CSE 190: Virtual Reality Technologies

LECTURE #8: 3D TRACKING TECHNOLOGIES

Upcoming Deadlines

Sunday, April 25: Project 1 late deadline

Monday, April 26: Discussion Project 2

Sunday, May 2: Project 2 due

Monday, May 3: Discussion Project 3

Sunday, May 9: Project 2 late deadline

App Presentations

Baichuan Wu

- VR Movie "Myth”

Jonathan Barnes

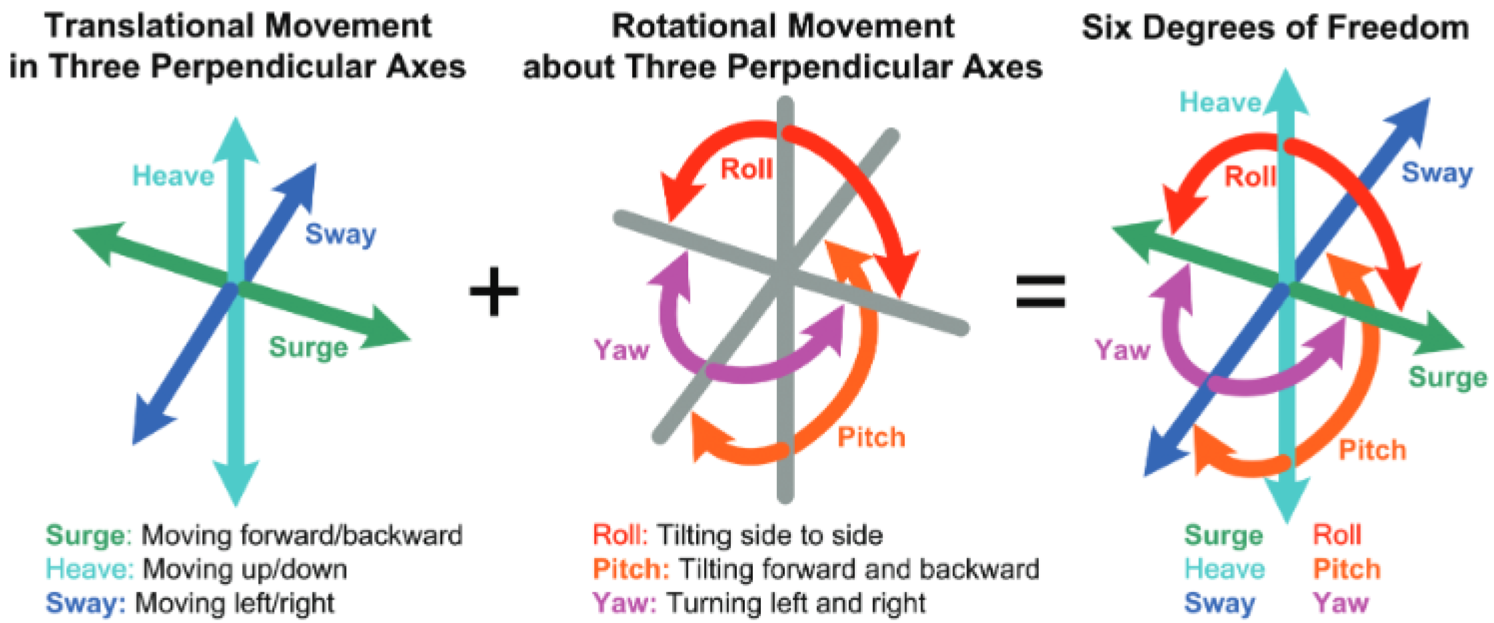
- Echo VR

David Cruz

- Poker Stars VR

Degrees of Freedom (DOF)

Overview


Translational Movement
in Three Perpendicular Axes
Heave
Sway
Surge
Surge: Moving forward/backward
Heave: Moving up/down
Sway: Moving left/right
+
Rotational Movement
about Three Perpendicular Axes
Roll
Yaw
Pitch
Roll: Tilting side to side
Pitch: Tilting forward and backward
Yaw: Turning left and right
=
Six Degrees of Freedom
Heave
Roll
Sway
Yaw
Surge
Pitch
Surge
Heave
Sway
Roll
Pitch
Yaw

Mouse
(Relative 2 DOF Position)

2 independent directions control a cursor

Rate of change proportional to force or velocity of motion

Harder to use with larger screen surfaces (e.g., 4k+ or wide screen monitor)

Gyration presentation controller

Touch or Pen-Based Tablets (Absolute 2 DOF Position)

Absolute 2D position
- 2 DOF

Microsoft Surface Dial
- Adds 1 DOF

Absolute 3 DOF Position: GPS

GPS = Global Positioning Satellite system

24 GPS satellites emit synchronized signals

GPS receiver needs to have line of sight connection with 4+ satellites

GPS receivers determine exactly how long it takes for the GPS signals to travel from each satellite

Measures:

- Latitude
- Longitude
- Altitude

Does not directly measure:

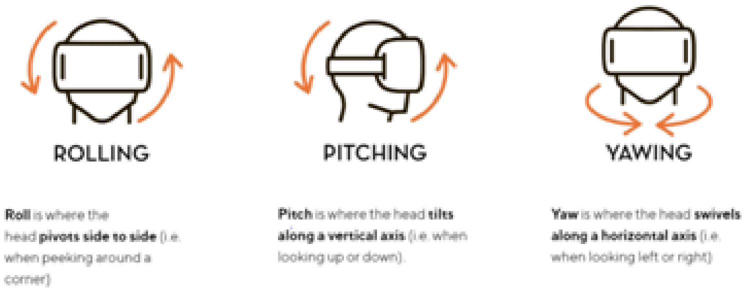
- Orientation
- Velocity
- Acceleration

Relative 3 DOF Rotation

Low end HMDs

3 rotational directions:

- Roll
- Pitch
- Yaw



6-DOF Relative Devices

Relative position and orientation

Move a cursor around 3D space

Cursor velocity is proportional to directional force

Spaceball

Space Navigator

Mechanical 6-DOF Tracking

Fakespace Boom: doubles as a stereo display. Options:

- Monochrome BOOM 2
- Two primary color (16-bit color) BOOM 2C
- Full color BOOM 3C
- All models are 1280x1024 pixels stereo displays

Geomagic Touch: doubles as a haptic feedback device

Fakespace BOOM

Geomagic Touch

Keyboard, Game Controller

How many DOF?

