Universidade de Aveiro
Departamento de Electrónica,
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Input Devices

Virtual and Augmented Reality 2024

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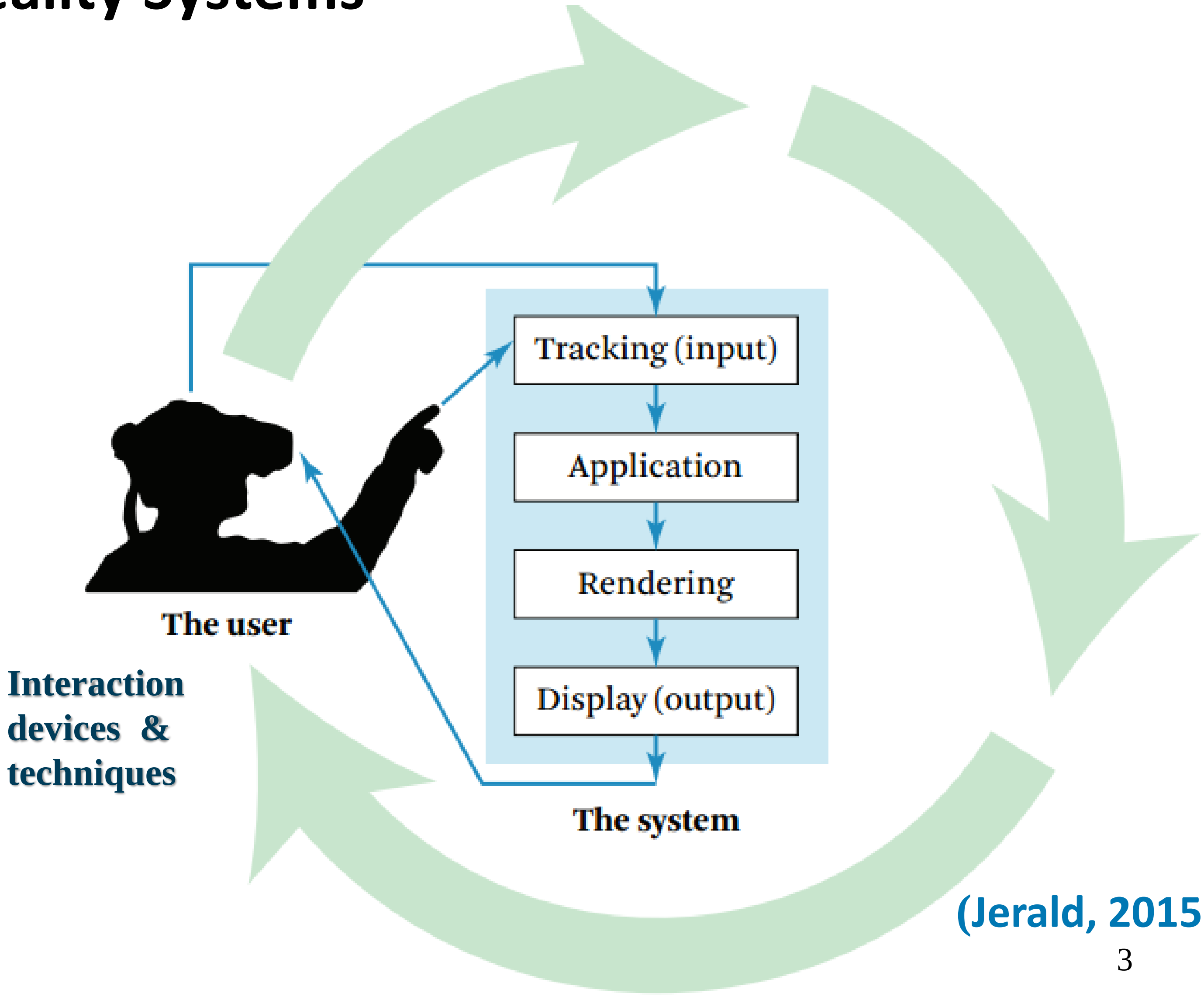
What is Virtual Reality?

"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, 2015)

Crucial technologies

for VR

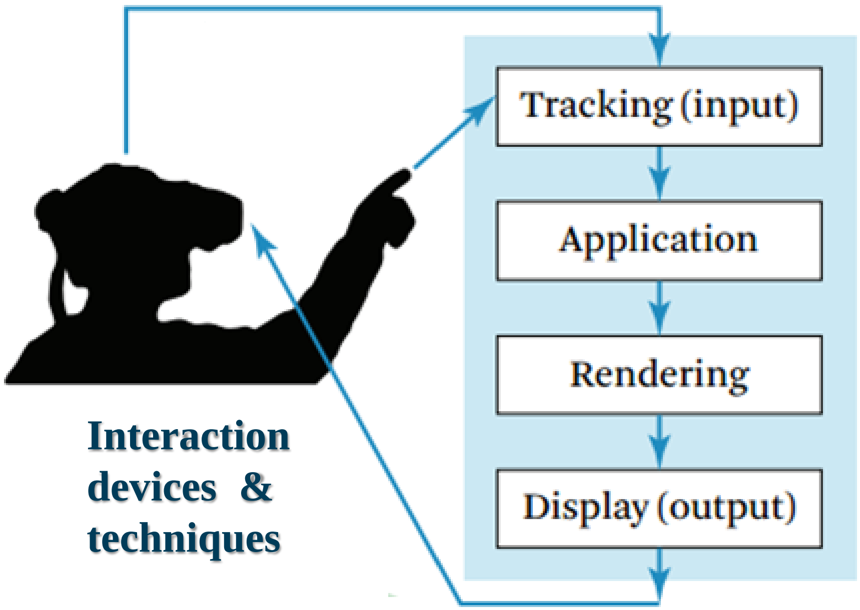
- Visual displays
- Graphics rendering system
- **Tracking system**
- Database system
- **Interaction devices**
- Interaction techniques
- Sound and haptic displays

  (if possible…)

for AR

\+ Cameras and registering

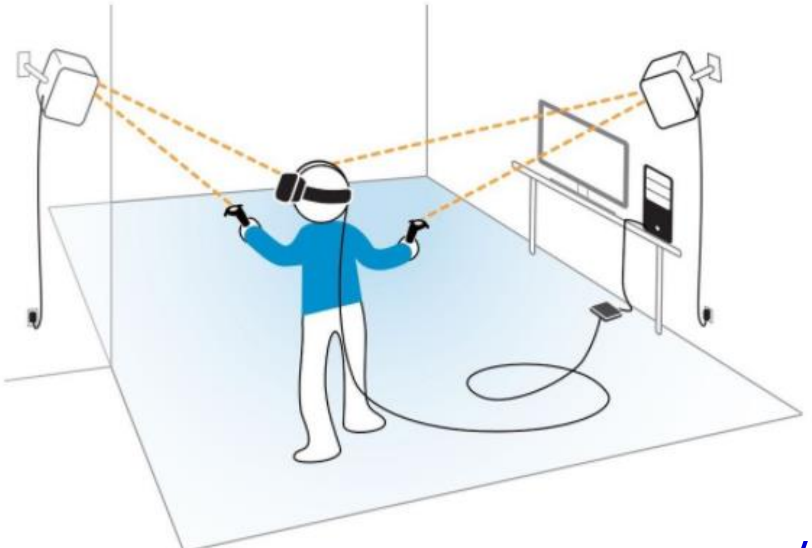
Input devices



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

- **Navigation and manipulation interfaces**:
  - Tracker-based
  - Controllers
  - ...

