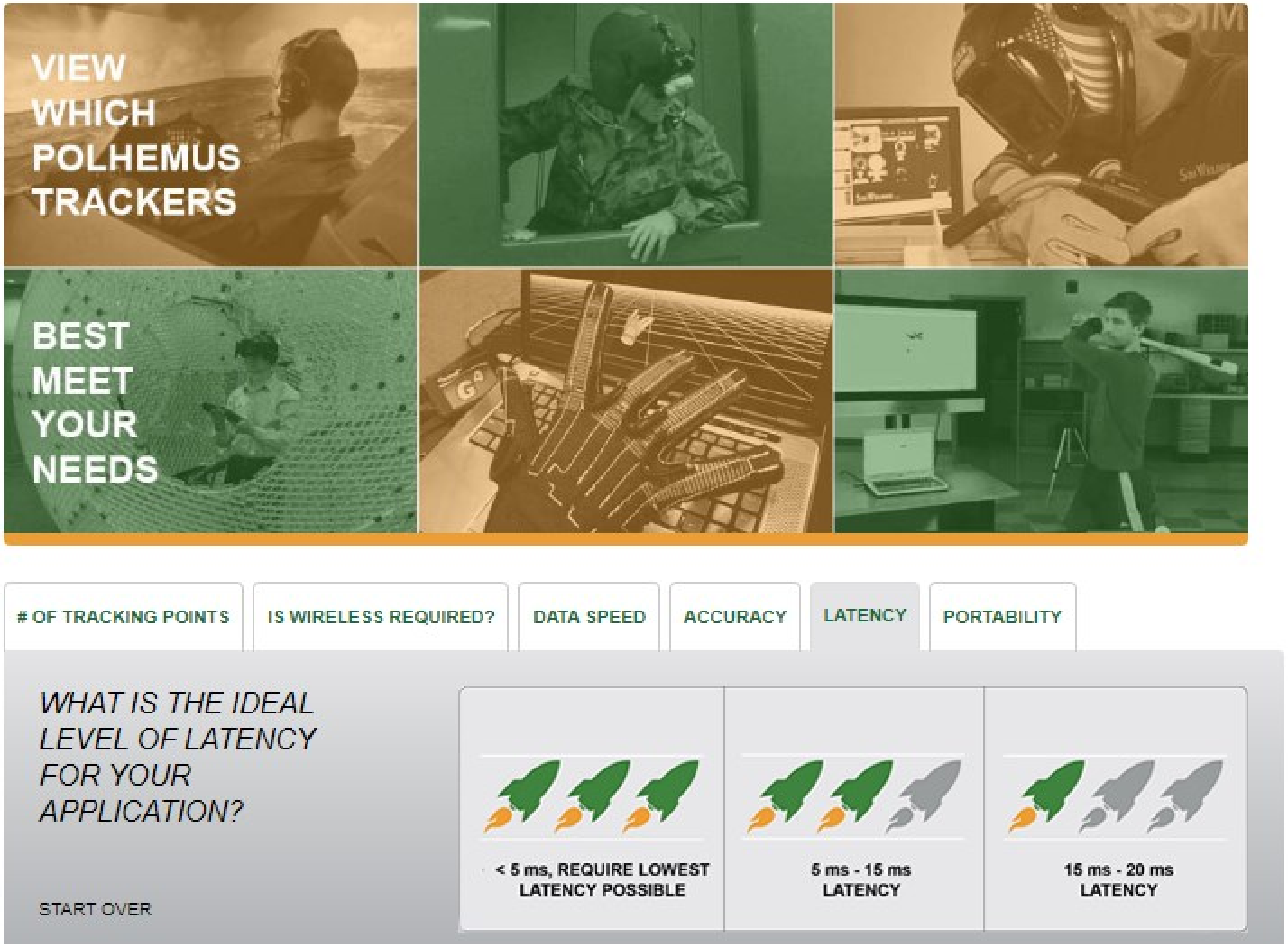
  (mild steel and ferrite)

- Both are affected by copper

- **AC trackers have better resolution and accuracy**

- AC trackers have slightly shorter range

How to select a tracker: example



https://polhemus.com/motion-tracking/motion-tracking-selection-guide

A “standard” for motion tracking for years:

Polhemus (proprietary AC electromagnetic technology)

High Accuracy Head Tracking with low latency

Applications:

Training and Simulation

Eye Tracking

Neuroscience

Biomechanics

FASTRAK®

THE WORKHORSE 6DOF MOTION TRACKER THAT SET THE STANDARD IN TRACKING

https://polhemus.com/_assets/img/FASTRAK_Brochure_1.pdf
https://www.vrealities.com/motion-trackers

