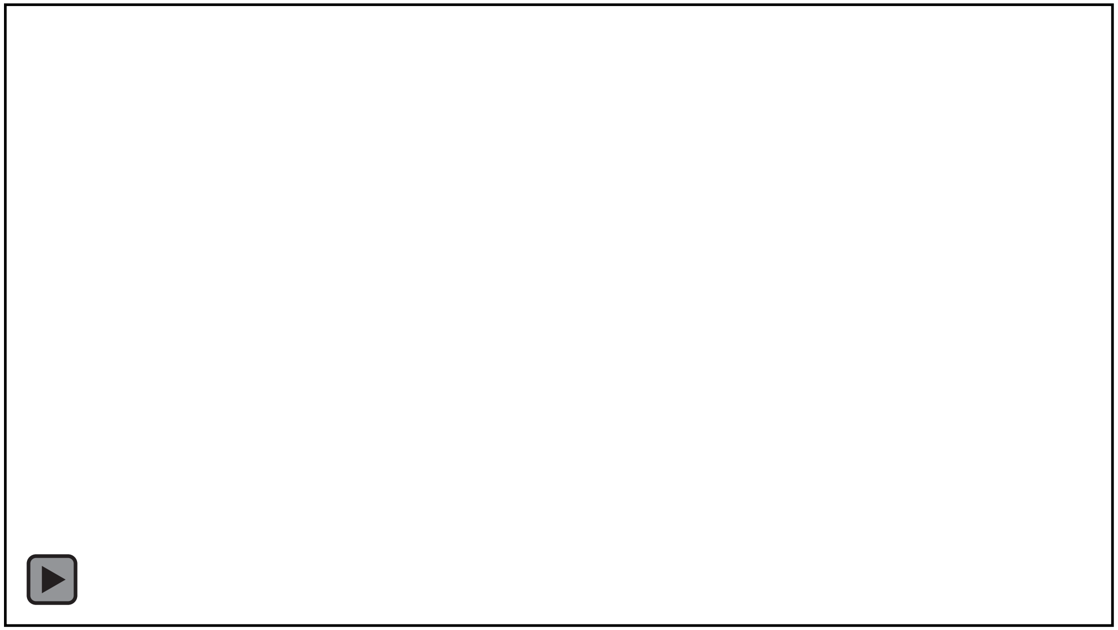
CSE 191: Virtual Reality Technologies

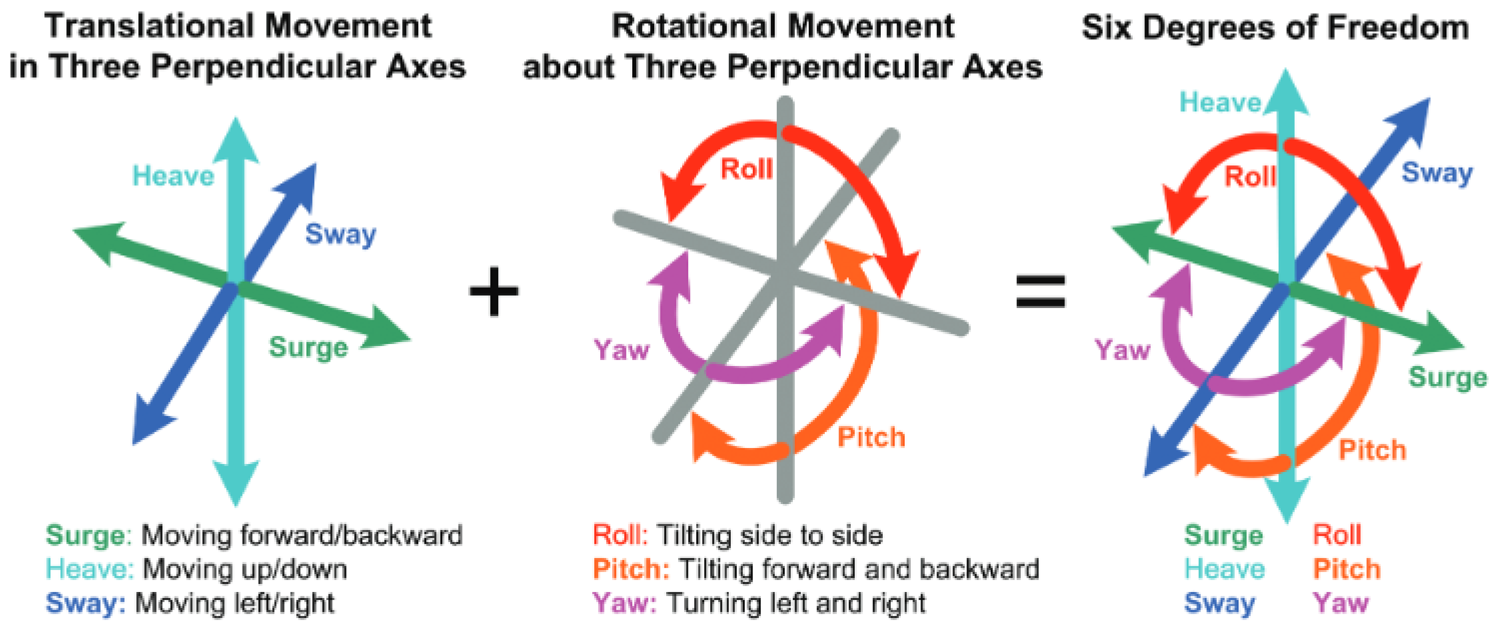
LECTURE #6: 3D TRACKING TECHNOLOGIES

Degrees of Freedom (DOF)

Degrees of Freedom



Overview



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

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

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

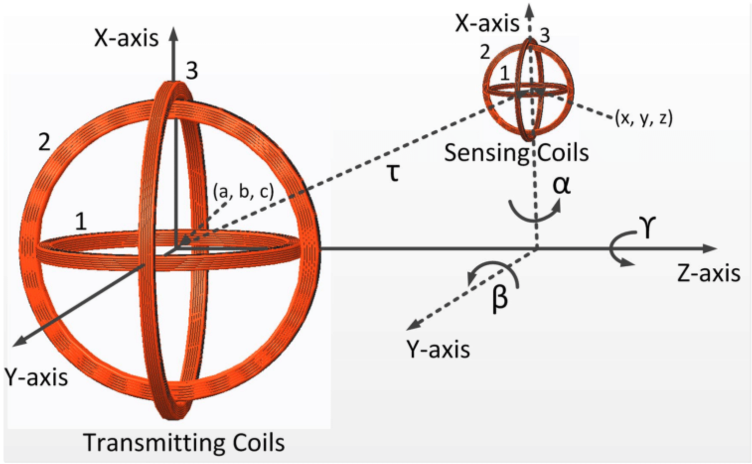
Electromagnetic Tracking

Concept:

- Transmitter generates pulsed low-level magnetic fields with 3 orthogonal coils in sequence
- Fields generate current in receiver unit(s)
- 6-DOF tracking achieved by analyzing signal strength in receiving coils:
  - Axes aligned: signal is strong; weakest when axes are perpendicular
  - Distance between sender/receiver changes amplitude of all three signals in same way