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



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

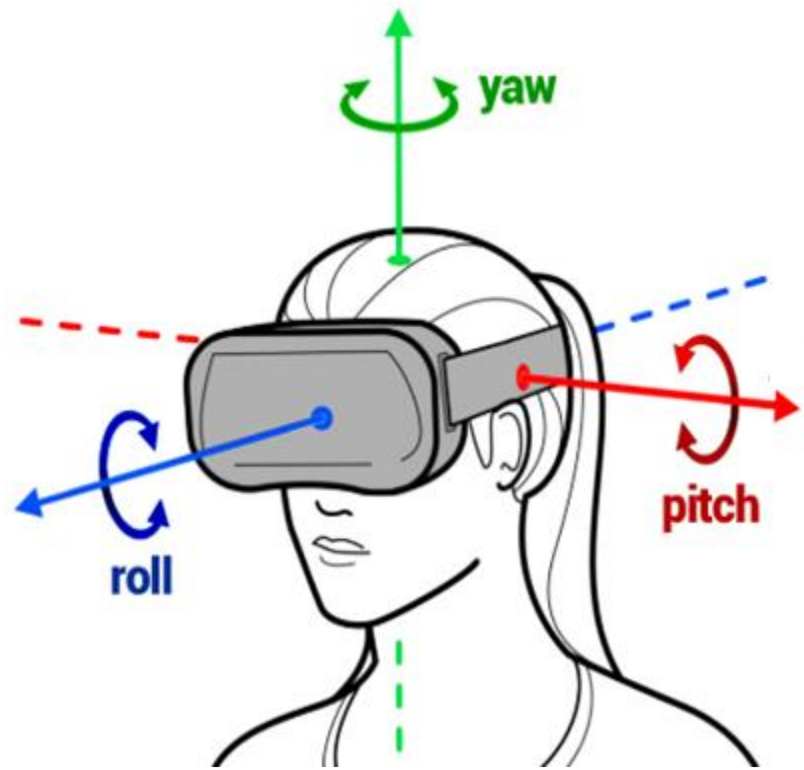
Tracker is a special purpose H/W to measure the real-time change in a 3D object position and orientation

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

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

-**three translations**;

-**three rotations**.

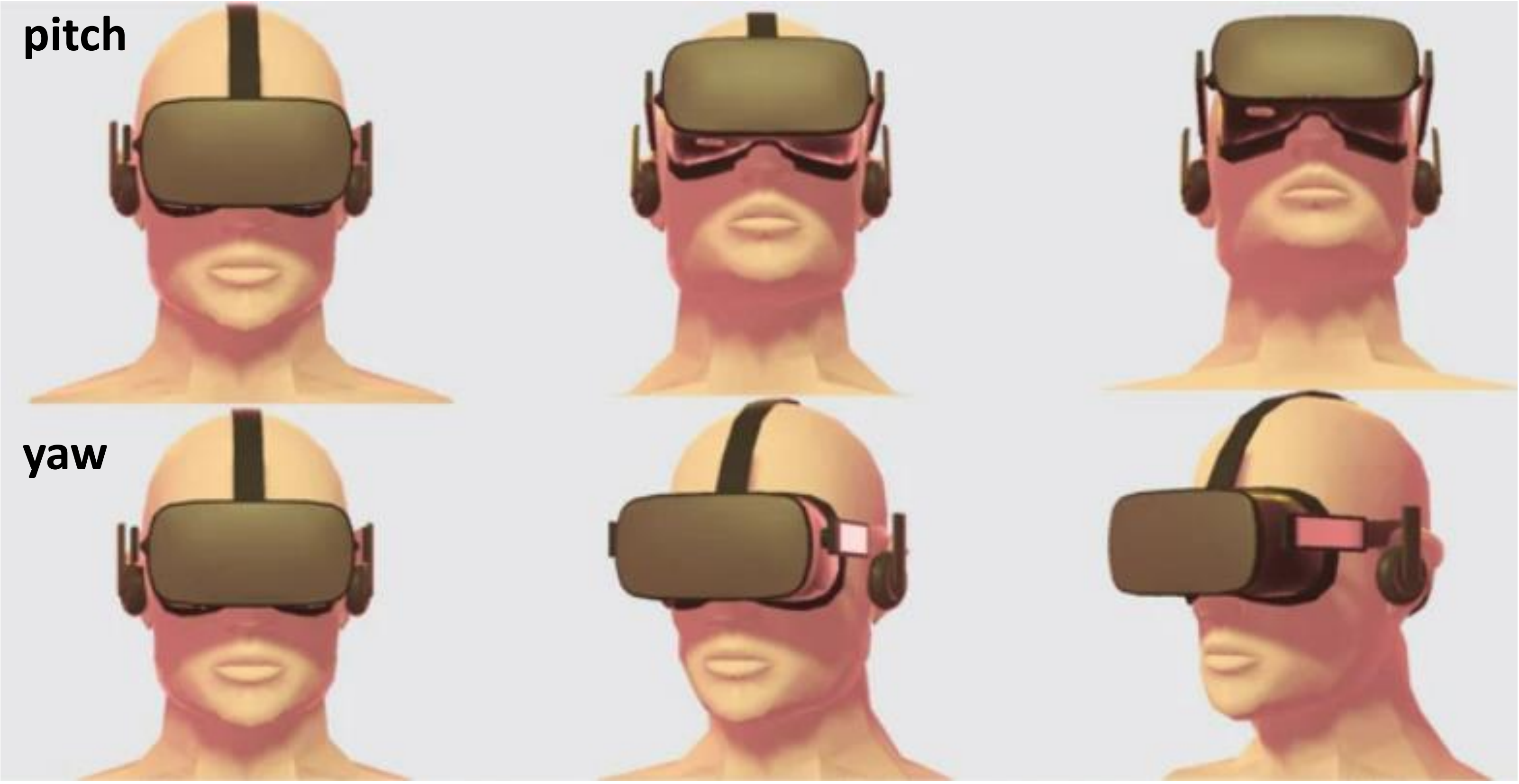


Oculus Rift Coordinate System

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

Note: you may find slightly different definitions…

Example: Head motions are important also for cybersickness



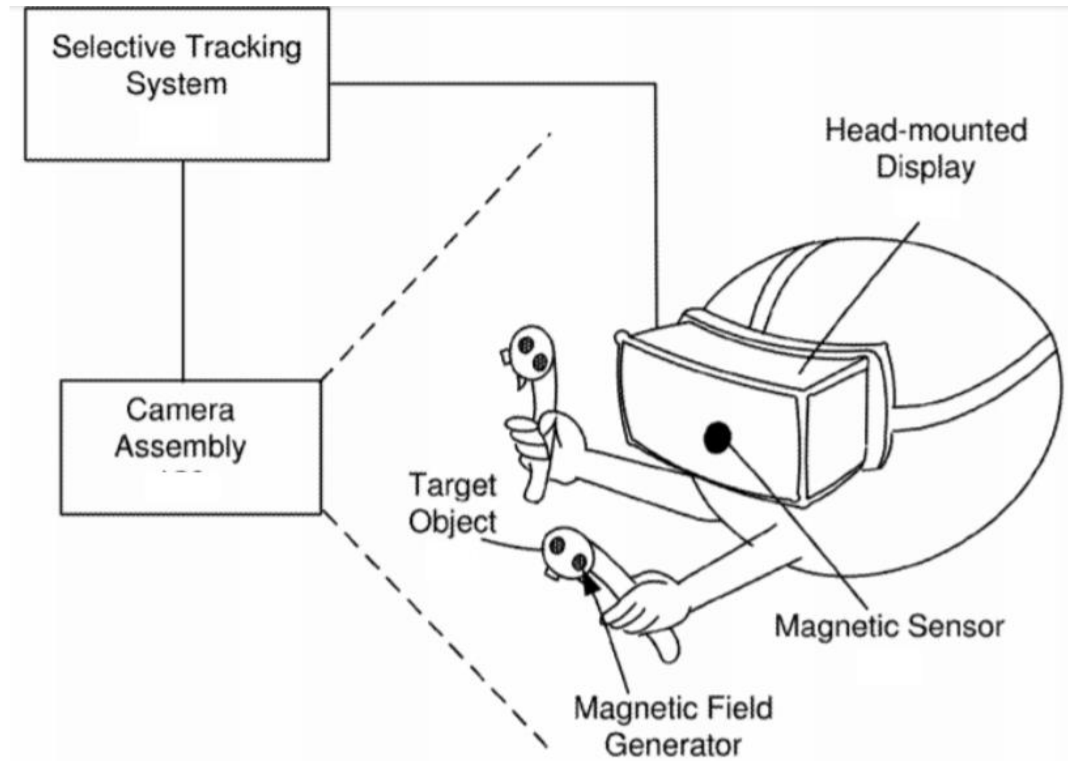
[Testing the 'differences in virtual and physical head pose' and 'subjective vertical conflict' accounts of cybersickness | Virtual Reality, 2024]

Example: 3D magnetic sensors in a HMD and controllers

Without the head tracker
- the image
- the sound

cannot change to
match the head posture

Required tracking accuracy:
Image > sound



What is usually tracked?

