

CSE 191: Virtual Reality Technologies

LECTURE #6: 3D TRACKING TECHNOLOGIES

Agenda

App presentations:

- Gehan: Bait
- Calvin: Ragnarock

Tech presentation:

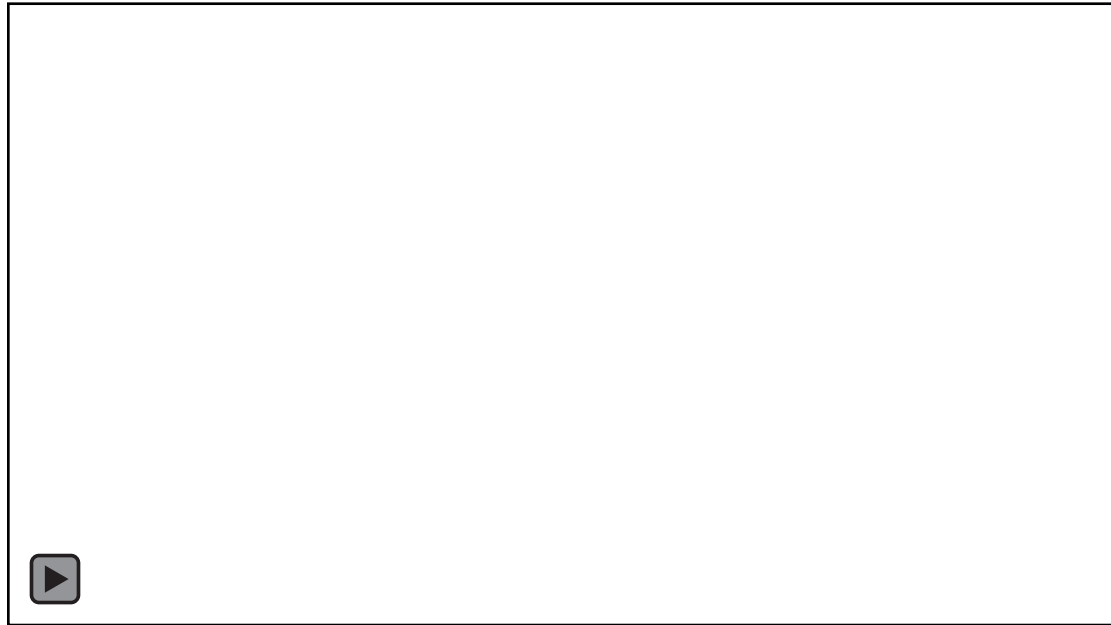
- Danny: Sensory Force Feedback

Reading

Today's topic: Tracking Technologies

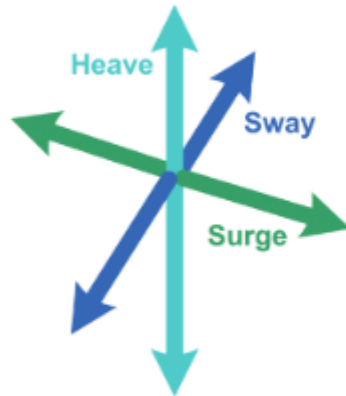
Degrees of Freedom (DOF)

Degrees of Freedom



Overview

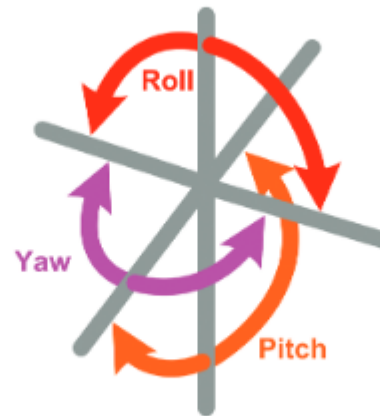
**Translational Movement
in Three Perpendicular Axes**



Surge: Moving forward/backward
Heave: Moving up/down
Sway: Moving left/right

+

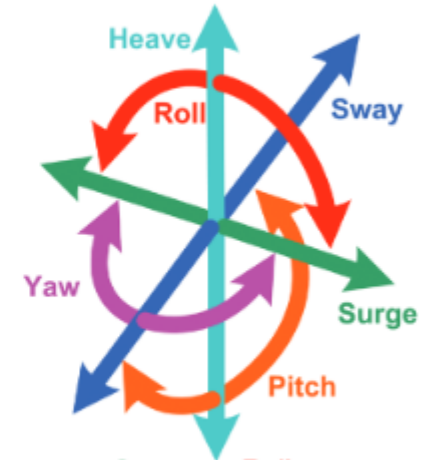
**Rotational Movement
about Three Perpendicular Axes**