Advantage: no line-of-sight restrictions

Disadvantage: metal in environment can cause interference



Magic Leap


Magic Leap One

Emitter is in controller.

Receiver is on right side of headset.

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

Interference would explain tracker's placement outside of frame.


Receiver


Emitter

Ultrasonic Tracking

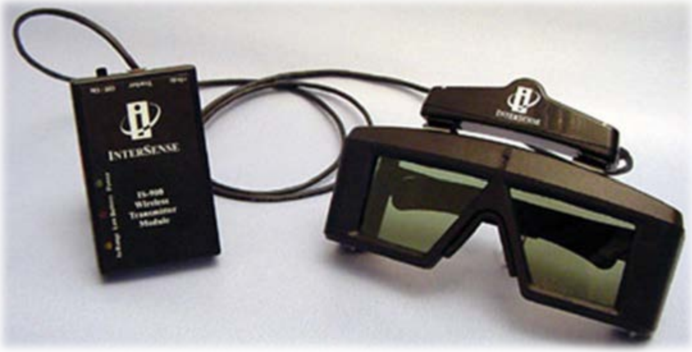
Ultrasonic Tracking

Measures duration of ultrasound signal to reach microphones

InterSense system uses combination of ultrasound and gyroscope

Problems with echoes from walls, people, objects in tracking space

Similar to parking sensors



InterSense IS-900 tracker

InterSense IS-900 Wand

Inertial Tracking

Inertial Tracking

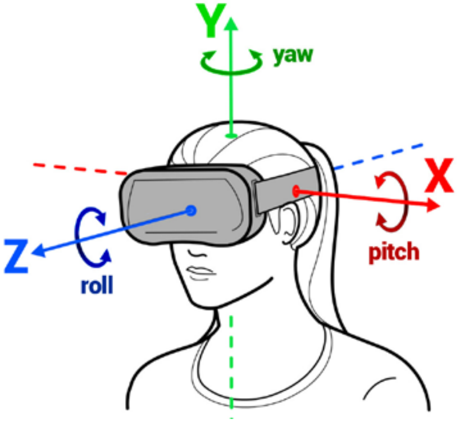
Trackers use **miniature gyroscopes** to measure orientation changes: 3 DOF