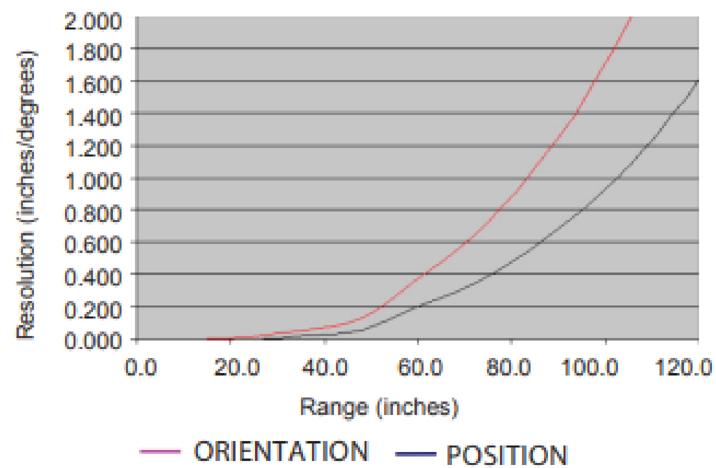
Polhemus Fastrak

SPECIFICATIONS

UPDATE RATE	120 updates/second divided by the number of sensors
INTERFACE	USB; RS-232 with selectable baud rates up to 115.2 K (optional RS-422)
LATENCY	4 milliseconds
STATIC ACCURACY	0.03 inches RMS for the X, Y, or Z position; 0.15° RMS for sensor orientation. The system will provide the specified performance when the sensors are within 30 inches of the source. Operation over a range of up to 10 feet is possible with slightly reduced performance.
OPERATING TEMPERATURE	10°C to 40°C at a relative humidity of 10% to 95%, noncondensing
POWER REQUIREMENTS	15 W, 100-240 VAC, 47-63Hz
SOFTWARE TOOLS	GUI included USB drivers for Microsoft Windows® Linux® - contact Polhemus
REGULATORY	FCC Part 15, class A EN61326-1: 2013 Emission EN61326-1: 2013 Immunity, Basic Environment

https://polhemus.com/_assets/img/FASTRAK_Brochure_1.pdf

RANGE VS RESOLUTION



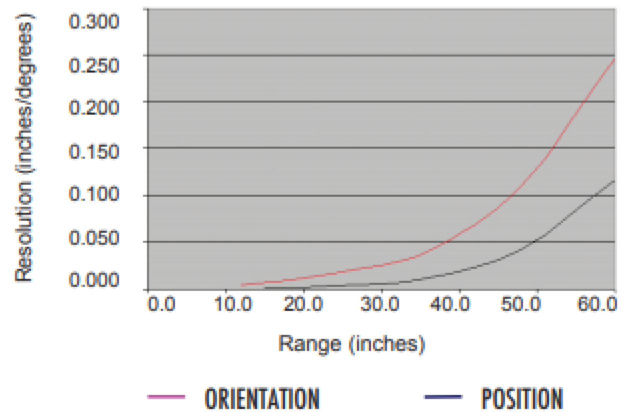
Range (inches)	Position Resolution (inches)	Orientation Resolution (degrees)
12.0	0.00023	0.0026
24.0	0.0030	0.0147
36.0	0.019	0.0558
48.0	0.055	0.1266
72.0	0.346	0.369
120.0	1.605	2.960

"Cost-effective": Polhemus Patriot

SPECIFICATIONS

UPDATE RATE	60Hz per sensor simultaneous sampling
INTERFACE	RS-232 with selectable baud rates up to 115.2 K USB 2.0 (high speed)
LATENCY	Less than 18.5 milliseconds
STATIC ACCURACY	0.06 in. RMS for X, Y, Z position; 0.40° RMS for sensor orientation. The system will provide the specified performance in a non-distorting environment when standard (RX2) sensors are within 36 inches of the standard (TX2) source; 42 inches with the optional TX4 source (Non-standard, smaller, sensors may reduce the specified range slightly). Operational out to 60 inches with slight degradation in performance.
OPERATING TEMPERATURE	10°C to 40°C at a relative humidity of 10% to 95%, noncondensing
POWER REQUIREMENTS	4W, 100-240 VAC, 50-60Hz
SOFTWARE TOOLS	PiMgr GUI for Microsoft Windows® USB driver package for Microsoft Windows® PDI SDK for Microsoft Windows® GUI for Linux®
REGULATORY	FCC Part 15, class B EN61326-1: 2013 Emissions EN61326-1: 2013 Immunity, Basic Environment
REGULATORY (Patriot M)	FCC Class B and CE Certified Tested to IEC 60601-1 Ed. 3.1: 2012 and IEC 60601-1-3rd Ed. 2007