Body Tracking:

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

Indirect tracking:
Using physical objects
(props and platforms)

Objects

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
- …

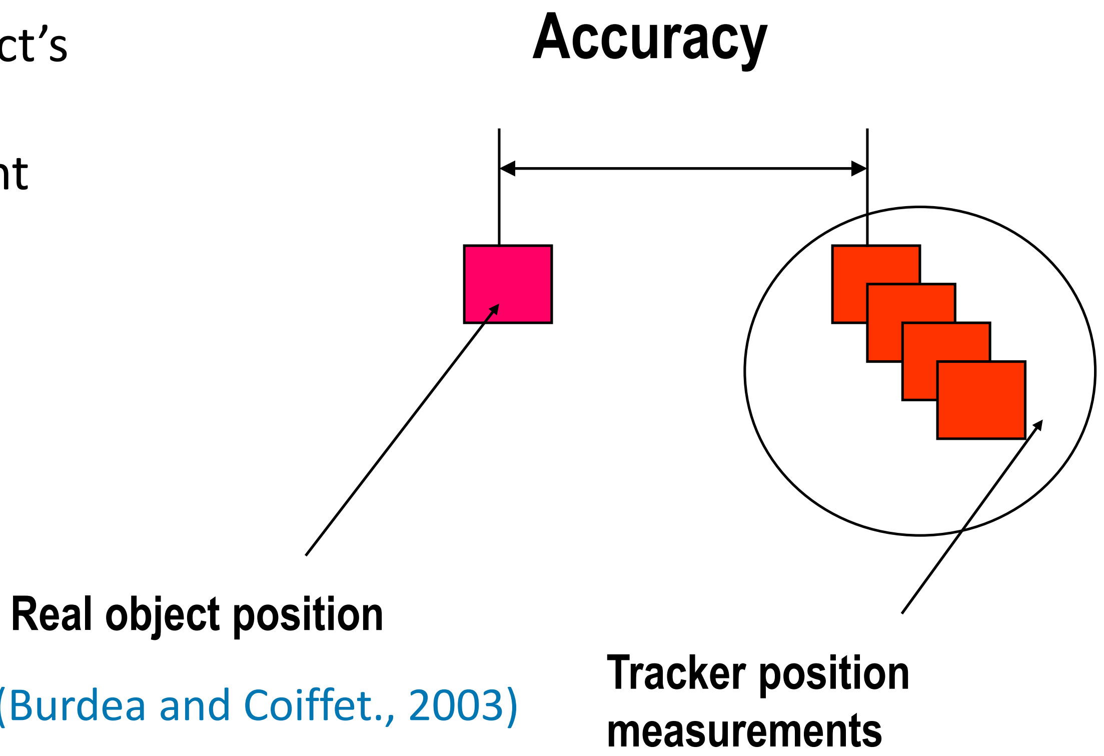
Tracker performance parameters:

- Accuracy
- Resolution
- 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)

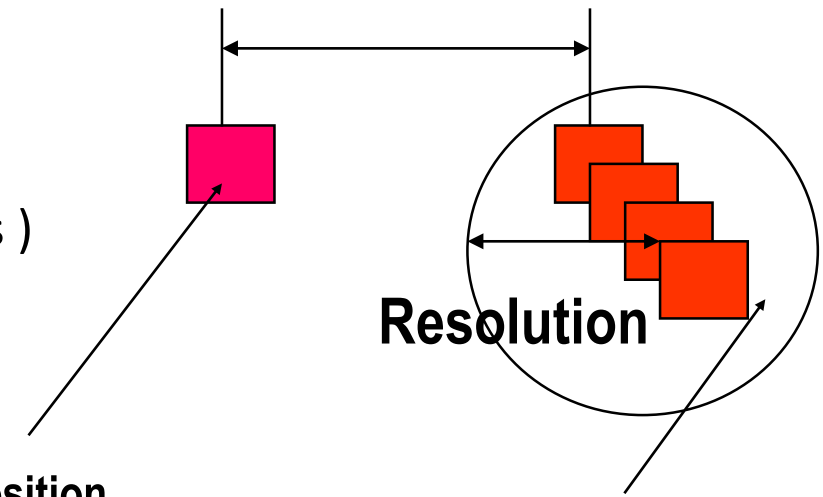
Tracker characteristics

Resolution:

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

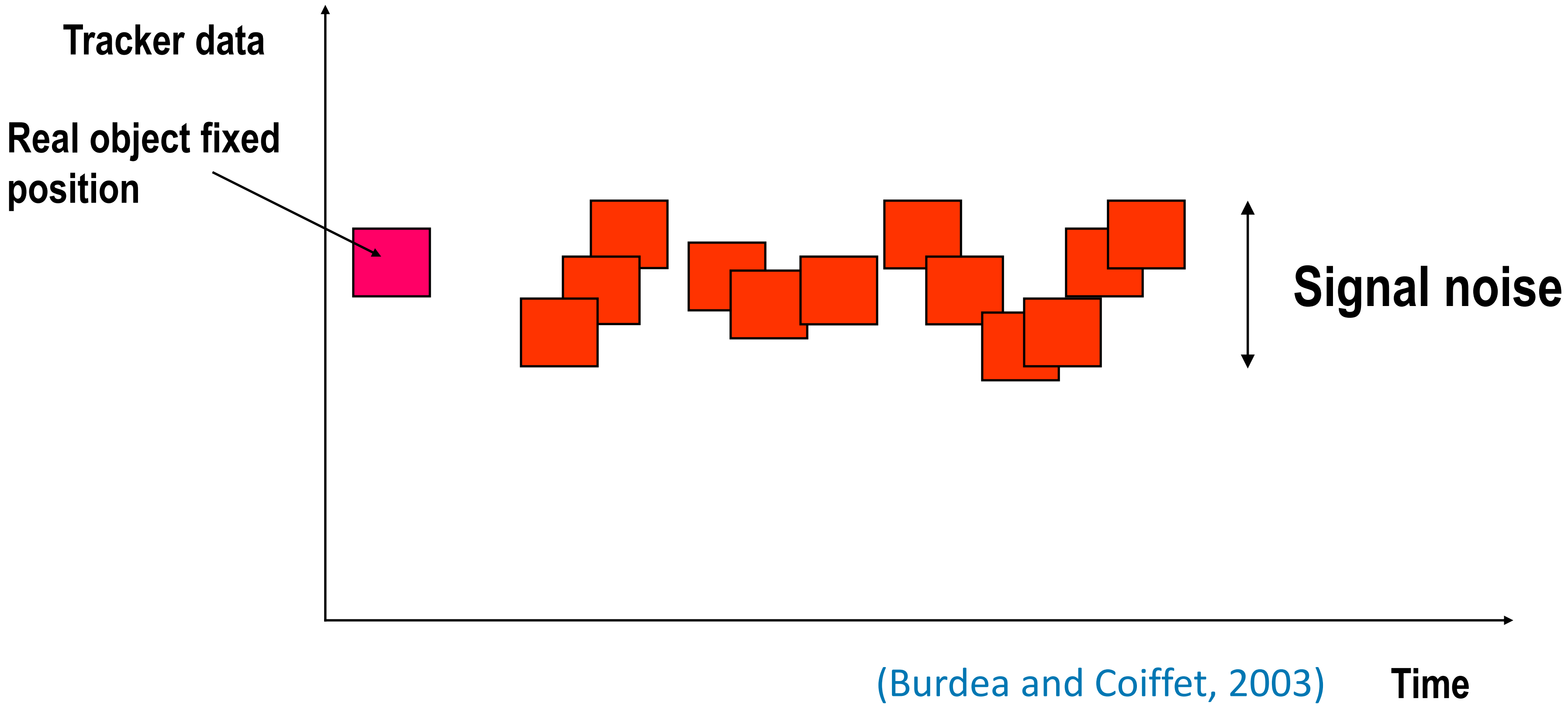
(used by Ascension)

(other makers may use different definitions)