Accelerometers can help calibrate, add position tracking

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

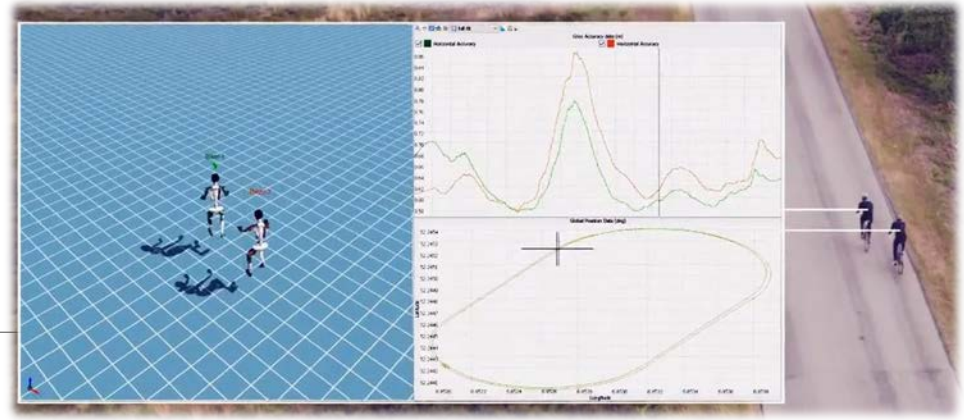
Disadvantage: drift between actual and reported values, accumulates over time

Gyroscope in Oculus Rift DK1

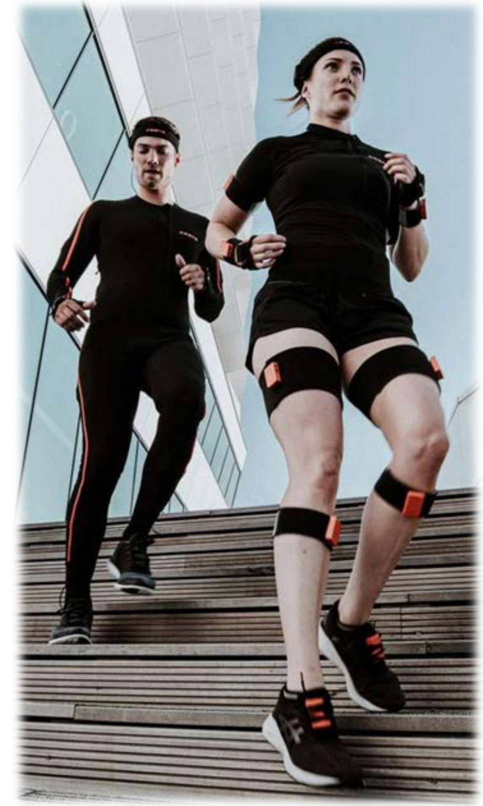


3 Rotational DOF

Xsens Motion Tracking



Long range motion tracking



Optical Tracking

Optical Tracking with Fiducial Markers

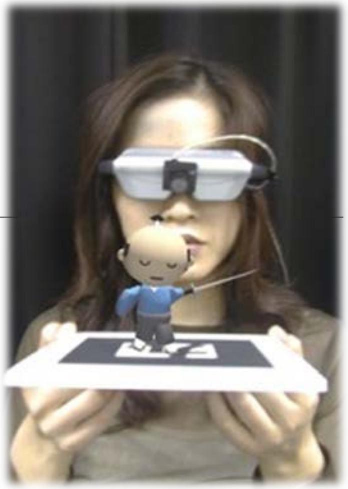
Printable markers placed in environment or on objects

A single camera can be sufficient

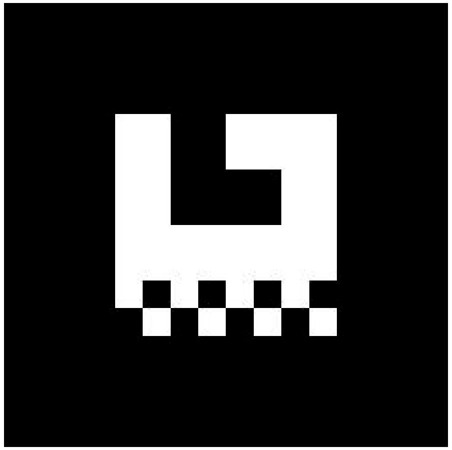
Flexible marker design: similar to QR codes

Markers cannot be rotationally symmetrical

6 DOF tracking possible



ARToolKit (2003)