RANGE VS RESOLUTION



Range (inches)	Position Resolution (inches)	Orientation Resolution (degrees)
12.0	0.00046	0.0038
24.0	0.0035	0.0168
36.0	0.0113	0.0407
48.0	0.0428	0.1108
60.0	0.1175	0.2470

https://polhemus.com/_assets/img/PATRIOT_brochure.pdf

Ultrasonic Trackers

A non-contact position measurement device that uses an ultrasonic signal produced by a stationary transmitter to determine the real-time position/ orientation of a moving receiver. (Burdea and Coiffet, 2003)

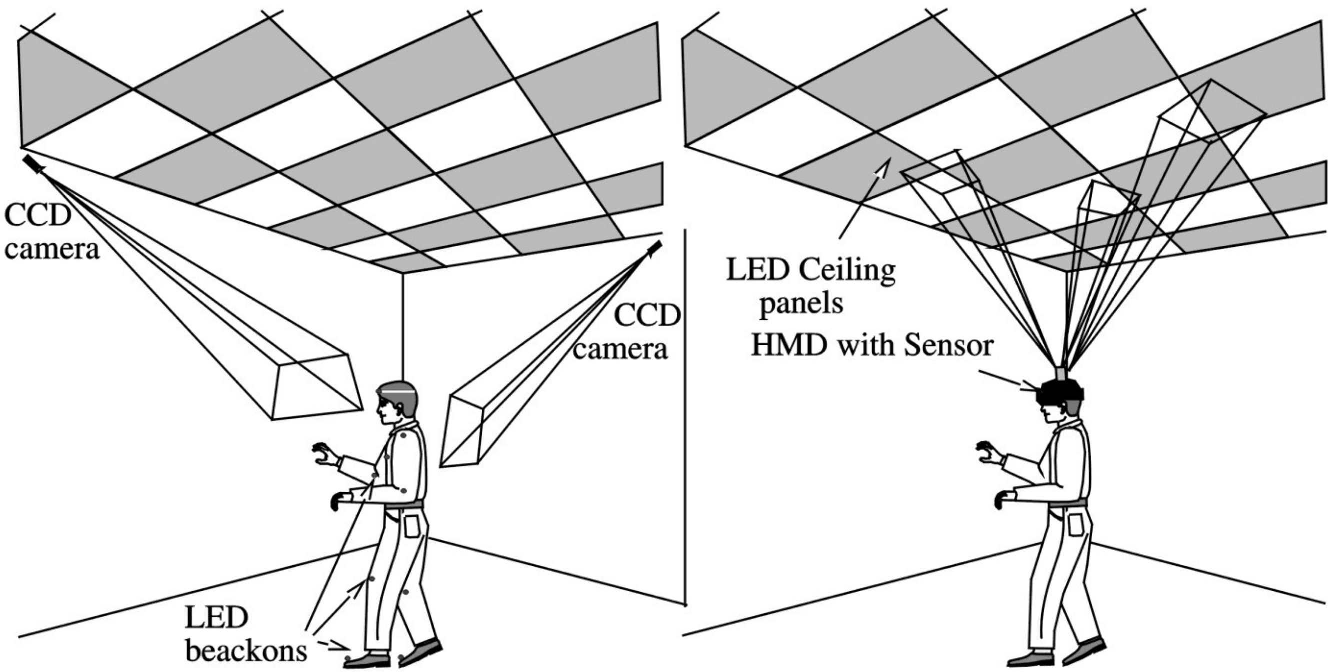
Ultrasonic Trackers

- Use low-frequency ultrasound to measure position
- Number of sources grows with the tracker work envelope
- Distance is inferred from the sound time of flight
- **Sensitive to air temperature and other noise sources**
- **Requires "direct line of sight"**
- Slower than magnetic trackers (max 50 updates/sec)
- More adequate to track hands than head

Vive: quickly upgraded Vive Focus Developer kits to support 6-DoF control input (2019)
https://www.invensense.com/news-media/TDK-announces-new-Chirp-SonicTrack-inside-out-6-DoF-ultrasonic-controller-tracking-solution-for-all-in-one-VR/
https://enterprise.vive.com/eu/product/vive-focus/