Roll: Tilting side to side
Pitch: Tilting forward and backward
Yaw: Turning left and right

=

Six Degrees of Freedom



Surge **Roll**
Heave **Pitch**
Sway **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



ROLLING

Roll is where the head **pivots side to side** (i.e. when peeking around a corner)



PITCHING

Pitch is where the head **tilts along a vertical axis** (i.e. when looking up or down).



YAWING

Yaw is where the head **swivels along a horizontal axis** (i.e. when looking left or right)



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

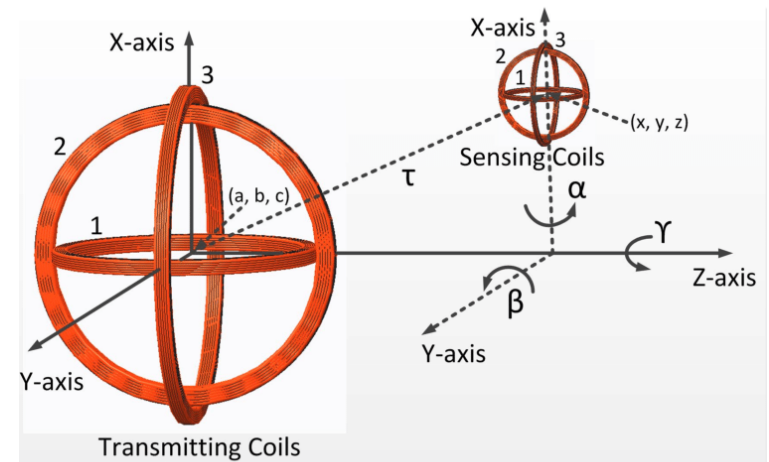
Concept:

- 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

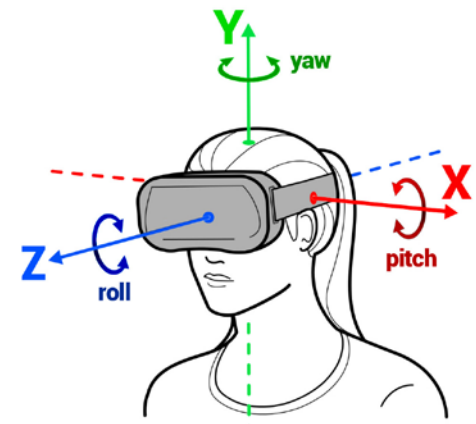
Advantages:

- 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



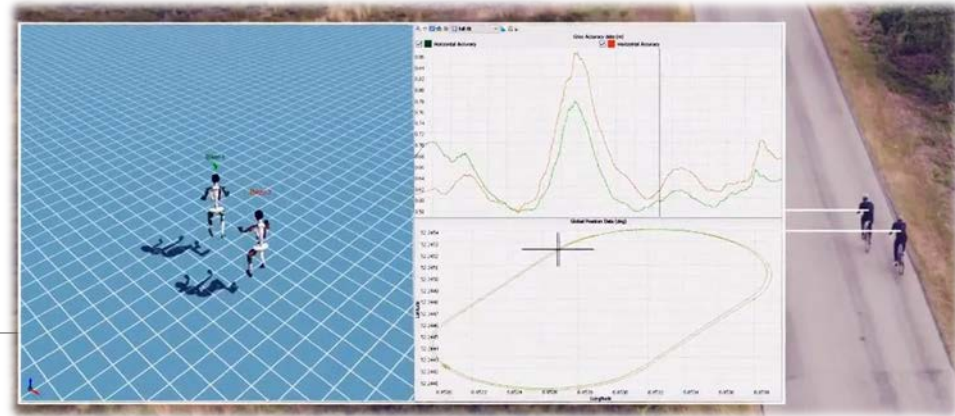
Gyroscope in Oculus Rift DK1



3 Rotational DOF

Xsens Motion Tracking

Long range motion tracking



Version
Lycra suit

Trackers
17 Wired

Motion data
Lab quality

Setup time
10 minutes

Latency
20 ms

Battery management
One battery

On-body recording
✓

Wireless data link
One Access Point for Multiple persons

Wireless range Indoor/outdoor
50/150 m (150/450 ft) Extendable

On-body buffering
10 m

Internal update rate
1000 Hz

Output rate
240 Hz

Accessibility
Lycra suit, 5 sizes

Battery life
9.5 h

Portability
Suitcase

Validated
✓



Optical Tracking

Optical Tracking with Fiducial Markers

Printable markers placed in environment or on objects

A single camera can be sufficient

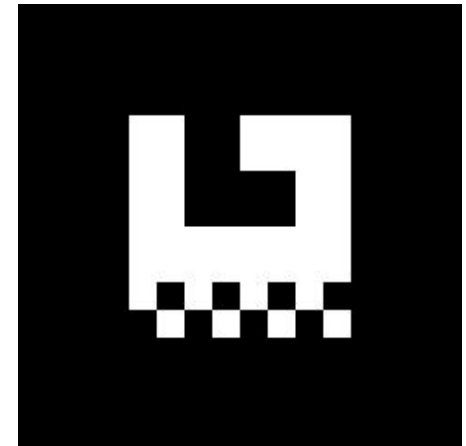
Flexible marker design: similar to QR codes

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

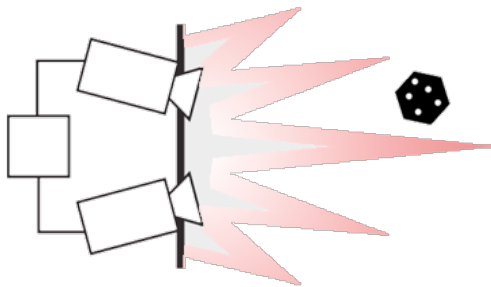


Optical Tracking with Marker Spheres

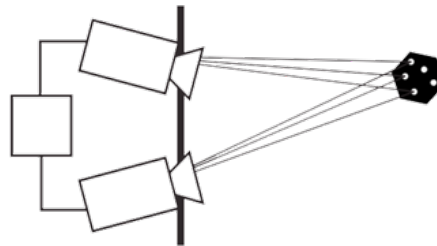
(Near-) Infrared light illuminates scene

Retro-reflective spheres reflect light back to the cameras

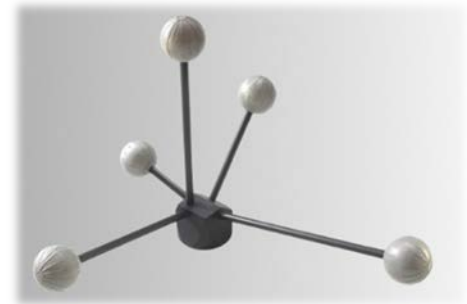
Spheres arranged in fixed, known configurations (constellations) allow for 6 DOF tracking



The object is lit using near IR light



Retro-reflective markers reflect back



Marker constellation



Motion Capture Suit

Optical Tracking with LEDs

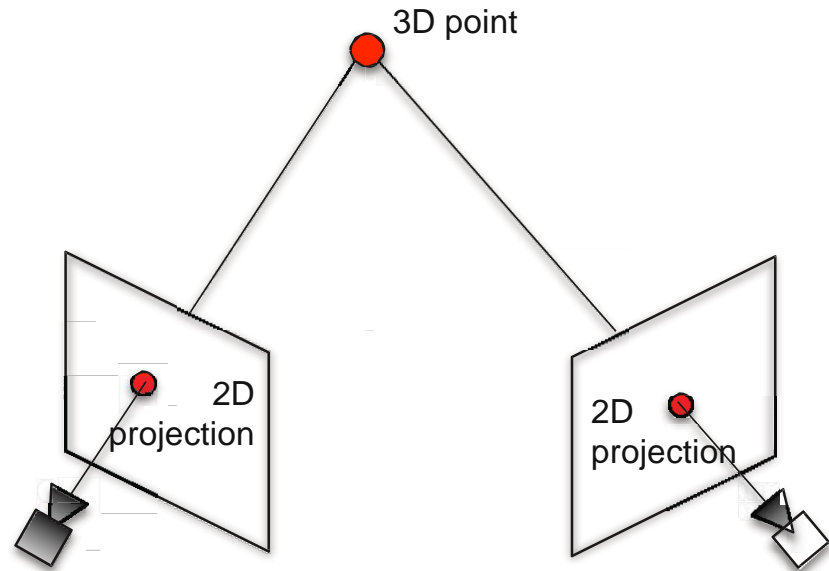
- Tracks IR LEDs with cameras
- Used on Oculus Quest 1 and 2