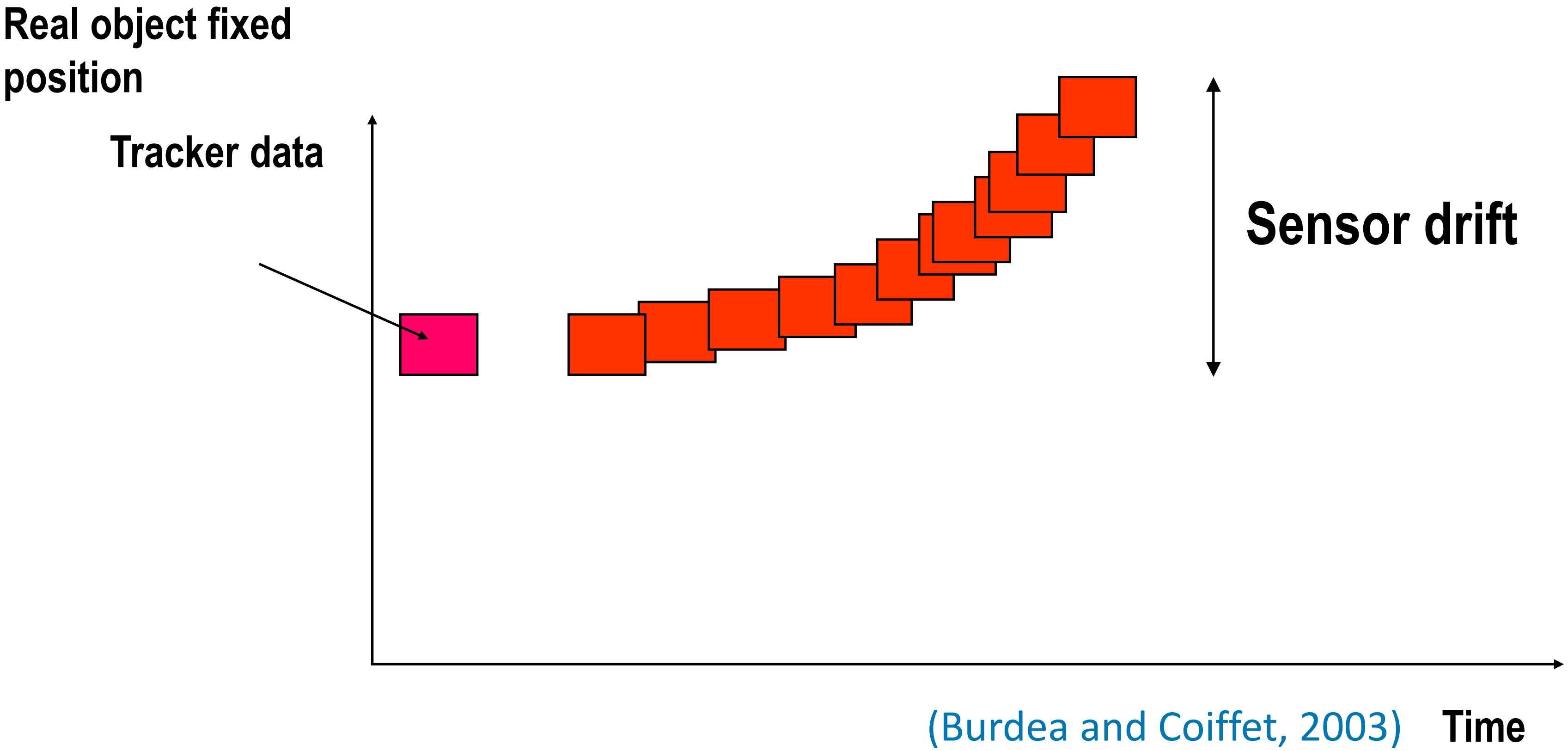
(Burdea and Coiffet., 2003)

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



(Burdea and Coiffet, 2003)

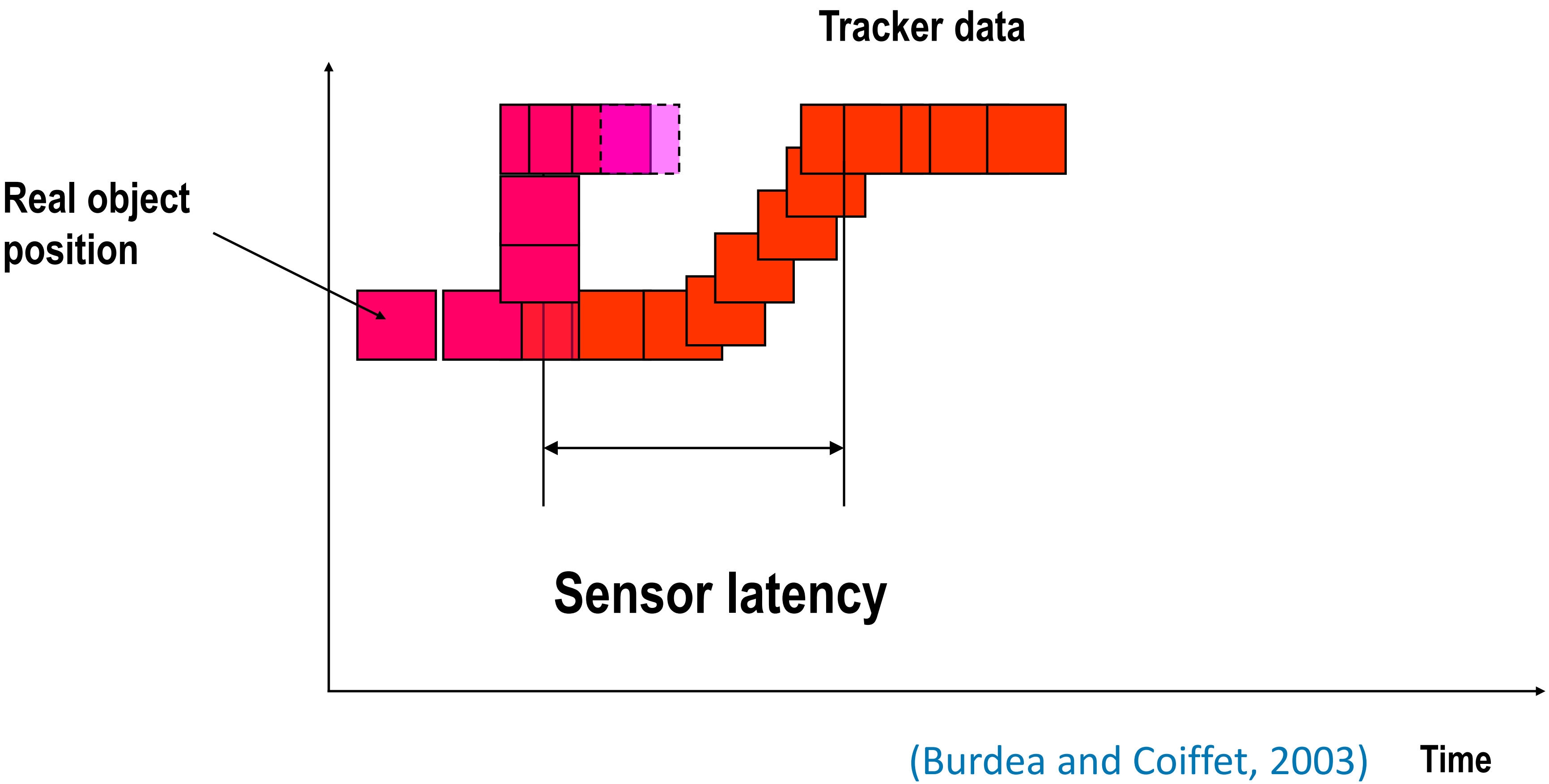
Drift: Steady increase in tracker error with time



(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)

Most used tracking technologies:

- Magnetic
- Ultrasonic
- Optical
- Inertial
- Hybrid
- …

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**
- Distance is inferred from the voltages induced in the antennas – **needs calibration**…
- Errors grow from source outwards

[Magnetic Tracker - an overview | ScienceDirect Topics]
[https://lavalle.pl/vr/vrch9.pdf]

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)