Optical Trackers

A non-contact position measurement device that uses optical sensing to determine the real-time position/ orientation of an object (Burdea and Coiffet, 2003)



outside-looking-in (e.g. Vicon)

inside-looking-out (e.g. HTC Vive)

Outside-looking -in
Vicon

- Motion tracking (high accuracy)
- e.g. for animation films characters
- Research, …

- VR simulators

- User wears reflective markers (small spheres)

https://www.vicon.com/

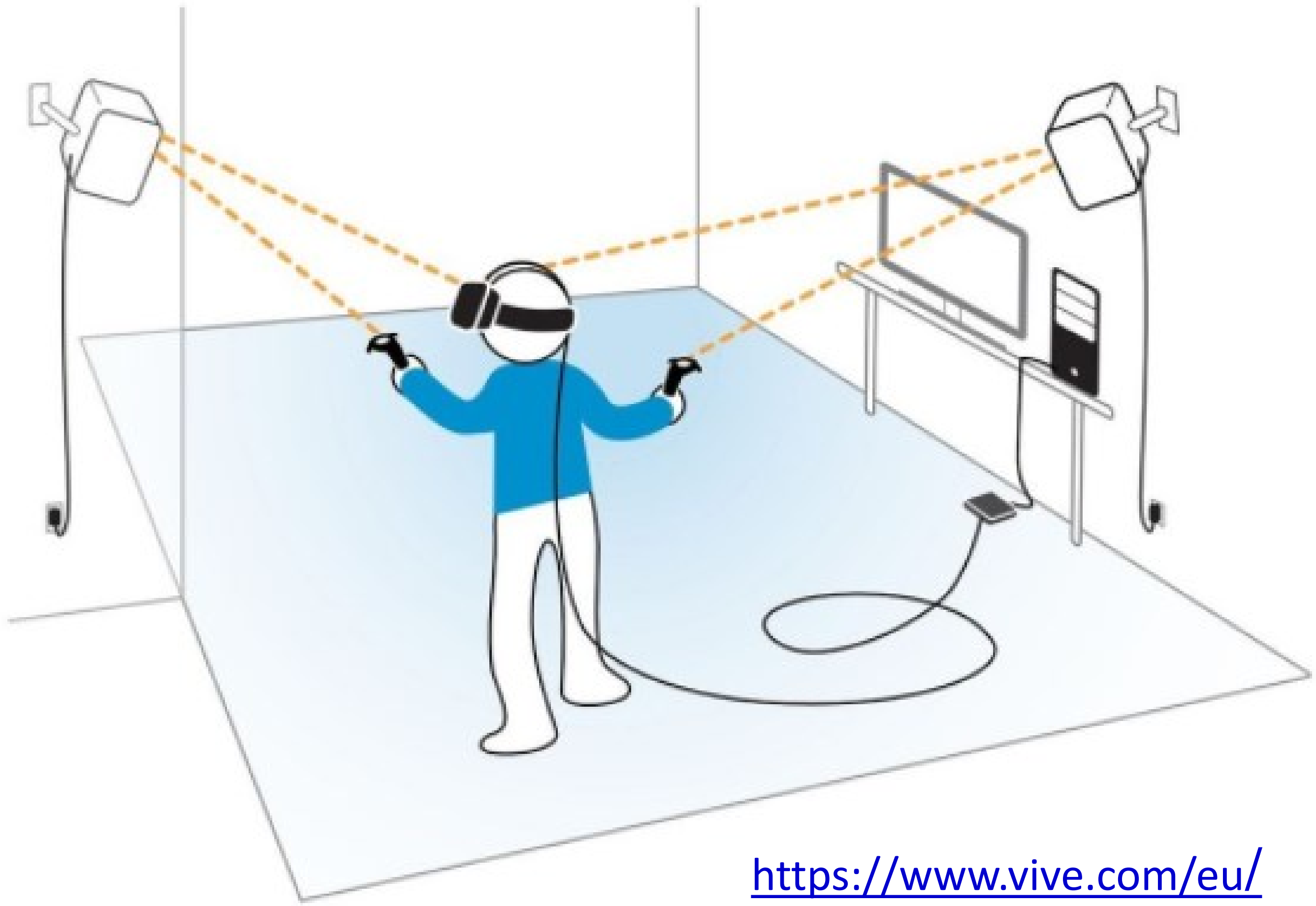
Location based VR

Immersive experiences

https://www.vicon.com/applications/location-based-virtual-reality/

Inside-looking-out
HTC Vive "Lighthouses"