Optical Positional Tracking

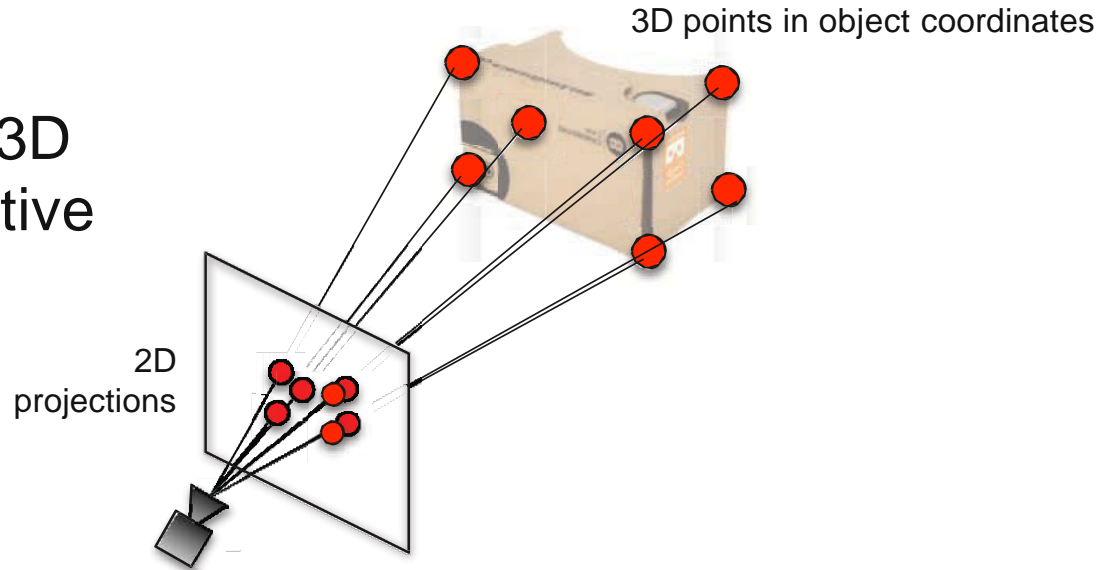
For tracking individual 3D points, multi-camera setups usually use triangulation