Overview

Position/Orientation Tracking
- Mechanical Tracking
- Electromagnetic Tracking
- Ultrasonic Tracking
- Inertial Tracking
- Optical Tracking
- Tracking with Radar

Outside-in/Inside-out Tracking

Hand/Finger Tracking

Eye Tracking

Application-specific Input Devices

Mechanical Tracking

Mechanical Tracking

Dependent on a physical link between a fixed reference point and the target

Example: BOOM display

- A HMD is attached on the rear of a mechanical arm with multiple points of articulation
- Detection of orientation and position is done through the arm

High tracking update rate

Limited range of motion for the user

Electromagnetic Tracking

Electromagnetic Tracking

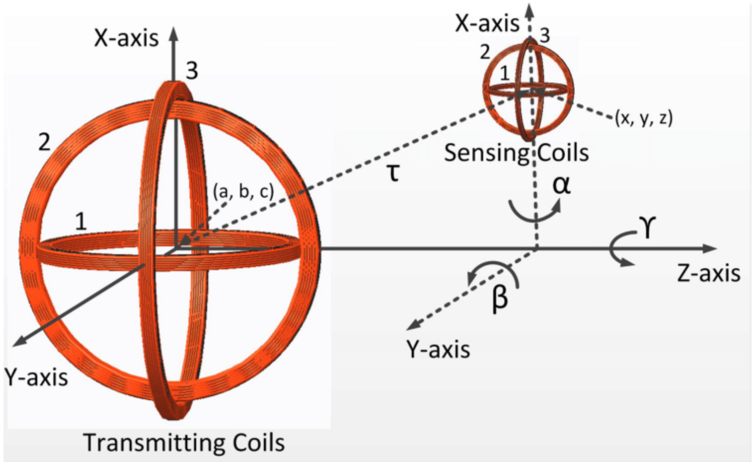
First used by military and in medical and animation industries

Concept:

- Fixed transmitter generates low-level magnetic field from 3 orthogonal coils
- Fields generate current in smaller receiver unit(s) worn by user
- 6-DOF tracking achieved by analyzing signal strength in receiving coils

Advantage: no line of sight restrictions

Disadvantage: metal in environment can cause interference



Electromagnetic Tracking

There are three pulses of about 2ms each.

The three pulses correspond to each of the three crossed coils in the base – they are pulsed in series.

The receiver coils in the tracked device receive each of the pulses with different amplitudes, depending on the relative orientation of the receiving and transmitting coils.

If their axes are aligned, the corresponding signal is strong. If they are not aligned, the signal is weaker, being weakest when the axes are perpendicular.

Changing the distance of the controller from the base changes the amplitude of all three signals in the same way.

From this information the computer can determine orientation and position of the tracked device.

One of the Earliest VR Tracking Technologies

1990 Ascention Flock of Birds

2011 Razer Hydra

2018 Magic Leap One

Flock of Birds

Magic Leap One

Razer Hydra

Magic Leap

Magic Leap One

Uses electromagnetic tracking to track controller's position and orientation.

Electromagnetic signal emitter is in controller.

Receiver in on right side of headset. Tracking will probably be worse for left-handed use.

Copper shielding sprayed into the coil housings protects from RF interference, while letting the magnetic field through.

Interference could explain the tracker's placement outside of frame.

Receiver

Emitter

Ultrasonic Tracking

Ultrasonic Tracking

Systems measure duration of an ultrasound signal to reach microphones.

InterSense system uses combination of ultrasound and gyroscope.

Problems with echos from walls, people, objects in tracking space.

Logitech 3D Mouse

InterSense IS-900 tracker

InterSense IS-900 Wand

Inertial Tracking

Inertial Tracking

Trackers use **miniature gyroscopes** to measure orientation changes: 3 DOF

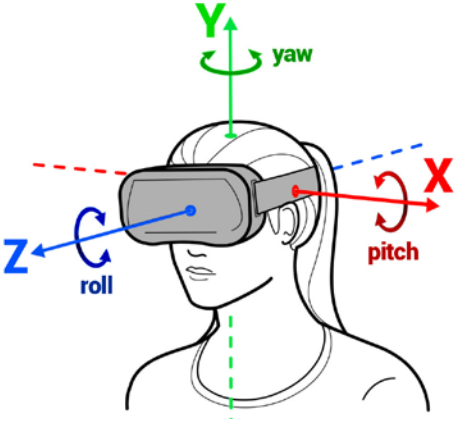
Accelerometers can help calibrate, add position tracking

Advantages:

- No external sensors needed
- Works outdoors
- No limitations on tracking space
- Cheap sensors mass manufactured for smartphones