ARToolKit marker

Objects as Markers

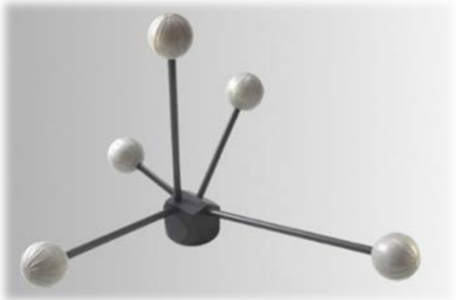
PTC's Vuforia library allows any image or object to be a marker

Optical Tracking with Marker Spheres

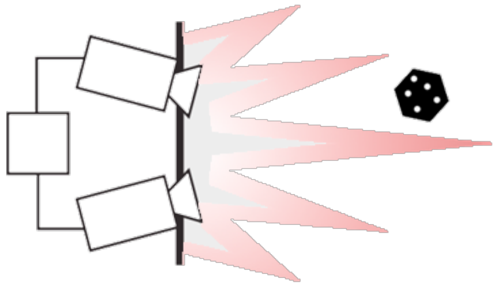
(Near-) Infrared light illuminates scene

Retro-reflective spheres reflect light back to the cameras

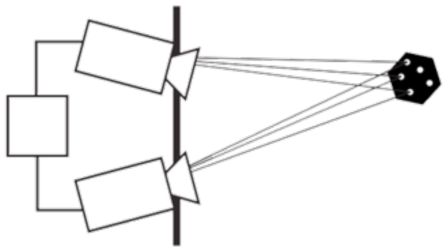
Spheres arranged in fixed, known configurations (constellations) allow for 6 DOF tracking



Marker constellation



The object is lit using near IR light



Retro-reflective markers reflect back

Motion Capture Suit

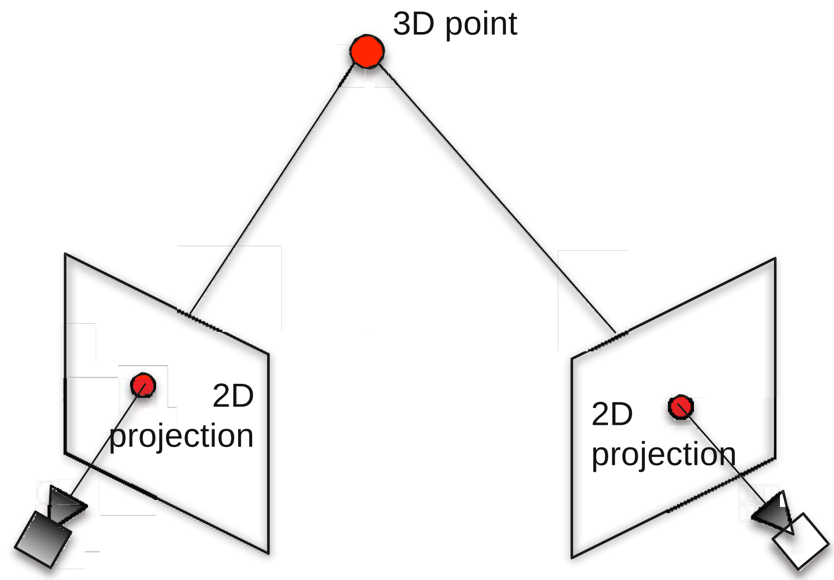
Optical Tracking with LEDs

- Tracks IR LEDs with cameras
- Used on Oculus Quest 1 and 2

Optical Positional Tracking

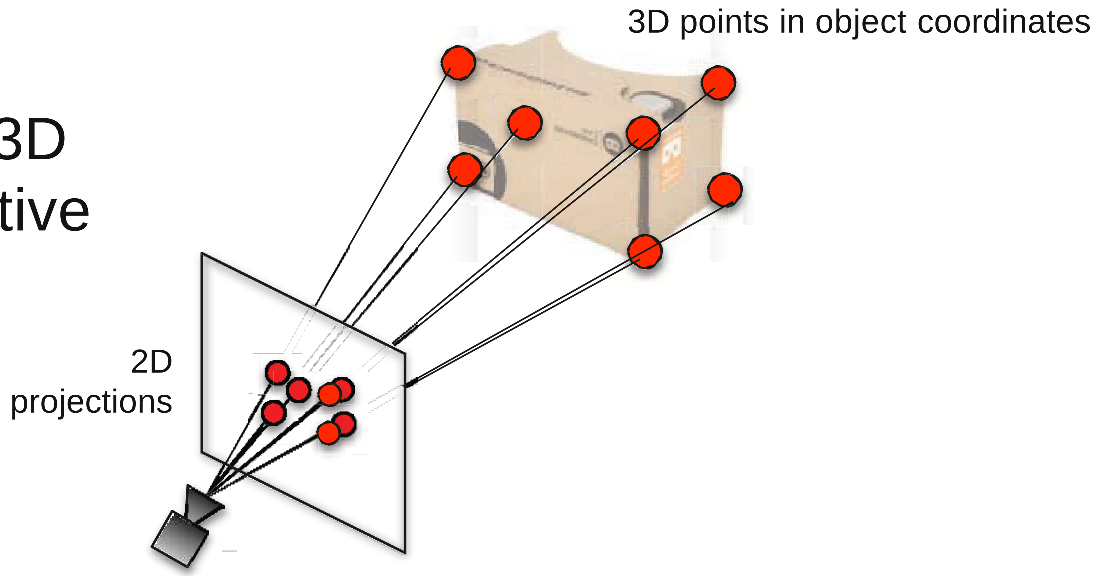
For tracking individual 3D points, multi-camera setups usually use triangulation