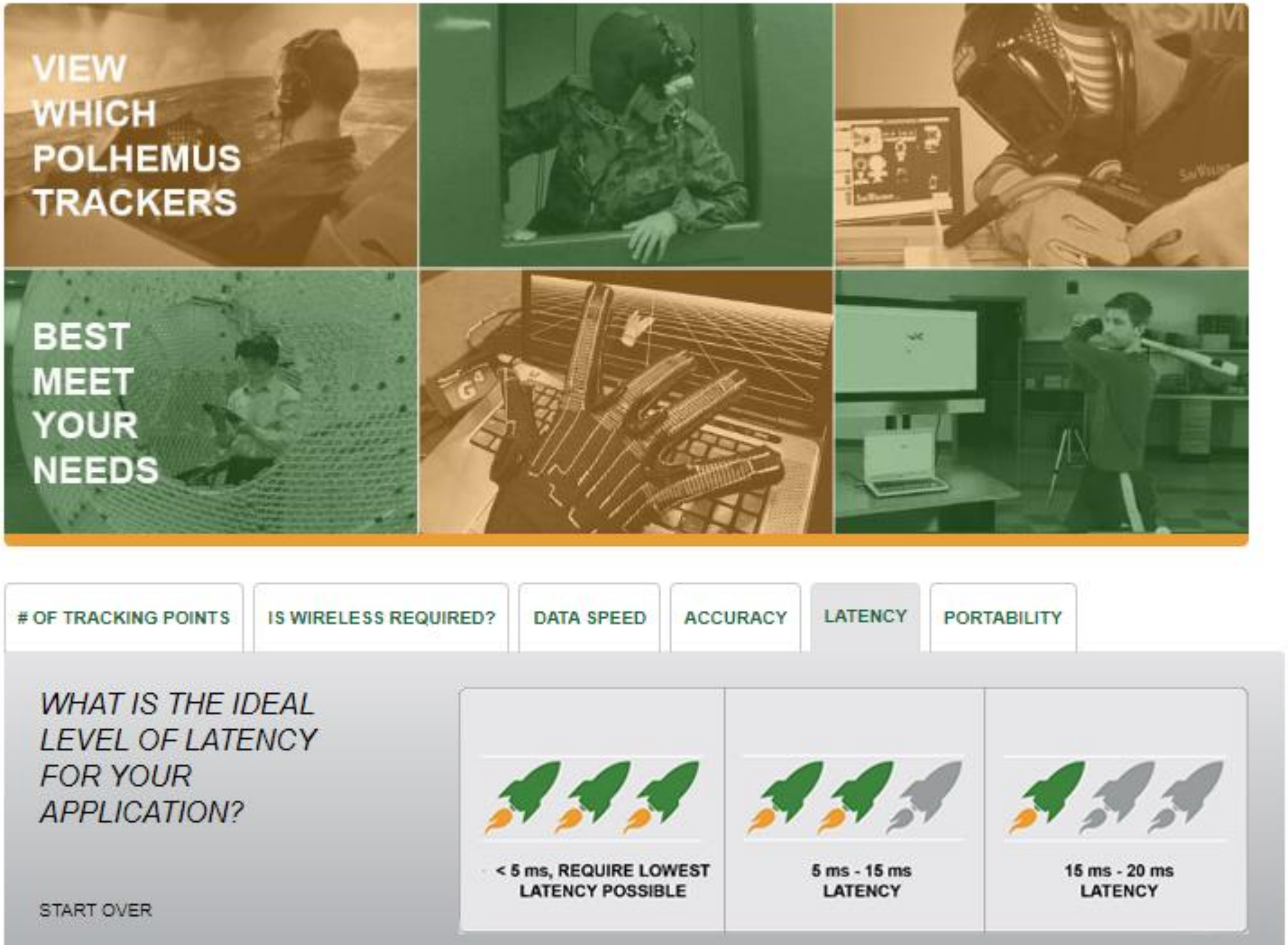
- Both are affected by copper

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

- AC trackers usually have slightly shorter range

- **DC trackers are generally simpler and faster**

How to select a tracker: example



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

Polhemus Viper in F-16 flight simulator

combines wide field of view virtual reality with a fully functional cockpit replica

VIPER offers ultra-fast update rates and accuracy

Realistic training experience

https://www.youtube.com/watch?v=jFaPNKRGwO4

Example: Polhemus Viper

SPECIFICATIONS

UPDATE RATE	240Hz per sensor max (VIPER 4) 960Hz per sensor max (VIPER 8/16)
INTERFACE	USB; RS-422, both standard; dual output available
LATENCY	1ms at 960Hz/ 2ms at 480Hz/ 3ms at 240Hz
STATIC ACCURACY	0.015 in (0.38mm) RMS for X, Y, Z position; 0.10° RMS orientation* for FT-Standard sensor and TX2, TX4, & HR sources 0.02 in (0.50mm) RMS for X, Y, Z position; 0.15 degrees RMS orientation* for FT-Standard sensor and TX1 source *Specified accuracy within 30 in (76 cm) radius from Source (using FT-Standard Sensor), smaller sensors and/or TX1 source may reduce specified accuracy range*
RESOLUTION	0.00004 in (0.0010 mm) at 12 in (30 cm) range; 0.0003° orientation (FT Standard Sensor and TX2 Source)
RANGE	Useful operation up to 72 in (182 cm) and beyond** Smaller sensors may reduce specified or useful range slightly
SYNC INPUT/ OUTPUT	Sync signal can be used as input or output to sync to or from another device
OPERATING TEMPERATURE	10° to 40°C
POWER REQUIREMENTS	5 Volts DC @ 5.5 Amps direct or 24 Volts DC @ 1.3A via external DC-DC converter 32 Watts
PREDICTION	User adjustable position & orientation prediction built-in
SOFTWARE TOOLS	GUI and SDK included Microsoft Windows® 10 and forward Unity: Sample open source code included Linux: Sample open source code included

Fast and customizable electromagnetic tracker

Latency as low as one millisecond

High price!

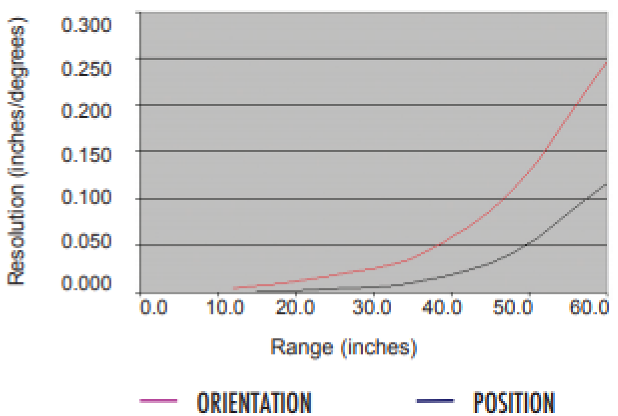
https://polhemus.com/_assets/img/Viper_Brochure_1.pdf

“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; 0.40º 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	10ºC to 40ºC 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

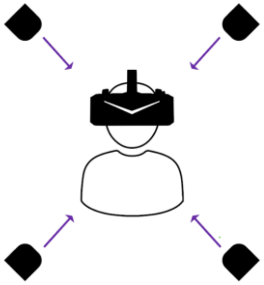
Latency less than 18.5 milliseconds

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

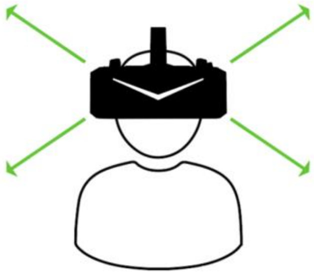
Optical Trackers

Non-contact position measurement devices that use optical sensing to determine the real-time position/ orientation of an object

Outside-in Tracking	Inside-out Tracking
External sensors Sensor reference points Accuracy and precision Potential for reduced occlusion Larger tracking areas	Embedded sensors Environment analysis Portability and ease of setup Potential tracking limitations Cost-effective solution



outside-looking-in



inside-looking-out

https://pimax.com/pose-tracking-methods-outside-in-vs-inside-out-tracking-in-vr/

Tracking Methods: Outside-in VS Inside-out Tracking

Examples for reference (May, 2023)

Headset	Tracking Method	Resolution	FOV	Price ($)
Oculus Rift S	Inside-out	1280 × 1440 per eye	115°	$399
HTC Vive Pro	Outside-in	1440 × 1600 per eye	110°	$1,399
Valve Index	Outside-in	1440 × 1600 per eye	130°	$999
PlayStation VR	Outside-in	960 × 1080 per eye	100°	Start from $399
Oculus Quest 2	Inside-out	1832 × 1920 per eye	100°	Start from $299
HP Reverb G2	Inside-out	2160 × 2160 per eye	114°	$599

https://pimax.com/pose-tracking-methods-outside-in-vs-inside-out-tracking-in-vr/

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/
https://www.youtube.com/watch?v=69IryHUbmBU