Disadvantage: drift between actual and reported values, accumulates over time

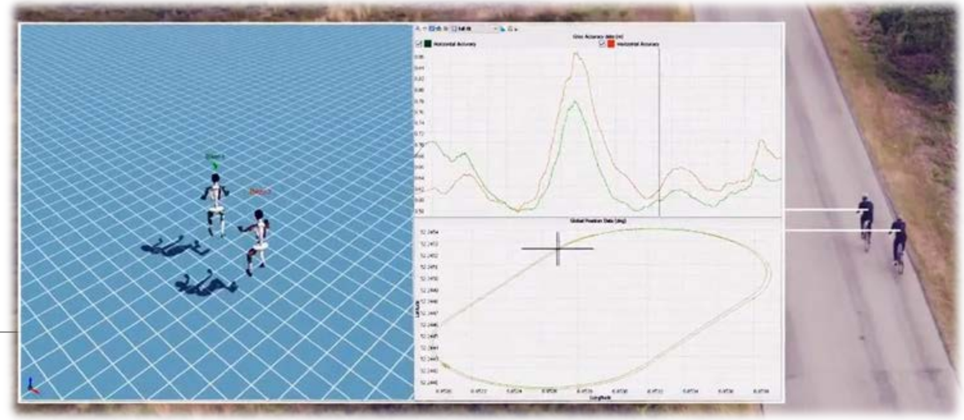
Gyroscope in Oculus Rift DK1

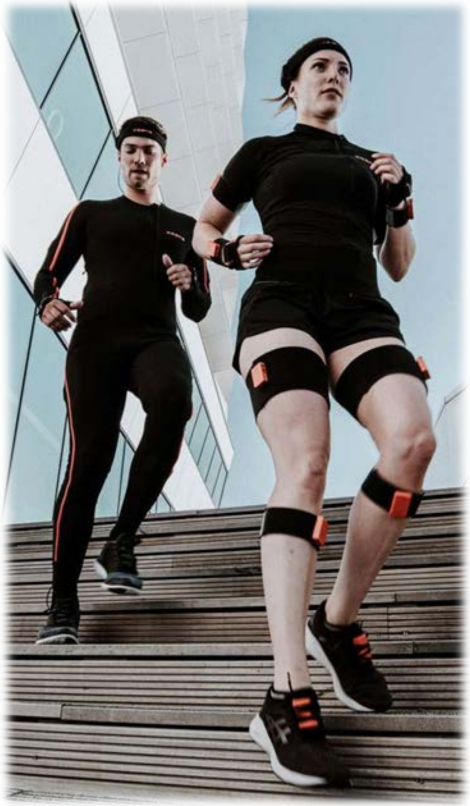


3 Rotational DOF

Xsens Motion Tracking

Long range motion tracking





Optical Tracking

Optical Tracking: HiBall

HiBall-3100 tracker system

Developed in 2001 at UNC Chapel Hill

System is composed of:

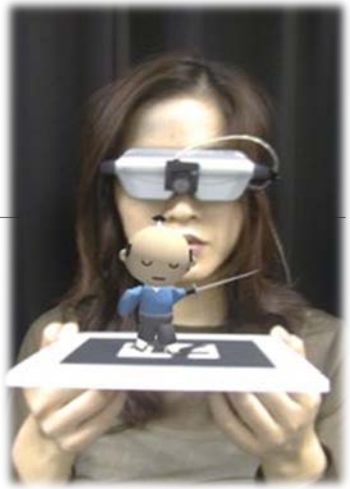
- HiBall Optical Sensor
  - Views infrared LEDs in beacon arrays on ceiling with 6 lenses and photodiodes
  - Ceiling beacon arrays

Tracker update rate: 2,000 Hz

No metal or sound interference

HiBall beacon array

Optical Tracking with Fiducial Markers



ARToolKit (2003)

Printable markers placed in environment or on objects

A single camera can be sufficient

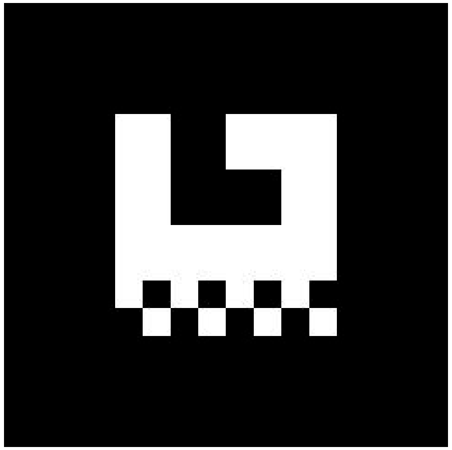
Flexible marker design: similar to QR codes

Markers cannot be rotationally symmetrical

6 DOF tracking possible

PTC’s Vuforia library allows any image or object to be a marker

- https://www.youtube.com/watch?v=ua9gRiHDHok



ARToolKit marker

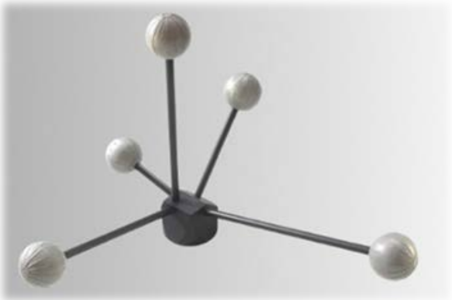
Optical Tracking with Marker Spheres

Available since 1990s

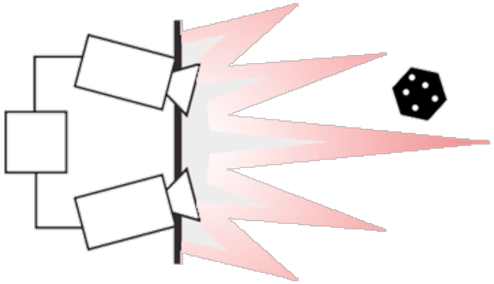
(Near-) Infrared light illuminates scene

Retro-reflective spheres reflect light back to the cameras

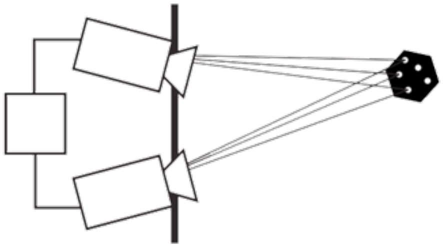
Spheres arranged in fixed, known configurations (constellations) allow for 6 DOF tracking



Marker constellation



The object is lit using near IR light



Retro-reflective markers reflect back

Motion Capture Suit

Optical Tracking with Infrared LEDs

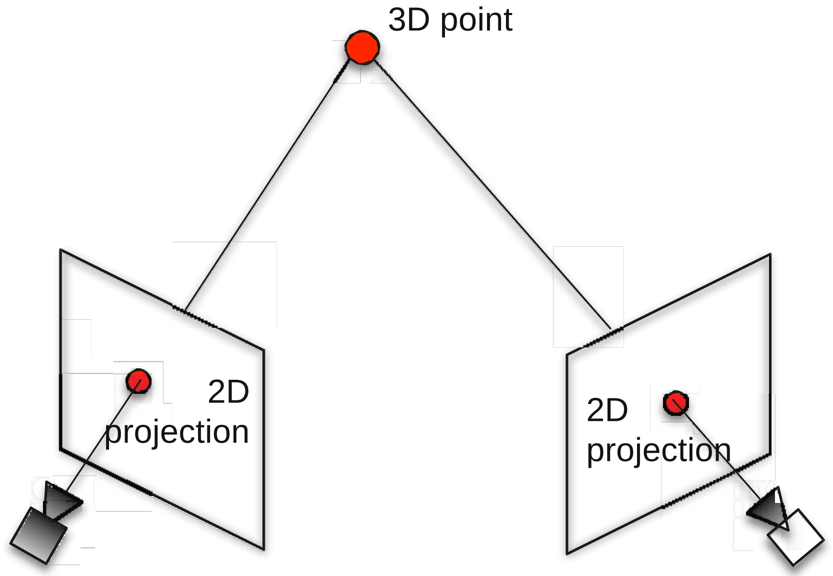
- Track active (near IR) LEDs with cameras
- Used on Oculus Rift