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



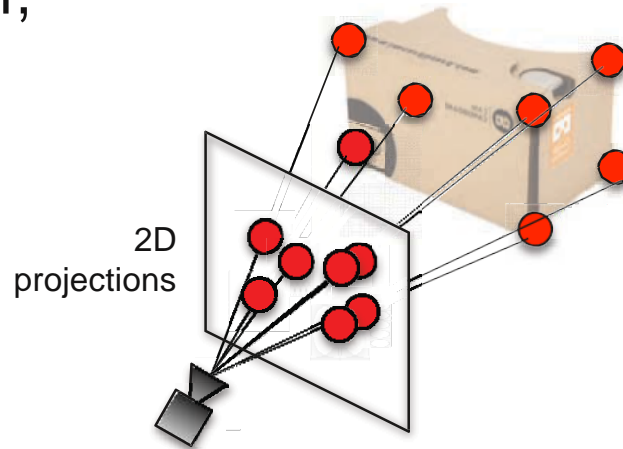
Optical Positional Tracking

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



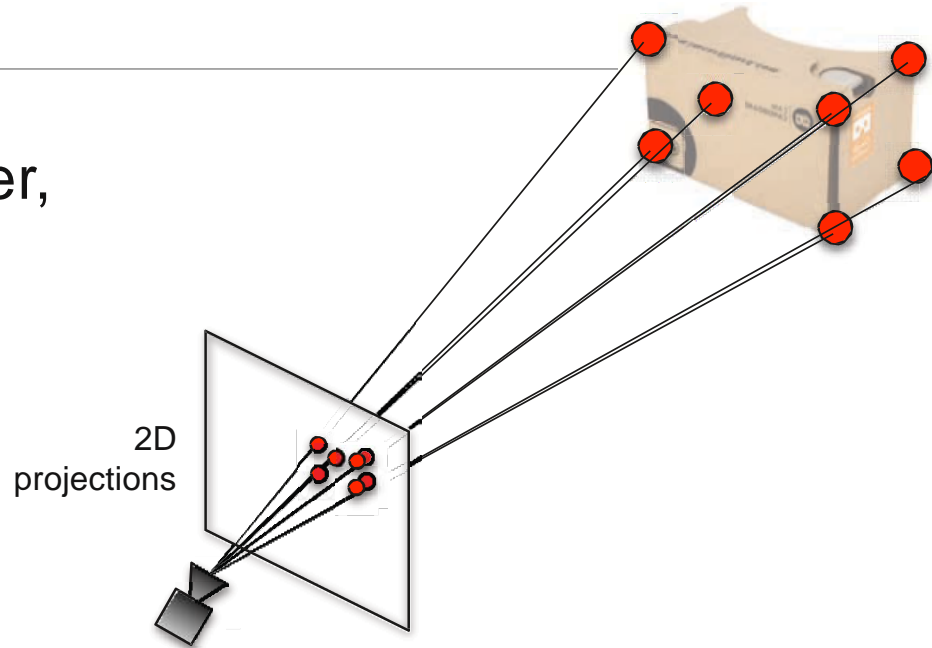
Optical Positional Tracking

When object is closer,
projection is bigger



Optical Positional Tracking

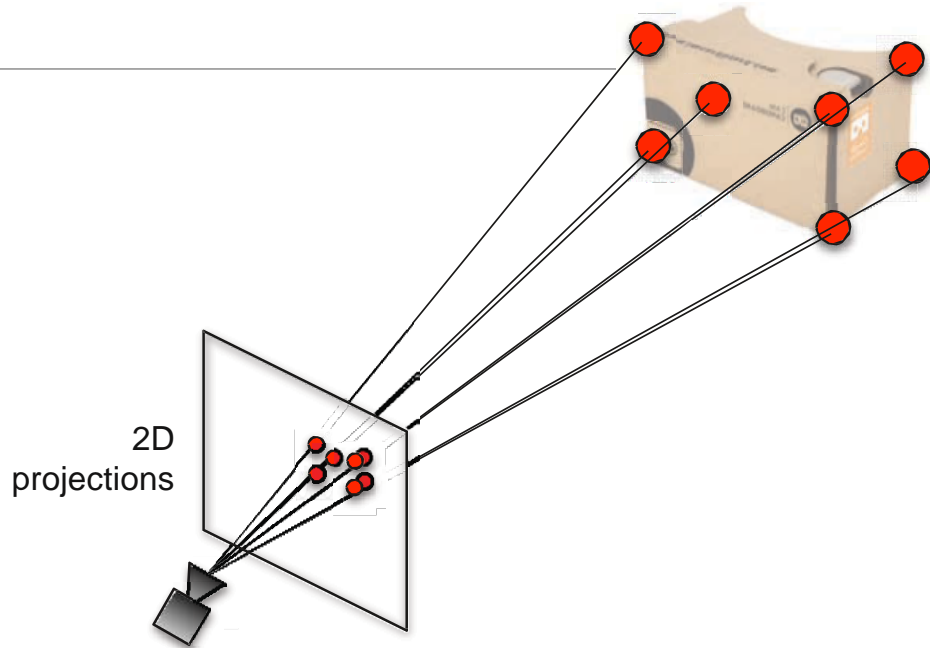
When object is farther,
projection is smaller