Location based VR

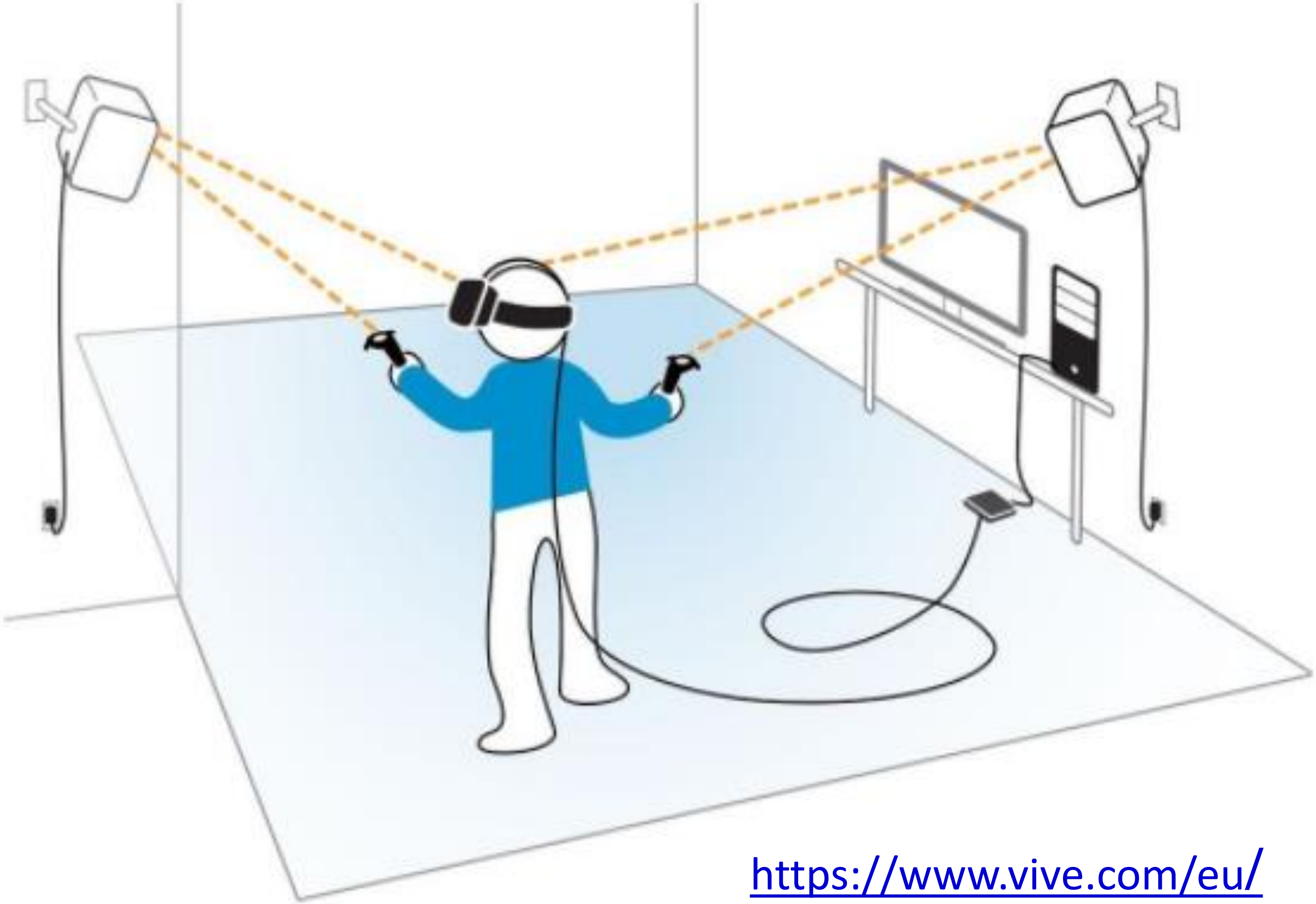
Immersive experiences

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

Vicon Origin Explainer - A New World Awaits

Inside-looking-out
HTC Vive “Lighthouses”

- The base stations beam (IR) signals to the headset and controllers (new models no longer use this solution)



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
- Work in any light conditions
- No line of sight requirements
- **Errors grow geometrically in time!**

https://www.xsens.com/

Example of Hybrid Solution for user's movements and objects

PICO Motion Trackers (Beta)

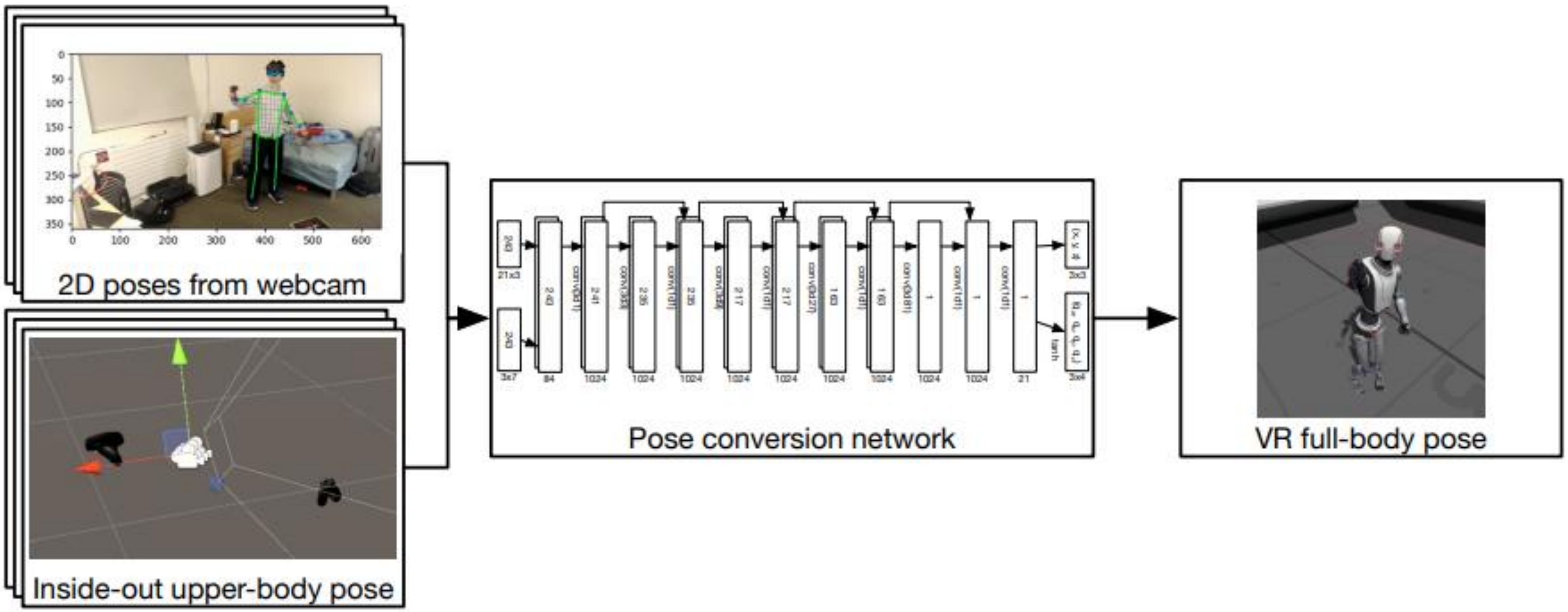
- IMU sensor + 12 infrared sensors to enable 6DoF
- Recognize subtle leg movements as small as 0.5°
- Capturing motion frequency of up to 80Hz
- Low latency ~30ms

[PICO devices | PICO Developer]

Example of Hybrid Solution for hand tracking

[VIVE Focus Plus | VIVE Business United States]()