Oculus Rift CV1

Optical Positional Tracking

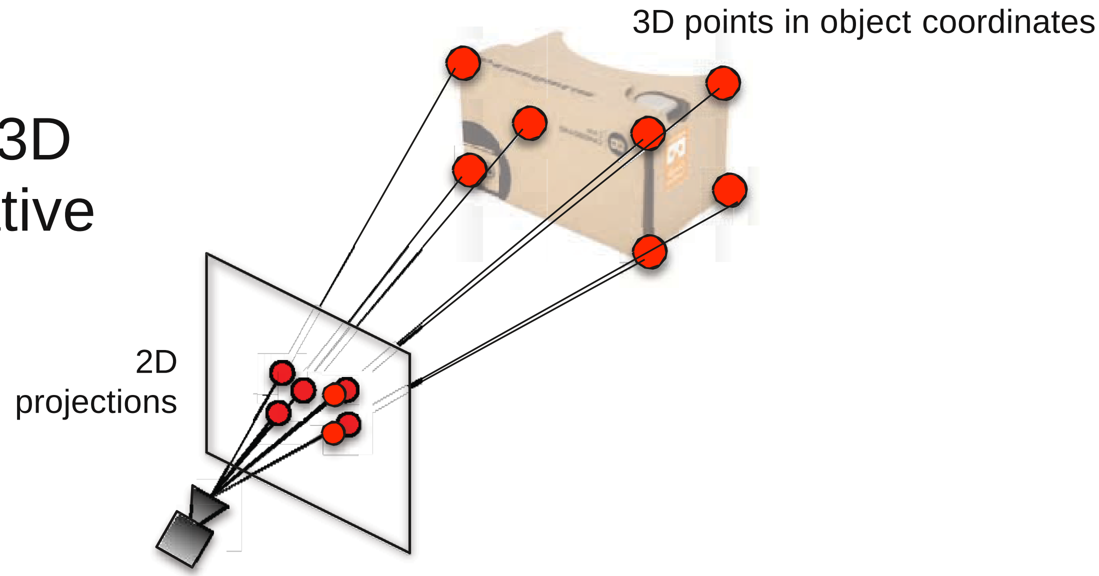
For tracking individual 3D points, multi-camera setups usually use triangulation

This does not give us the pose (rotation & translation) of camera or object yet



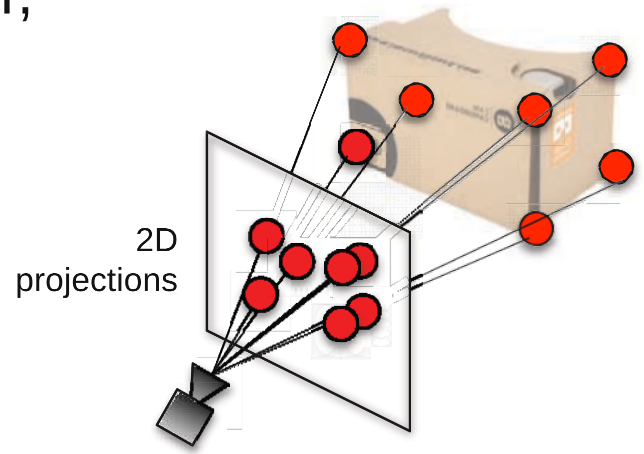
Optical Positional Tracking

For pose tracking, we need to track multiple 3D points with known relative coordinates