- The base stations beam (IR) signals to the headset and controllers



https://www.vive.com/eu/

Inertial Trackers

- No interference from metallic objects
- No interference from magnetic fields
- Large-volume tracking
- “Source-less” orientation tracking
- Full-room tracking
- **Errors grow geometrically in time!**

Xsens

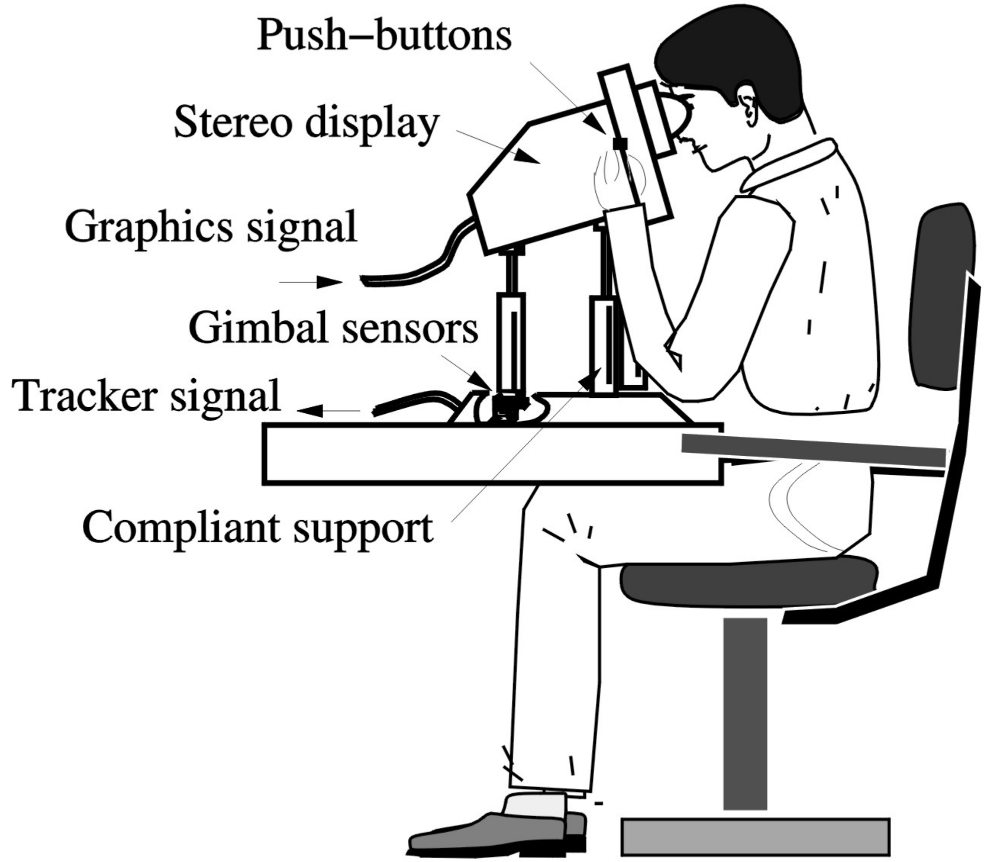
Example of Hybrid Solution for hand tracking

Mechanical Trackers

A mechanical tracker consists of a serial or parallel kinematic structure composed of links interconnected by sensorized joints.

(Burdea and Coiffet, 2003)

Were among the first tracking systems ever used



Mechanical tracker - Push 1280 stereo display (Fakespace Inc)