A research example

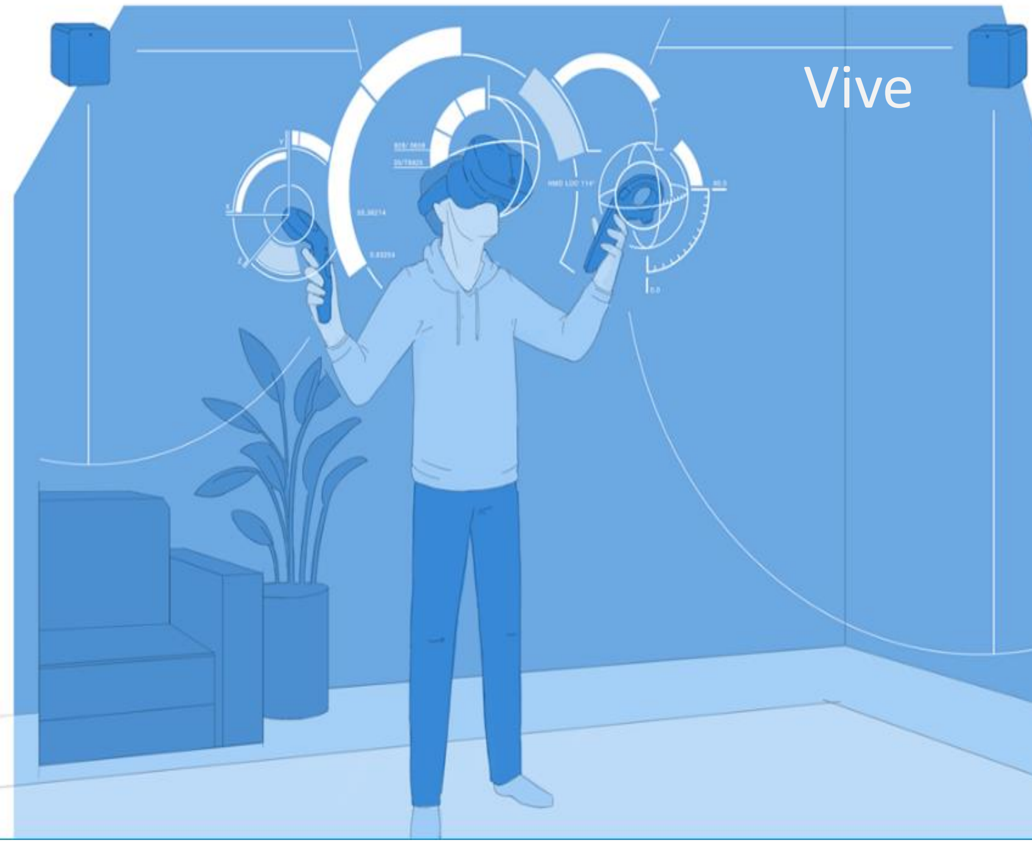


Yang et al.. “HybridTrak: Adding Full-Body Tracking to VR Using an Off-the-Shelf Webcam”, CHI '22, Article 348, 1–13.
https://doi.org/10.1145/3491102.3502045

Performance parameters of consumer-grade VR trackers

How It Works

The SteamVR Tracking Basestations sweep the room with multiple sync pulses and laser lines, reaching out to about 5 meters. By keeping careful track of the timings between pulses and sweeps, the SteamVR Tracking system uses simple trigonometry to find the location of each sensor to within a fraction of a millimeter. By combining multiple sensors, 2 basestations, as well as adding a high speed IMU (inertial measurement unit), SteamVR also calculates the tracked object's orientation, velocity, and angular velocity, all at an update rate of 1000Hz.



https://partner.steamgames.com/vrlicensing

Holzwarth et al., “Comparing the Accuracy and Precision of SteamVR Tracking 2.0 and Oculus Quest 2 in a Room Scale Setup”, *ICVARS 2021*, pp. 42–46, 2021 https://doi.org/10.1145/3463914.3463921

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, manipulation, drawing, …
Input Devices

- Controllers
- pens
- …

more or less sophisticated and expensive

- Perform relative position/velocity control of virtual objects

[MR Stylus for Meta Quest 3, Meta Quest 2 | Logitech]

[TactGlove consumer-ready haptic gloves for VR]

Gesture Input Devices

- May be cameras or gloves

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

  - Fakespace Pinch Glove (switches)

  - Immersion CyberGlove (stain gauges),

  - Avatar VR

[Nova Haptic Glove | SenseGlove]

- Most need some calibration for user's hand

- Gloves usually are also (haptic) output devices

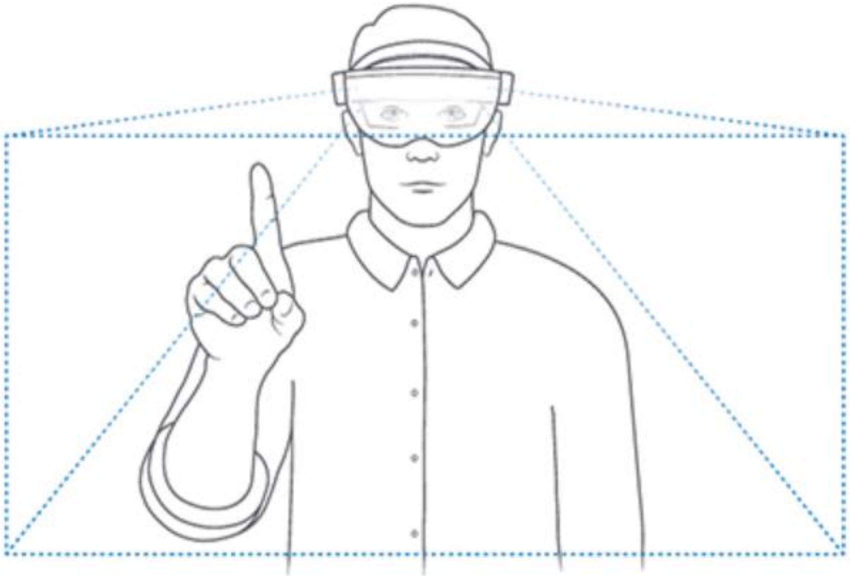
[CyberTouch]

Headsets may include hand tracking

Quest,

Hololens,

…



https://learn.microsoft.com/en-us/hololens/hololens1-basic-usage

https://tech.fb.com/making-technology-feel-natural/

Headsets may include eye tracking

Include 2 small high quality cameras, illuminators and algorithms

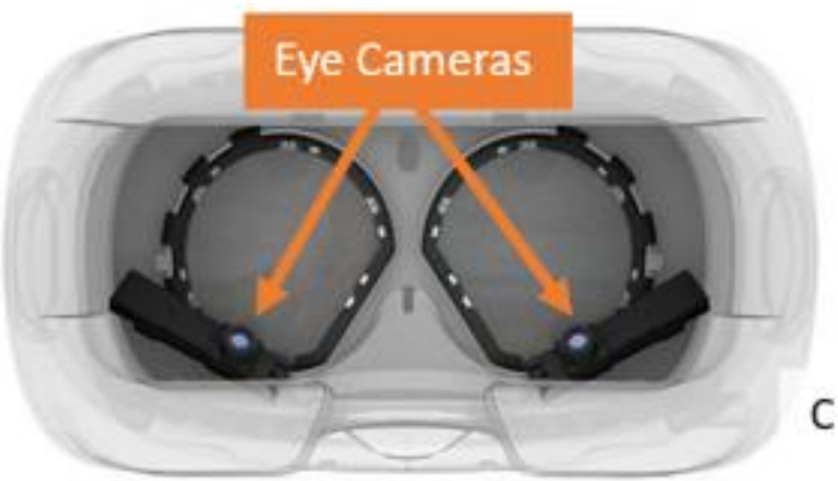
Allow for fast and accurate monitoring of eye movements