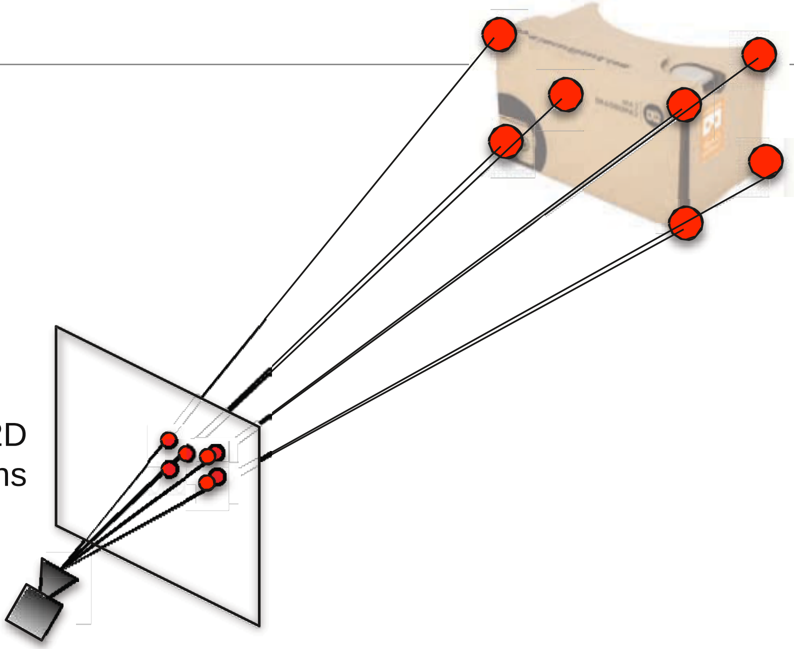
Optical Positional Tracking

When object is closer, projection is bigger



Optical Positional Tracking

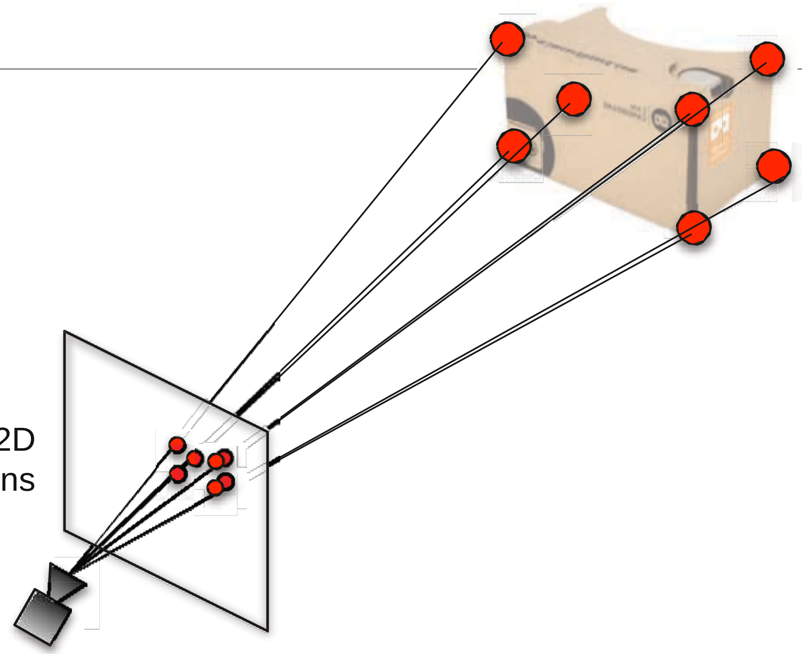
When object is father, projection is smaller



Optical Positional Tracking

Pose estimation via optimization

Nonlinear least squares problem



$$\underset{\{R,T\}}{\text{minimize}} \left\| \underbrace{\left(p_1^{2D}, p_2^{2D}, \ldots, p_N^{2D}\right)}_{\text{observed 2D points}} ! \; f\left(\underbrace{p_1^{3D,\,object}, p_2^{3D,\,object}, \ldots, p_N^{3D,\,object}}_{\text{known 3D points}}, \underbrace{R,t}_{\text{unknown pose}}\right) \right\|_2^2$$

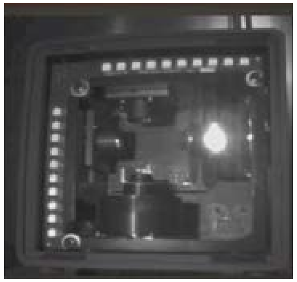
observed 2D points known 3D points unknown pose

Summary: Optical Tracking

Optical tracking works well for positional tracking (3 DOF)

Can provide full 6 DOF tracking with marker constellations

HTC Vive Lighthouse



- Runs at 60 Hz
  - i.e. horizontal & vertical update combined 60 Hz
  - broadband sync pulses in between each laser sweep (i.e. at 120 Hz)
- Each laser rotates at 60 Hz, but offset in time
- Usable field of view: 120 degrees
- Sync pulse emitted 120 times per second (Hz)
- Each sync pulse indicates beginning of new sweep

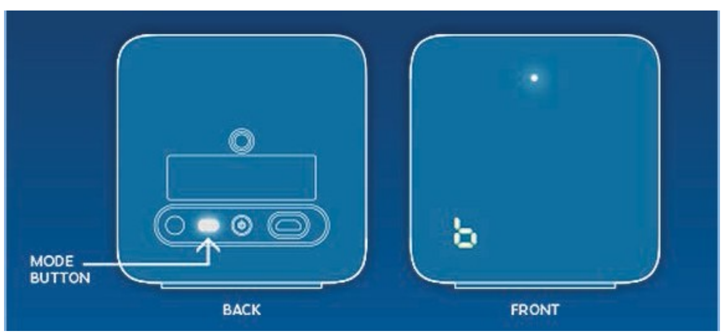
HTC Lighthouse – Base Station

- Can use multiple base stations simultaneously via *time-division multiplexing* (TDM)
- Base station modes:

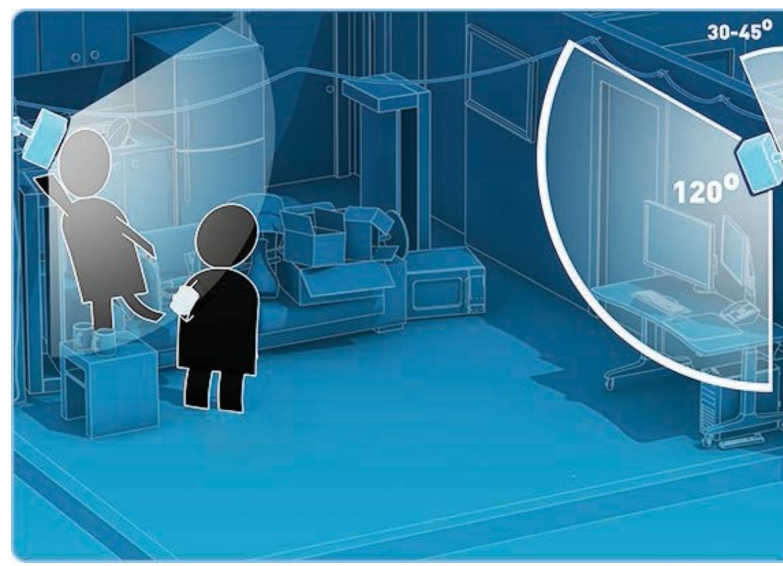
  A: TDM slave with cable sync

  B: TDM master

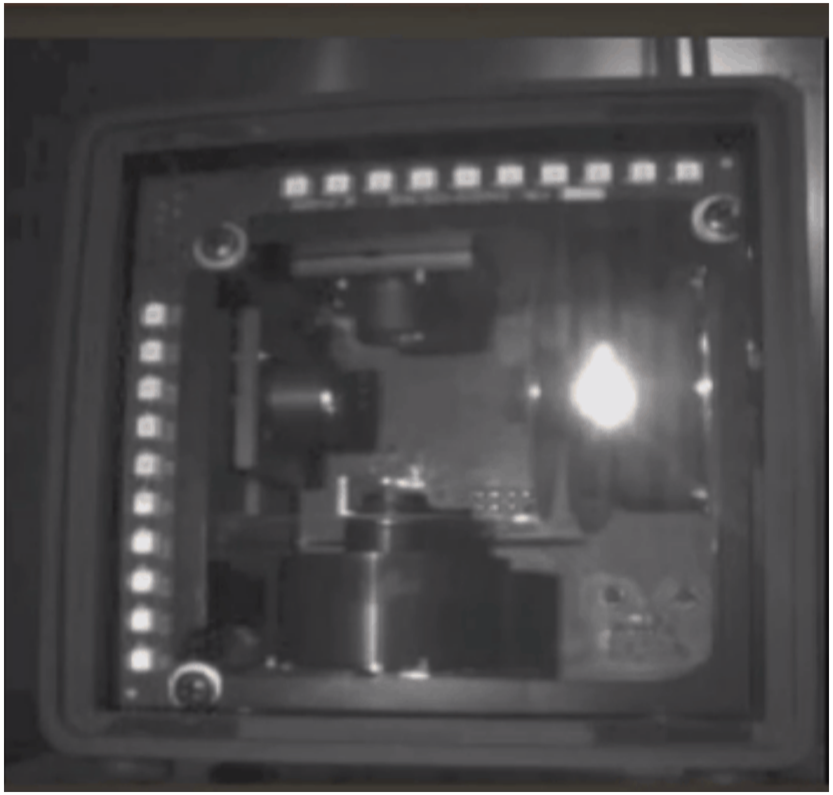
  C: TDM slave with optical sync

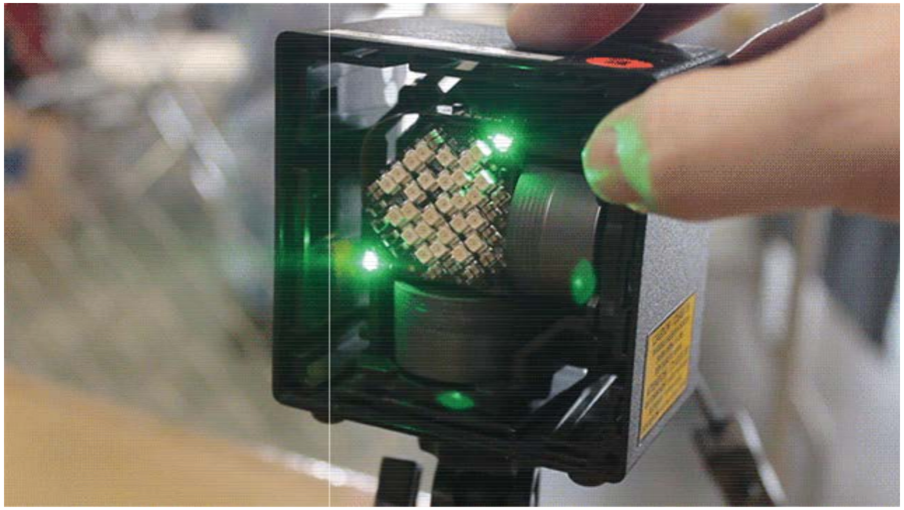


HTC



HTC Lighthouse





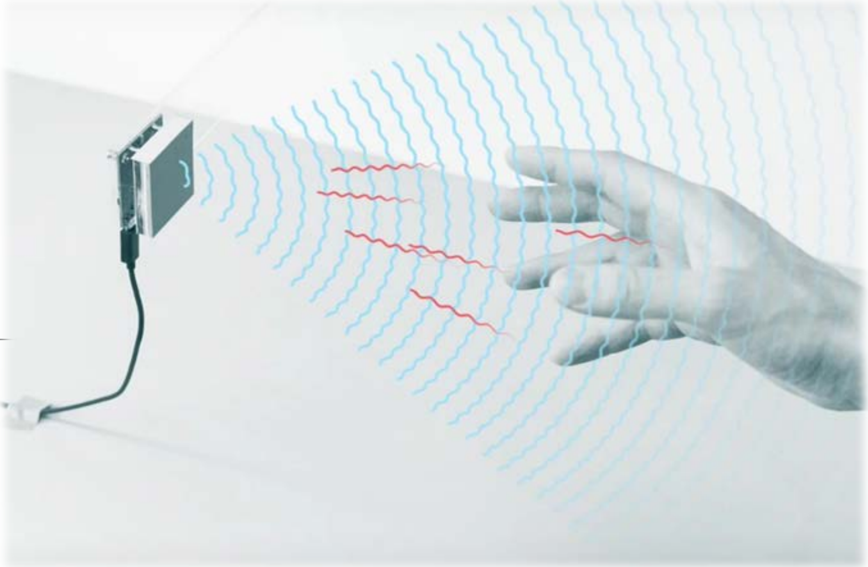
http://gizmodo.com/this-is-how-valve-s-amazing-lighthouse-tracking-technol-1705356768

HTC Lighthouse

https://www.youtube.com/watch?v=J54dotTt7k0

Tracking with Radar

Radar



Tracking with radar is early stage technology.

Most prominent example: Google's Project Soli from 2015

- https://www.youtube.com/watch?v=0QNiZfSsPc0

Soli sensor technology works by emitting electromagnetic waves in a broad beam.

Objects within the beam scatter this energy, reflecting some portion back towards the radar antenna.

Properties of the reflected signal, such as energy, time delay, and frequency shift capture information about the object's characteristics and dynamics, including size, shape, orientation, material, distance, and velocity.

Application-Specific Tracking

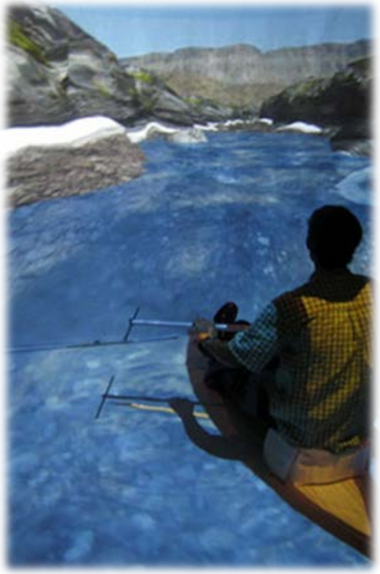
Application-Specific Devices

Virtual hang-gliding over Rio de Janeiro (Soares at. al., 2005)

Virtual canoe, Siggraph 2005

Miscellaneous devices:

- https://www.youtube.com/watch?v=8kjZ-nKjfgE

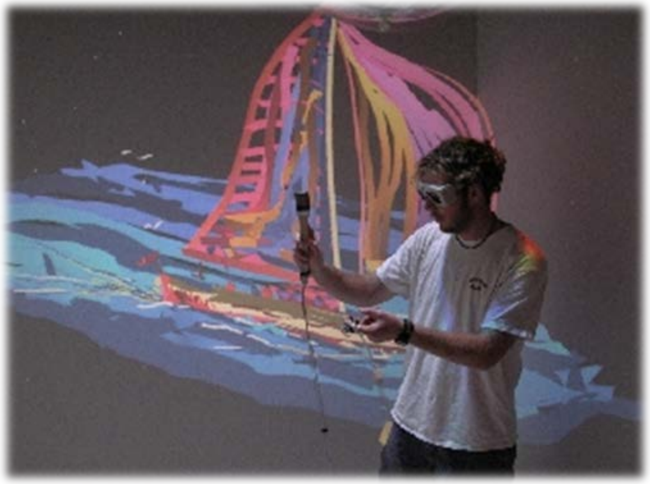


Cave Painting

Physical props (brush, color palette, bucket) allow intuitive painting

Created by Daniel Keefe at Brown University (now Prof. at Univ. of Minnesota) in 2001

Google Tilt Brush and Oculus Quill are modern versions for HMDs



Cave Painting Video

http://www.youtube.com/watch?v=WQv-LnHrmwU

Google Tilt Brush

Live performance at the Louvre Museum Paris by Anna Dream Brush in August 2018

- https://www.youtube.com/watch?v=Zs3n07Clw7A

3D interpretation of the “Liberty Leading the People” by Eugène Delacroix

Finger Tracking

Hybrid Devices: Haptic Feedback Devices

PHANToM haptic device

Force feedback joystick

Exoskeleton-like devices

Geomagic Touch

LEXOS: Frisoli et. al., Italy

Immersion CyberForce

Pinch Gloves

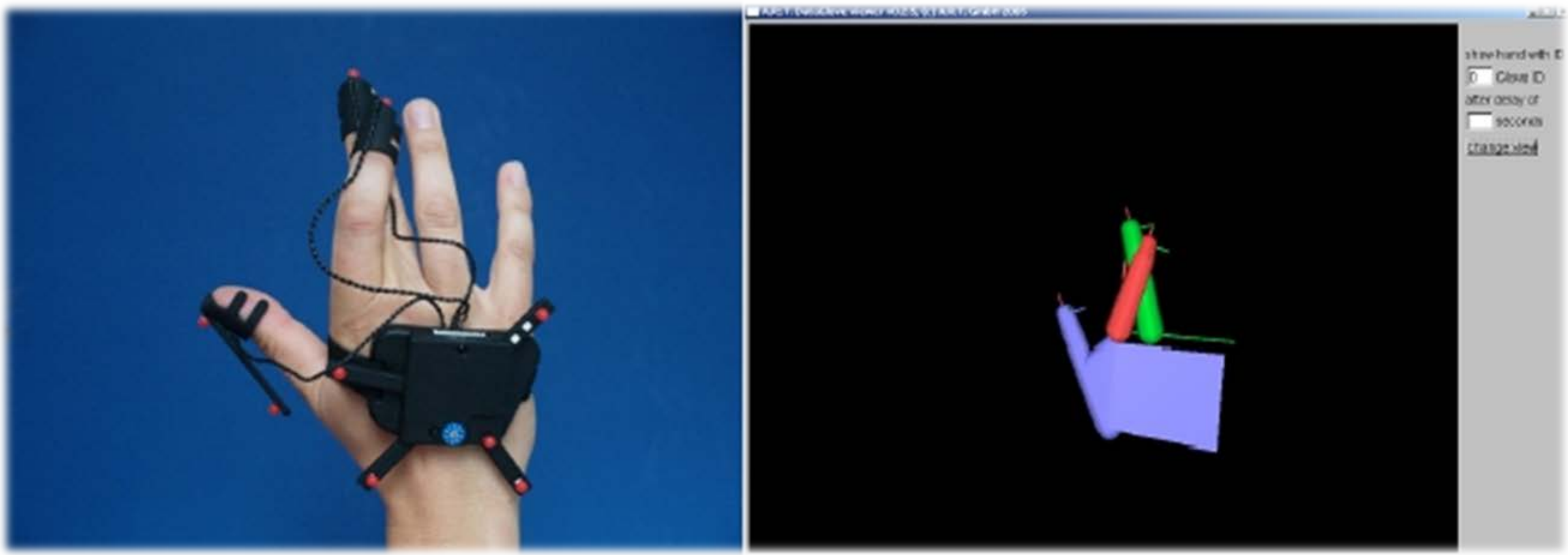
- Released 2001
- Determine if two or more fingertips are touching
- Use conductive cloth to close circuit
- Tethered to controller box
- Designed for pinching and grabbing gestures
- Recognize any gesture of 2 to 10 fingers touching, plus combinations of gestures