Item is no longer available

Mechanical Trackers

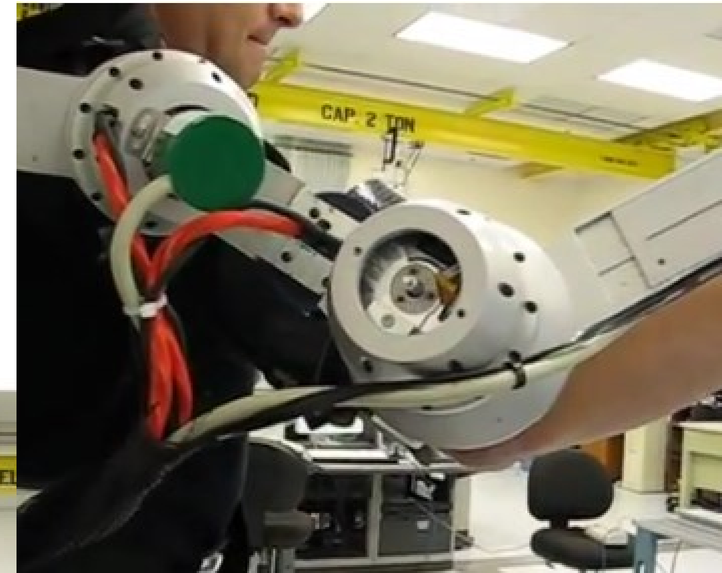
Pros

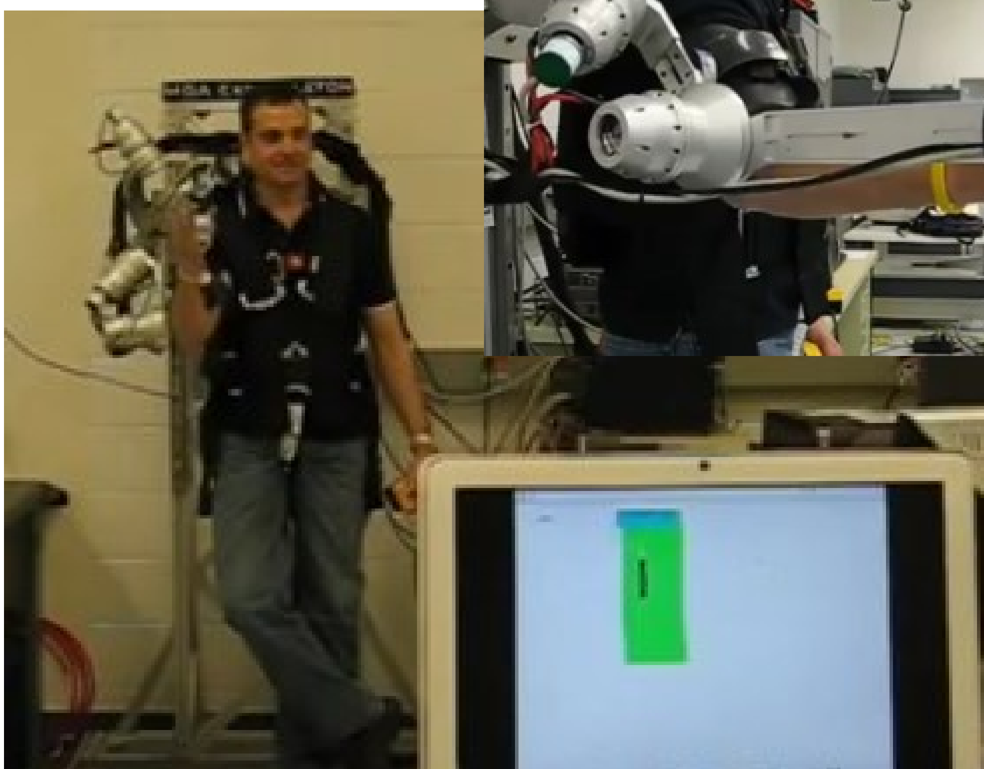
- Use sensors imbedded in exoskeletons to measure position
- Have extremely low latencies
- Are immune to interference from magnetic fields and large metal objects

Cons

- Limit the user’s freedom of motion
- Can be heavy if worn on the body
- Expensive

Example of an exoskeleton (mechanical tracker)





http://www.youtube.com/watch?v=uJza6G-7tD4

Painting a virtual wall: example of a virtual rehabilitation task for a patient recovering from stroke or traumatic brain injury

Navigation and Gesture Input Devices

- Navigation interfaces allow relative position control of virtual objects (including a virtual camera)
- Gesture interfaces allow dexterous control of virtual objects and interaction through gesture recognition.

Navigation and manipulation
Input Devices

- Controllers
- 3D mice
- …

more or less sophisticated and expensive

- Perform relative position/velocity control of virtual objects

Item is no longer available

Gesture Input Devices

- There are/ have been various sensing gloves such as:

  - Fakespace Pinch Glove (switches)