Much used for research in human perception and behavior

Allow foveated rendering

…

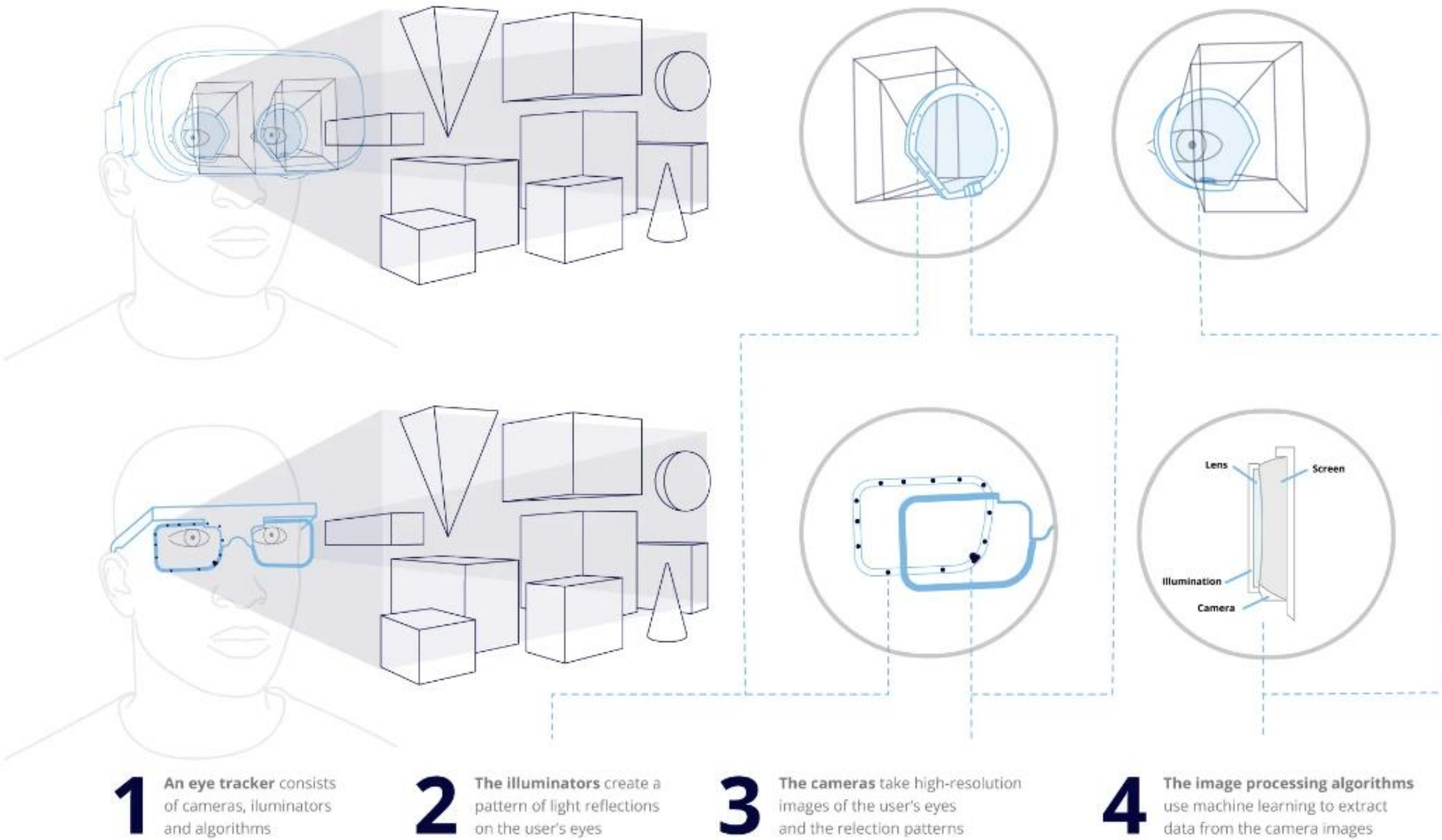
[Eye tracking in VR 2019]



C

Headsets may include eye tracking

Involving illuminators, cameras and image processing algorithms



[Eye tracking in VR – A vital component - Tobii]

Speech recognition is also an interesting possibility:

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

Some 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 infinite VE”: a treadmill for VR

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

Omnidirectional Treadmill:

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

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

Another input device “providing an infinite VE”: VR shoes

https://newatlas.com/vr/freeaim-vr-shoes/

Virtusphere (“the VR hamster ball”)

Another curious input device…

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

Input + output

Tactgloves Haptic Gloves

https://www.auganix.org/bhaptics-unveils-its-tactglove-consumer-ready-haptic-gloves-for-vr/
https://www.youtube.com/watch?v=dMGnsMccZHU&t=1s

Input + output

Meta Haptic Gloves still under research

[Facebook Reality Labs Haptic Gloves]

A new commercial solution?

(based on air…)

https://g1.haptx.com/learnabout

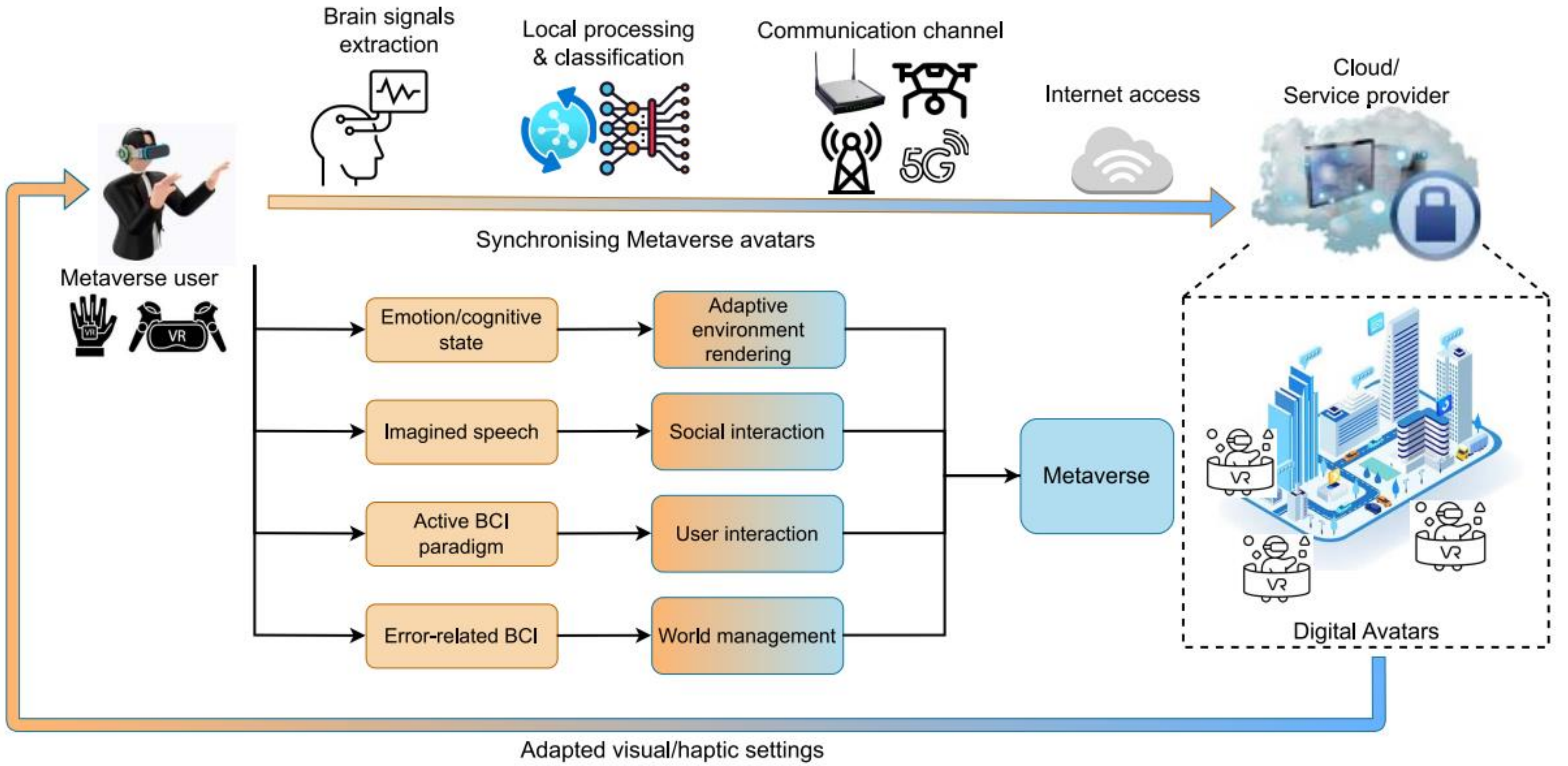
Will Brain Computer Interface (BCI) be a viable VR Input technology?

[NextMind's Dev Kit for mind-controlled computing offers a rare 'wow' factor in tech | TechCrunch]

[The Current Research of Combining Multi-Modal Brain-Computer Interfaces With Virtual Reality (2021) IEEE Xplore]

[Frontiers | Editorial: Brain-Computer Interfaces and Augmented/Virtual Reality]

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



Integration of BCI with the Metaverse: Through BCI, the Metaverse user's brain signals could be extracted, processed, and communicated into the Metaverse.

[A Human-Centric Metaverse Enabled by Brain-Computer Interface: A Survey (2024) IEEE Xplore]

BMW //M Mixed Reality technology using Unreal
Web summit, Lisbon, 2022

https://www.motor1.com/news/620587/bmw-m2-mixed-reality-simulation/

https://www.youtube.com/watch?v=vQ20Prr4CZM

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, 2015

- La Valle, S., Virtual Reality, Cambridge University Press, 2023 http://vr.cs.uiuc.edu