

# CSE 190: Virtual Reality Technologies

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LECTURE #10: 3D TRACKING PART 2

# Upcoming Deadlines

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Sunday, May 2: Project 2 due

Monday, May 3: Discussion Project 3

Sunday, May 9: Project 2 late deadline

Monday, May 10: Discussion Project 3

Sunday, May 16: Project 3 due

# App Presentations

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Qing Wei

- Spatial

# Optical Tracking

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# 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

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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

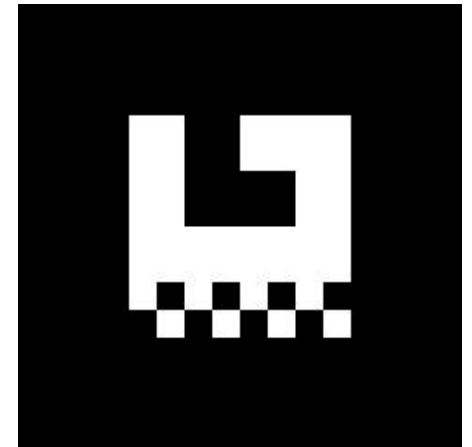
6 DOF tracking possible

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

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



ARToolKit (2003)



ARToolKit marker

# Optical Tracking with Marker Spheres

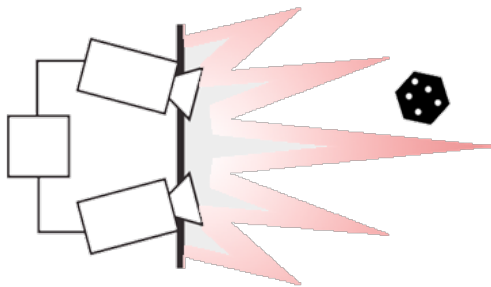
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Available since 1990s

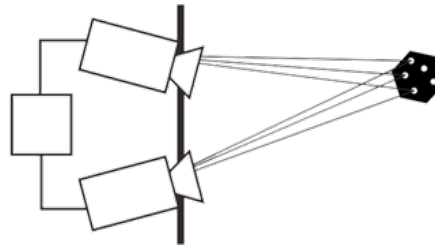
(Near-) Infrared light illuminates scene

Retro-reflective spheres reflect light back to the cameras

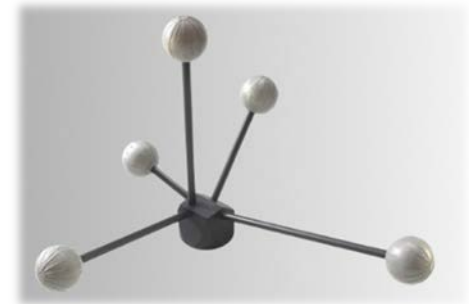
Spheres arranged in fixed, known configurations (constellations) allow for 6 DOF tracking