Optical Positional Tracking

Pose estimation via optimization

Nonlinear least squares problem



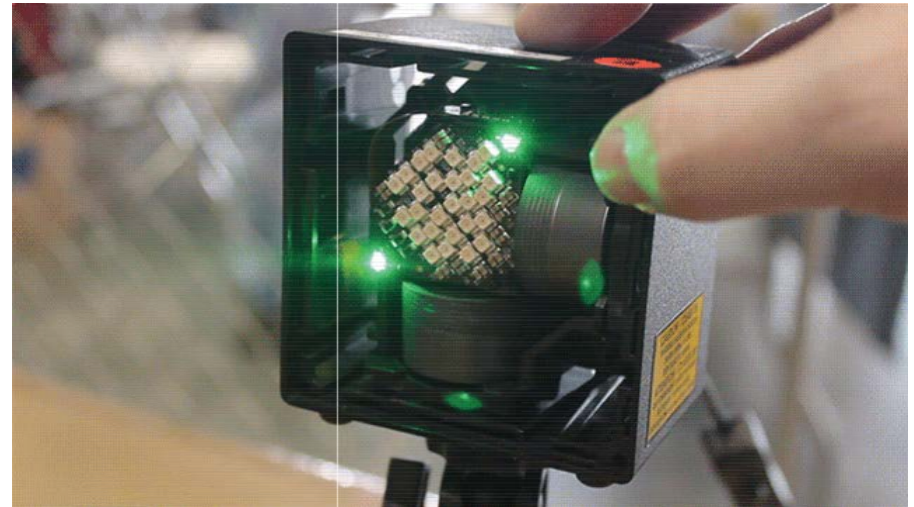
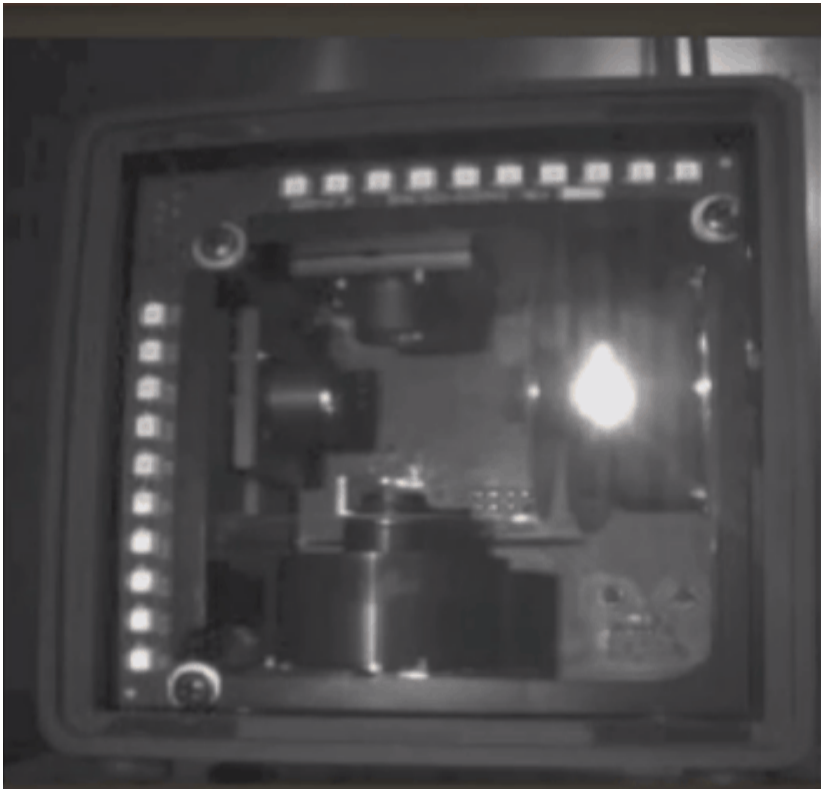
$$\underset{\{R, T\}}{\text{minimize}} \left\| \underbrace{\left(p_1^{2D}, p_2^{2D}, \dots, p_N^{2D} \right)}_{\text{observed 2D points}} - \underbrace{f \left(\underbrace{p_1^{3D, \text{object}}, p_2^{3D, \text{object}}, \dots, p_N^{3D, \text{object}}}_{\text{known 3D points}}, \underbrace{R, t}_{\text{unknown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

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:

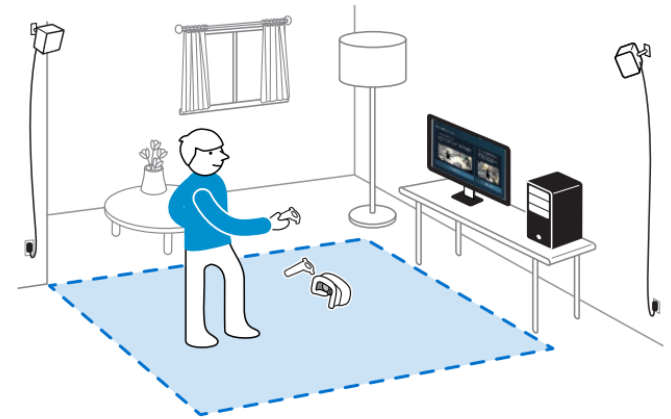
- Oculus Rift, HTC Vive

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