www.fakespacelabs.com

Optical Finger Tracking

Extension of ART Tracking system

Tracks three fingers and the hand with IR LEDs

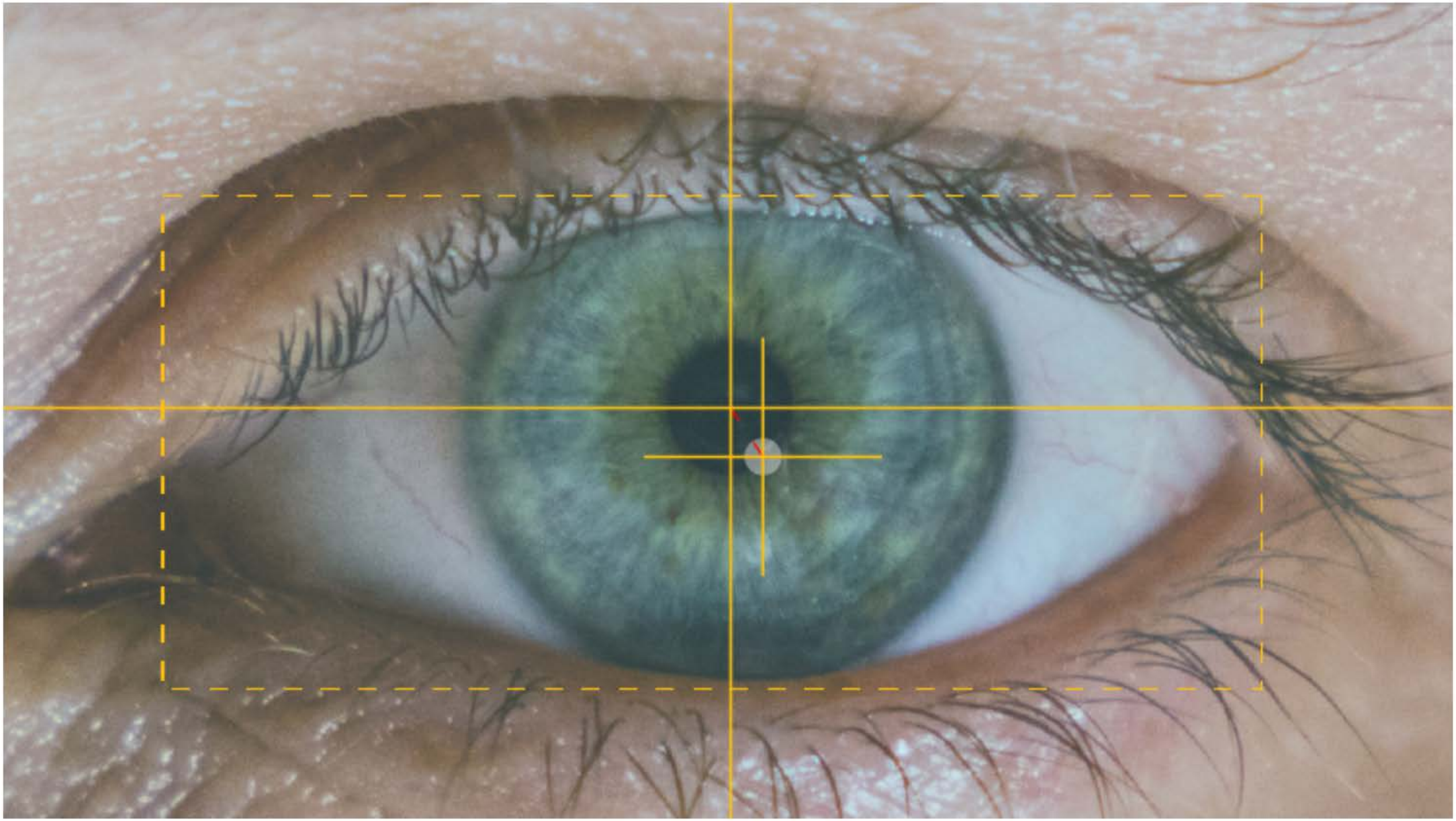


Optical Finger Tracking

Oblong Industries g-speak

- Video: http://www.youtube.com/watch?v=9OpmxbPzDM0

Eye Tracking



The center of the eye (pupil center) is tracked in relation to the position of the corneal reflection. The relative distance between the two areas allows the calculation of the direction of the gaze.

Tobii Eye Tracking

Add-on for VR headsets

Video: https://www.youtube.com/watch?v=q8GhIfsrizM

Vive Pro Eye

Vive Pro with built-in eye tracking

Separate product from regular Vive Pro

FOVE

Released Nov 2016

OLED display

2560×1440 pixels

70Hz refresh rate

90-100 degree field of view

6 DOF tracking with external camera

Eye Tracking: 120FPS infrared x2 (accuracy <1 degree)

Headphone jack (no built-in audio)

Magic Leap

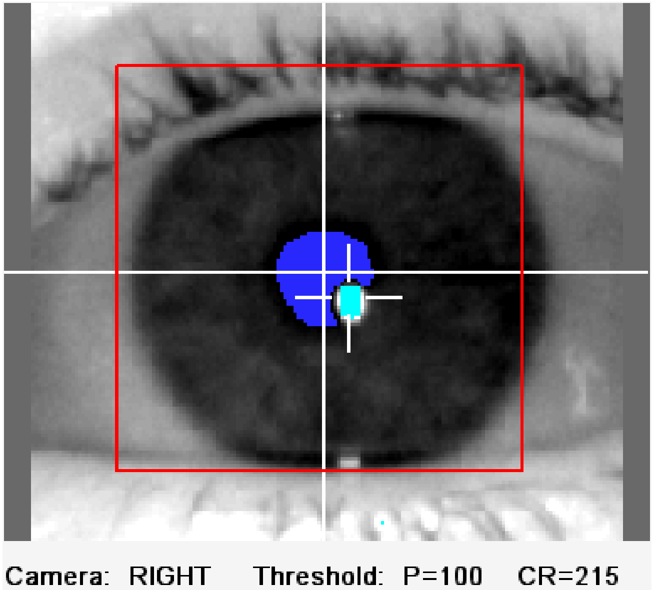
Built-in infrared eye tracking

Eye Tracking Challenges

Pupil deforms during fast eye motion, inertia effects

Eye motion can be very fast

Small angular eye motion can mean large differences for distant objects



Outside-In/Inside-Out Tracking

Outside-In Tracking

Cameras or markers are placed around the room

Examples:

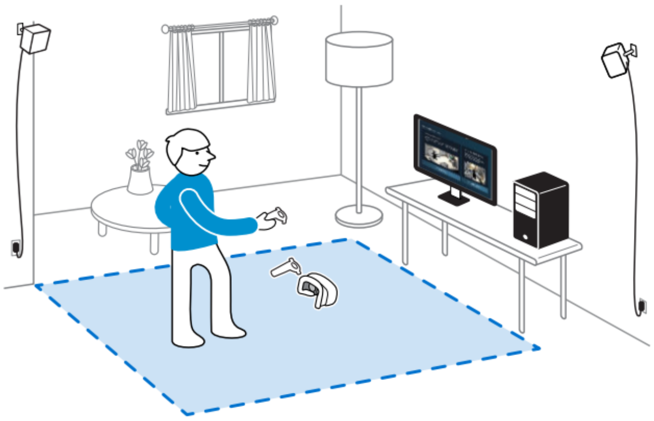
- Oculus Rift, HTC Vive

Pros:

- Higher tracking accuracy and latency than inside-out tracking
- More trackers can be placed to increase accuracy and tracking volume

Cons:

- Finite tracking volume
- Equipment needs to be placed in the environment
- Setup takes time



Inside-Out Tracking

Device tracks itself without special preparation of environment

Examples:

- Oculus Quest, Rift S
- Microsoft Mixed Reality, HoloLens
- Magic Leap One
- Smartphone with ARKit/ARCore

Typical solution:

- Simultaneous localization and mapping (SLAM)

Pros:

- Unrestricted tracking volume
- No cameras or other objects need to be placed in the environment

Cons:

- Lower accuracy and latency than many outside-in tracking solutions
- Significant computational requirements for image processing