The object is lit using near IR light



Retro-reflective markers reflect back



Marker constellation



Motion Capture Suit

# Optical Tracking with Infrared LEDs

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



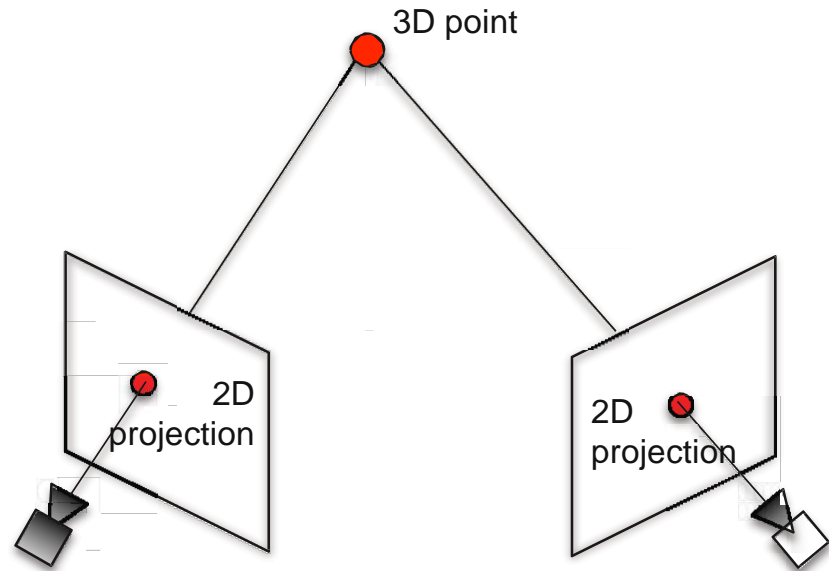
Oculus Rift CV1



# Optical Positional Tracking

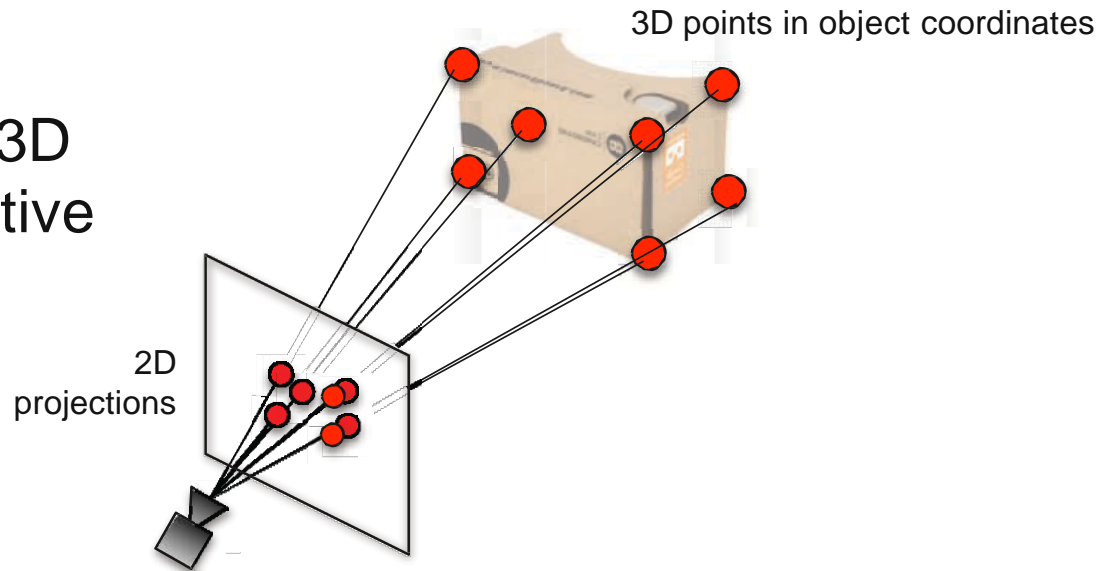
For tracking individual 3D points, multi-camera setups usually use triangulation

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



# Optical Positional Tracking

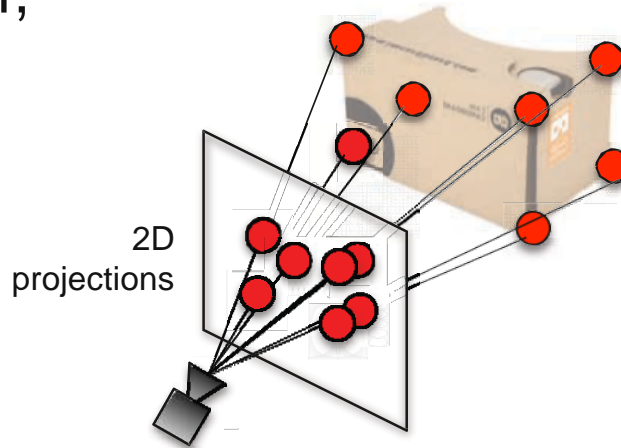
For pose tracking, we need to track multiple 3D points with known relative coordinates



# Optical Positional Tracking

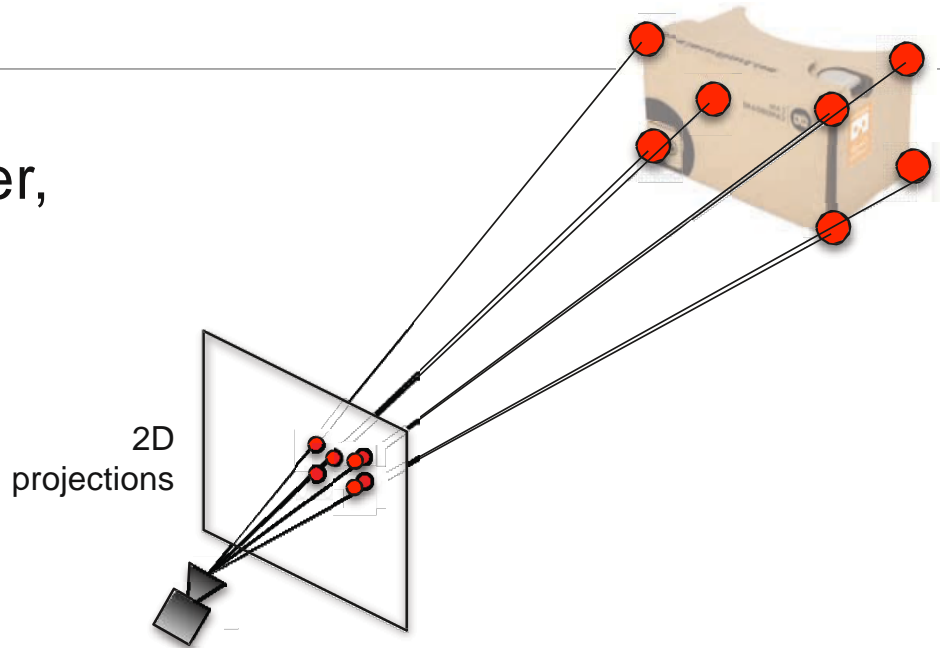
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When object is closer,  
projection is bigger