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



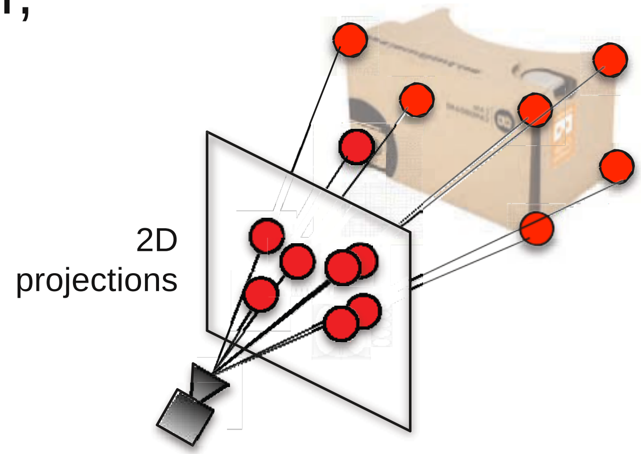
Optical Positional Tracking

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



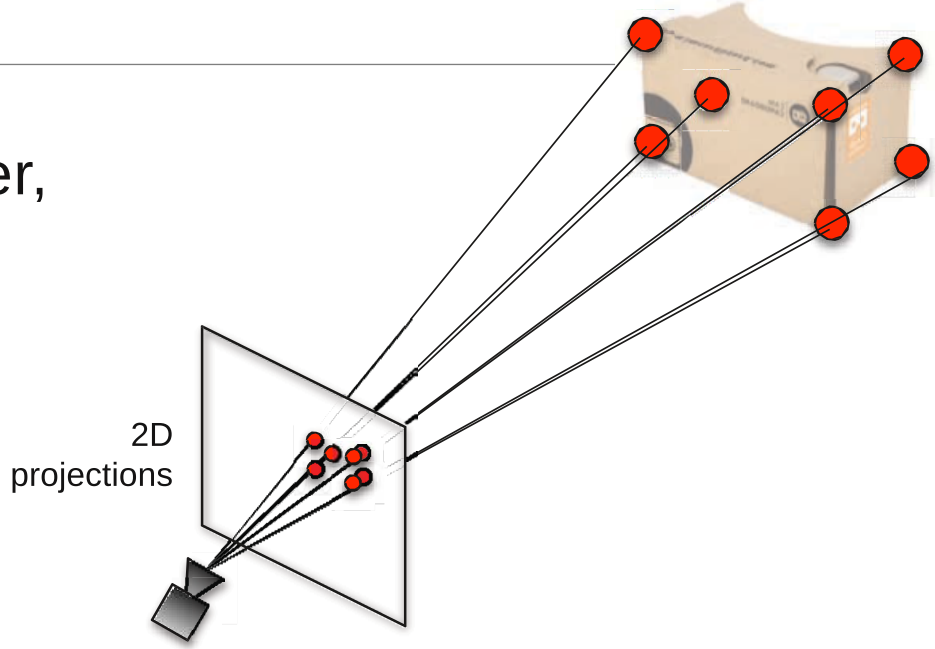
Optical Positional Tracking

When object is closer, projection is bigger



Optical Positional Tracking

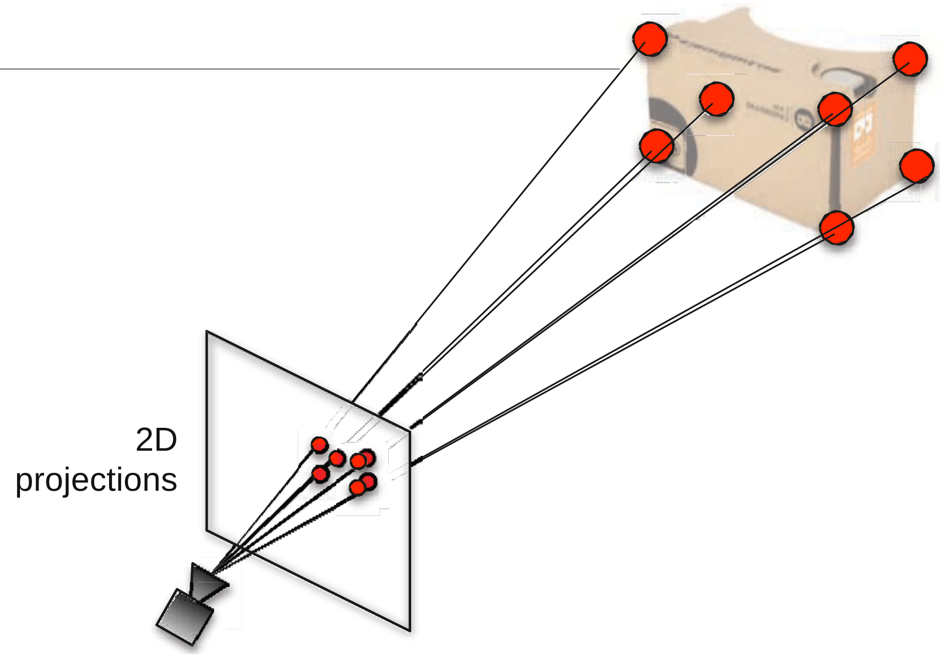
When object is father,
projection is smaller