  - Immersion CyberGlove (stain gauges),

  - Avatar VR

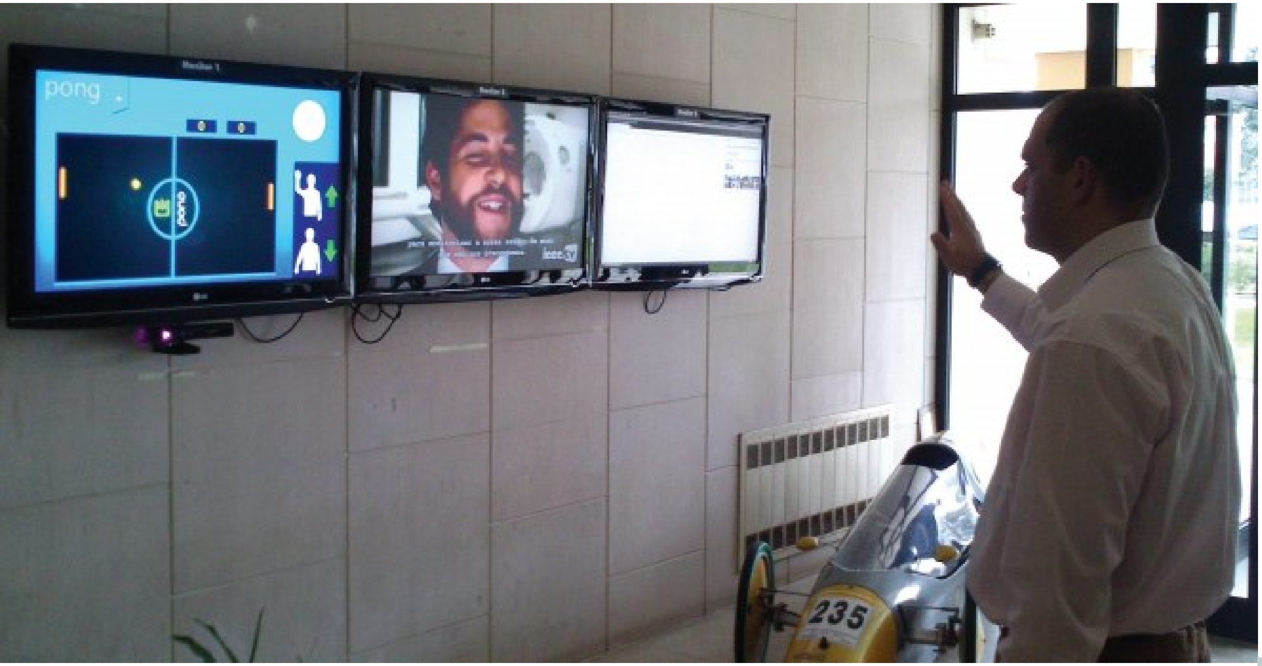
- Have larger work envelope than trackballs/3-D probes

- Most need calibration for user’s hand

Pinch Glove

CyberGlove

Other devices can be used to detect hand gestures (at low cost)



https://www.leapmotion.com/

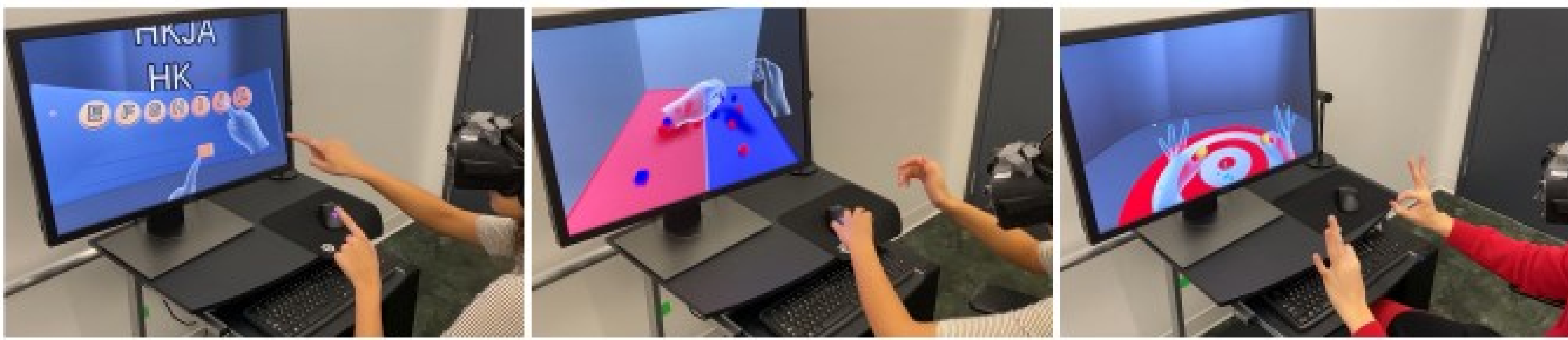
https://developer.microsoft.com/en-us/windows/kinect
http://kinectvr.com/
https://azure.microsoft.com/en-us/services/kinect-dk/

Stand alone (all-in-one) headsets already include hand tracking (Oculus Quest)

https://www.oculus.com/blog/how-researchers-cracked-hand-tracking-technology-on-quest/
https://tech.fb.com/making-technology-feel-natural/