# Optical Positional Tracking

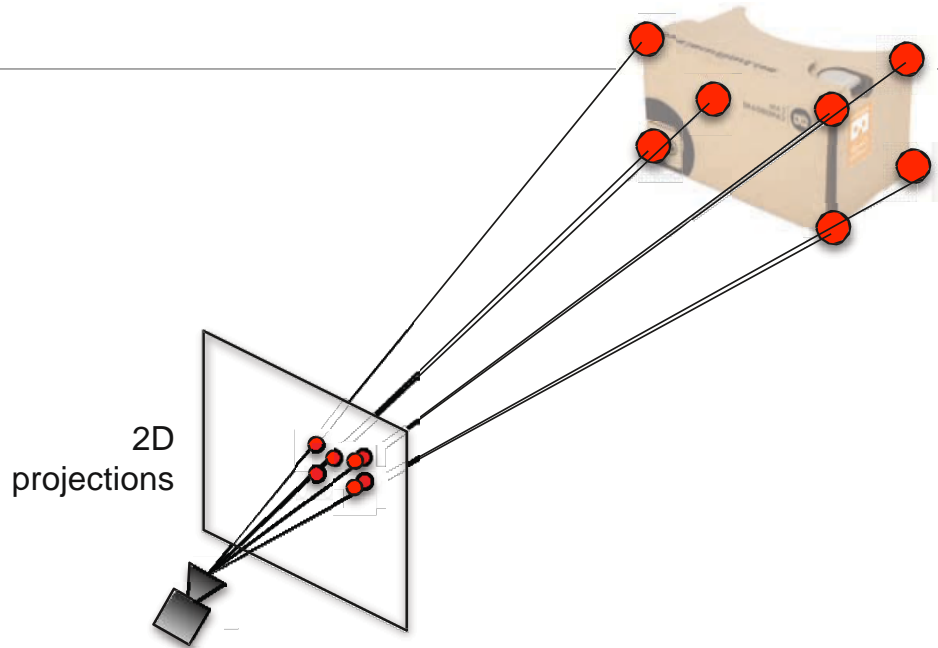
When object is farther,  
projection is smaller



# Optical Positional Tracking

Pose estimation via  
optimization

Nonlinear least  
squares problem



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

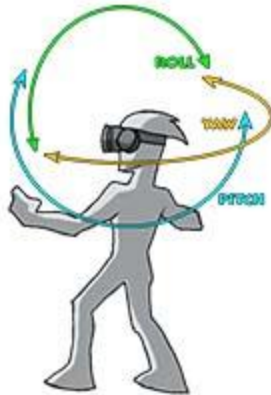
# Summary: Optical Tracking

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Optical tracking works well for positional tracking (3 DOF)

Can provide full 6 DOF tracking with marker constellations

3 degrees of freedom (3-DoF)



6 degrees of freedom (6-DoF)



# HTC Vive Lighthouse

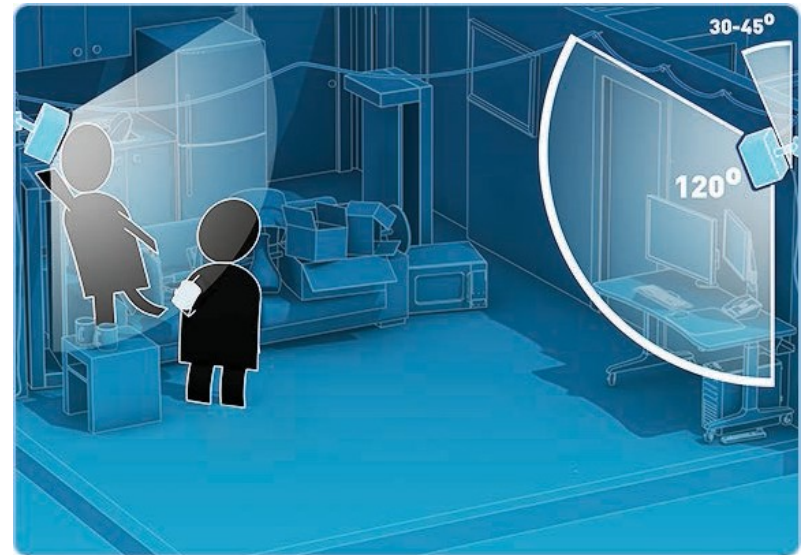
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- Runs at 60 Hz
  - i.e. horizontal & vertical update combined 60 Hz
  - broadband sync pulses in between each laser sweep (i.e. at 120 Hz)
- Each laser rotates at 60 Hz, but offset in time
- Usable field of view: 120 degrees
- Sync pulse emitted 120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