Optical Positional Tracking

Pose estimation via optimization

Nonlinear least squares problem

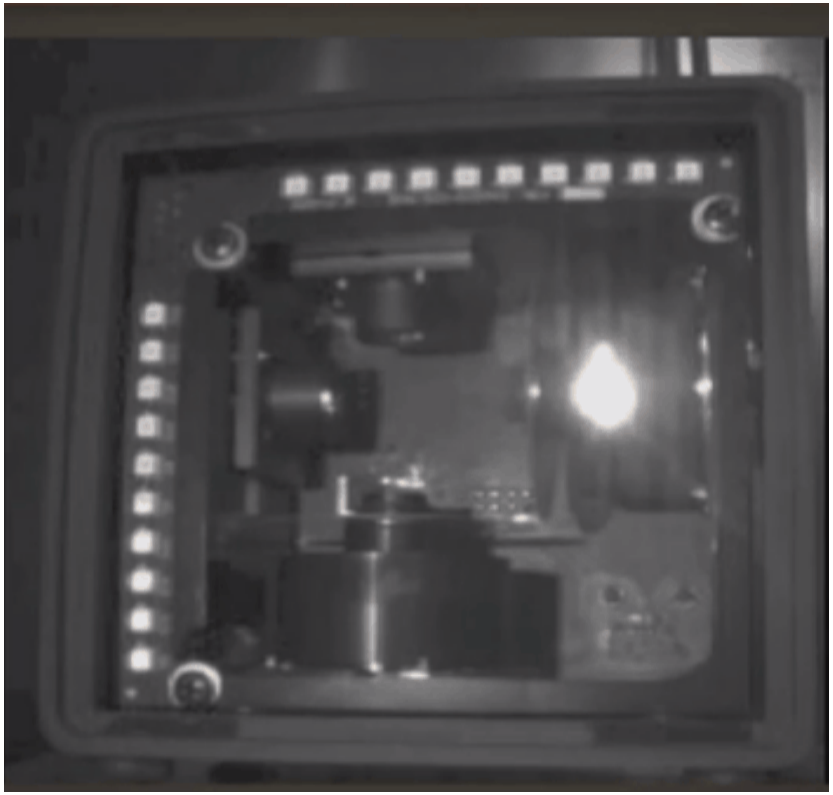


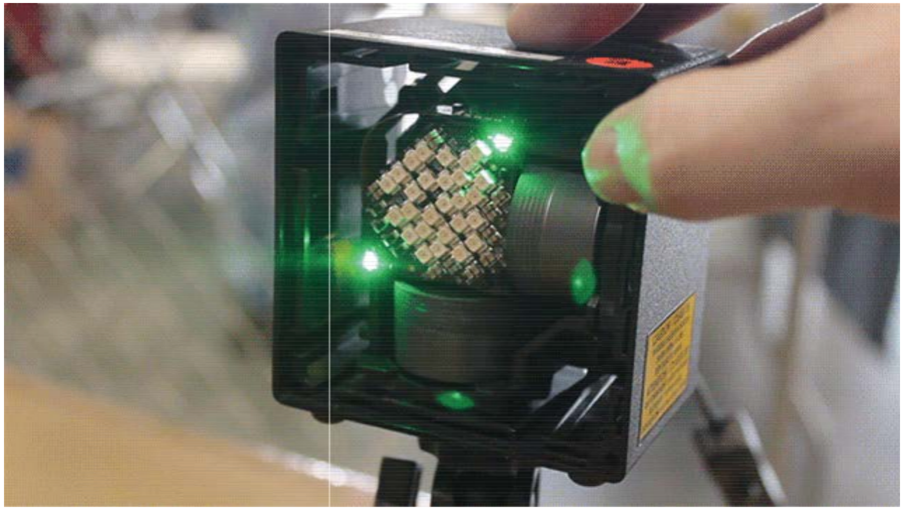
$$\underset{\{R,T\}}{\text{minimize}} \left\| \underbrace{\left(p_1^{2D}, p_2^{2D}, \ldots, p_N^{2D}\right)}_{\text{observed 2D points}} ! \; f\left(\underbrace{p_1^{3D,object}, p_2^{3D,object}, \ldots, p_N^{3D,object}}_{\text{known 