Hand tracking (Oculus Quest)

“Real-time hand-tracking to drive virtual and augmented reality (VR/AR) experiences. Using four fisheye monochrome cameras, … generates accurate and low-jitter 3D hand motion across a large working volume for a diverse set of users … is the default feature on the Oculus Quest VR headset”



Han, et al., “MEgATrack: Monochrome Egocentric Articulated Hand-Tracking for Virtual Reality”, SIGGRAPH 2020 https://dl.acm.org/doi/abs/10.1145/3386569.3392452

Speech recognition is also an interesting possibility:

- Frees hands
- Allows multimodal input
- Specialized software
- **Issues**: recognition, ambient noise, training, false positives

Some AR HMDs allow voice and gesture control

https://vrgineers.com/xtal/

https://docs.microsoft.com/en-us/windows/mixed-reality/design/voice-input

An input device “providing an infinit VE”: a treadmill for VR

May have applications, beyond gaming: promote physical exercise, train people, …

Omnidirectional Treadmill:

https://invest.virtuix.com/

https://www.youtube.com/watch?v=fvu5FxKuqdQ

https://thetechinfluencer.com/best-vr-treadmill/

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

Virtusphere ("the VR hamster ball")

https://www.youtube.com/watch?v=2e5Qvac3BB8

Will Brain Computer Interface (BCI) be a viable VR Input technology?

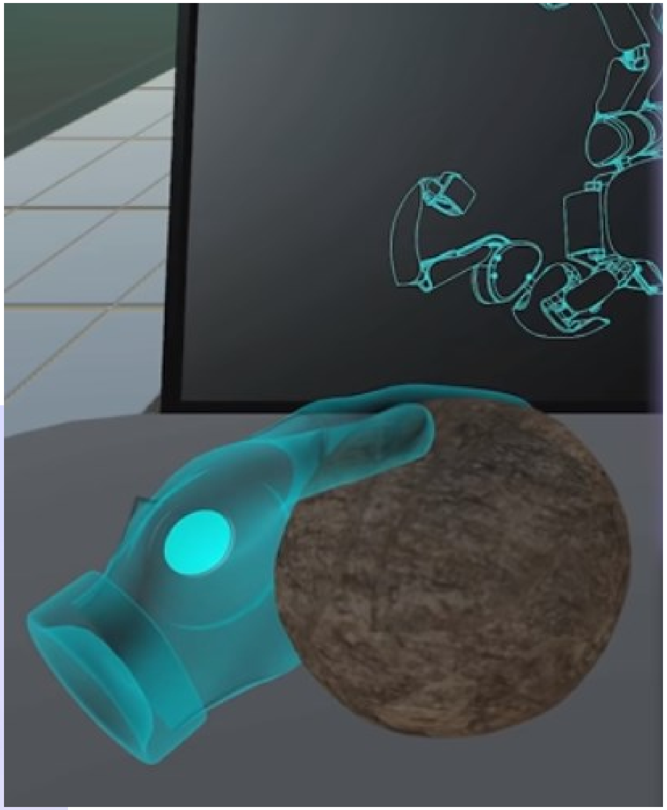
https://techcrunch.com/2020/12/21/nextminds-dev-kit-for-mind-controlled-computing-offers-a-rare-wow-factor-in-tech/

https://www.next-mind.com/

Input + output
CyberTouch Glove

https://est-kl.com/manufacturer/cyberglove-systems/cybertouch.html#technical-specifications
https://www.youtube.com/watch?v=TbxMY_rmOdM

Input + output
Dexmo Haptic Gloves



https://www.roadtovr.com/dexmo-vr-exoskeleton-glove-force-feedback-launches-kickstarter-campaign/
https://www.youtube.com/watch?v=IYf-QAW27ao

Concluding remarks

Every year new devices appear, some will prove useful and usable,
others will not …

When choosing a device, consider:

- Cost
- Generality
- DOFs
- Ergonomics / human factors
- Typical scenarios of use
- Output devices
- Interaction techniques, …

Do not select one just because it seems a cool technology!

Main bibliography

- Jerald, J., The VR Book: Human-Centered Design for Virtual Reality, ACM and Morgan & Claypool, 2016

- La Valle, S., Virtual Reality, Cambridge University Press, 2017 http://vr.cs.uiuc.edu

- G. Burdea and P. Coiffet, *Virtual Reality Technology*, 2nd ed. John Wiley and Sons, 2003