3D points}}, \underbrace{R,t}_{\text{unknown pose}}\right) \right\|_2^2$$

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

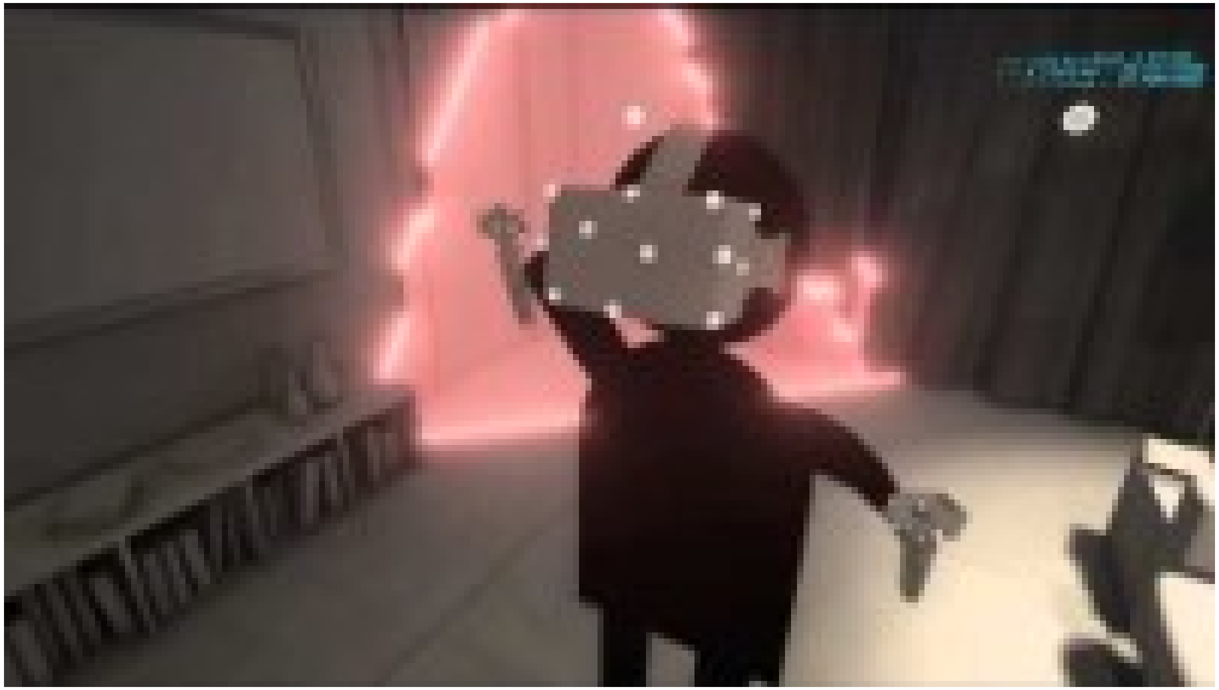
HTC Lighthouse





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

HTC Lighthouse



Tracking Configurations

Outside-In Tracking

Cameras or markers are placed around the room

Examples:

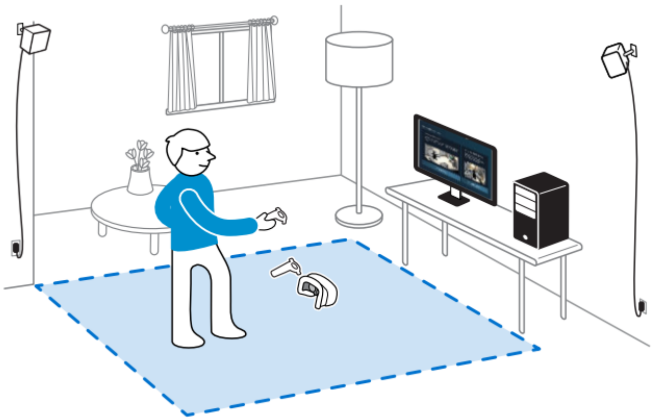
- Oculus Rift, HTC Vive

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

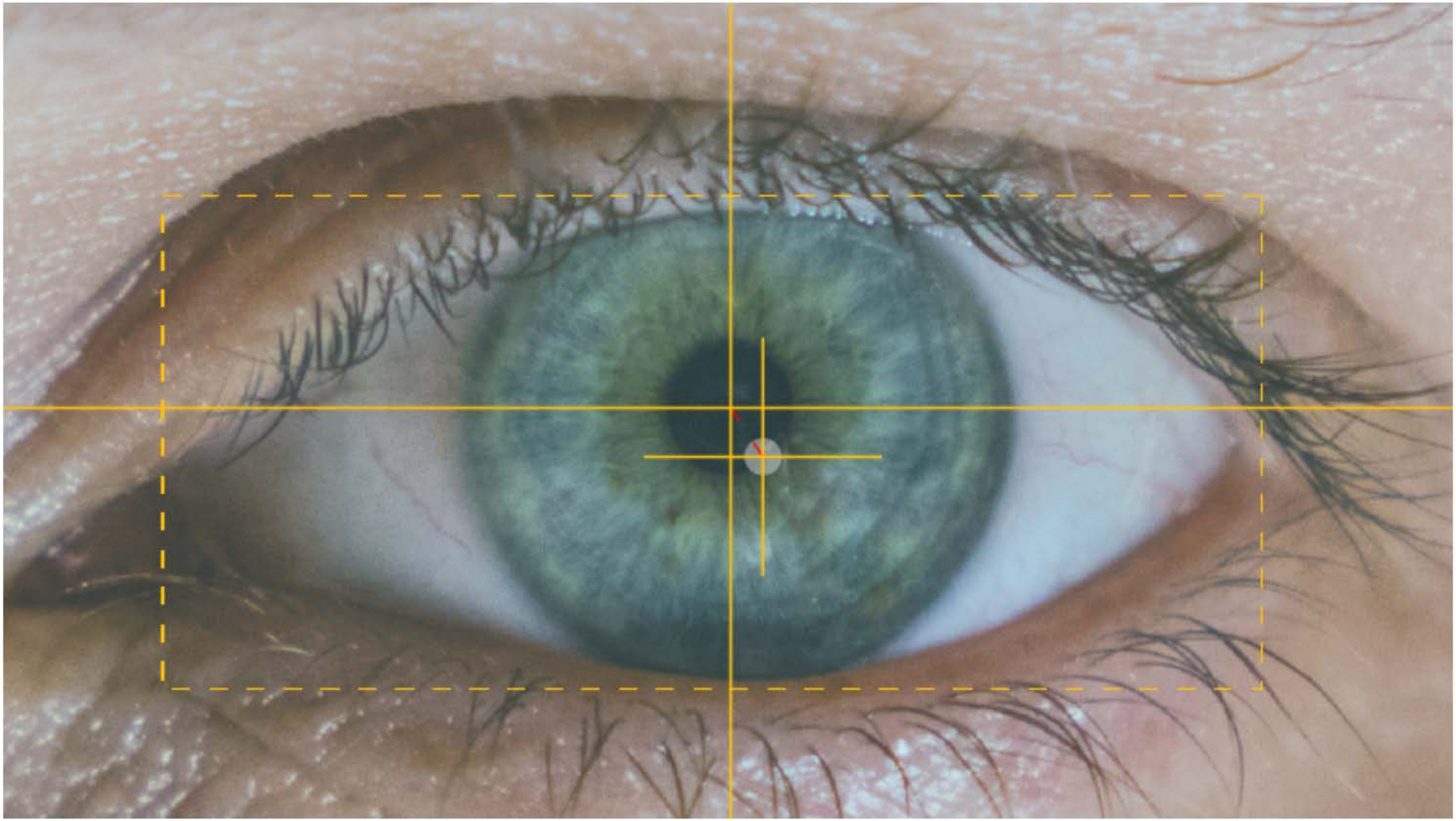
Examples:
- Oculus Quest
- Microsoft HoloLens
- Magic Leap One
- Smartphone with ARKit/ARCore

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

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.

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