# HTC Lighthouse – Base Station

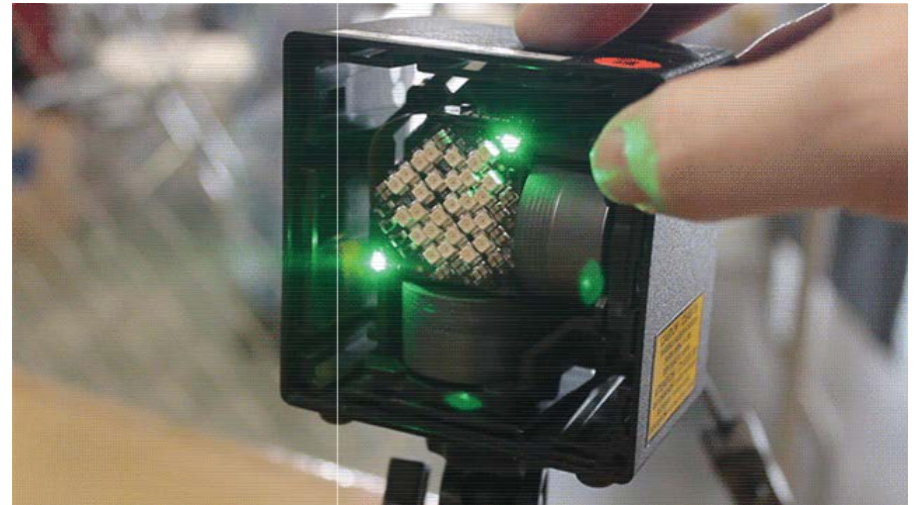
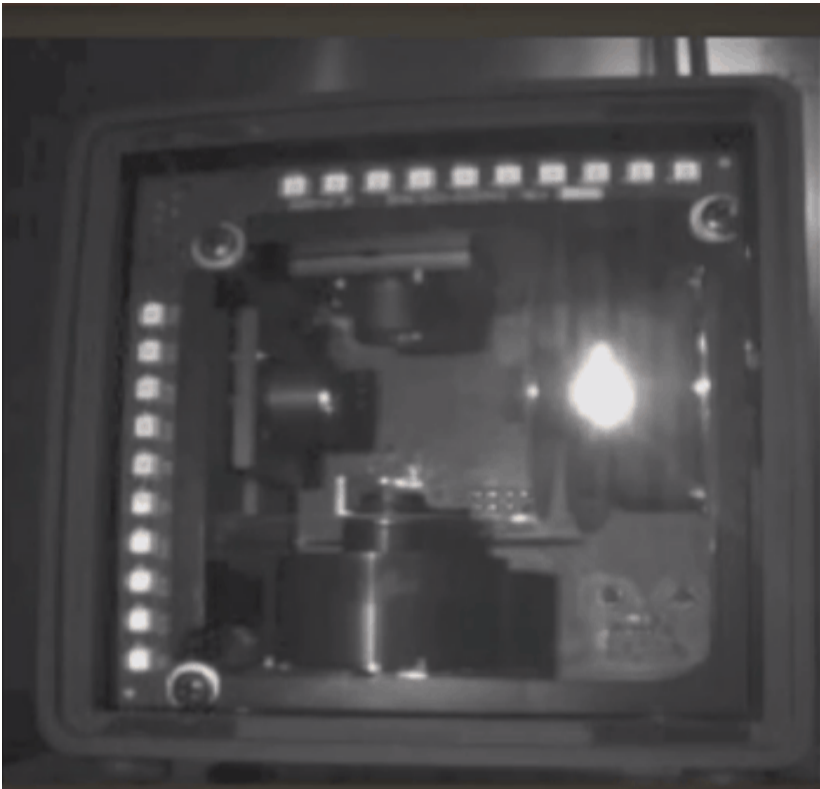
- Can use multiple base stations simultaneously via *time-division multiplexing* (TDM)
- Base station modes:
  - A: TDM slave with cable sync
  - B: TDM master
  - C: TDM slave with optical sync





# HTC Lighthouse

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

# HTC Lighthouse



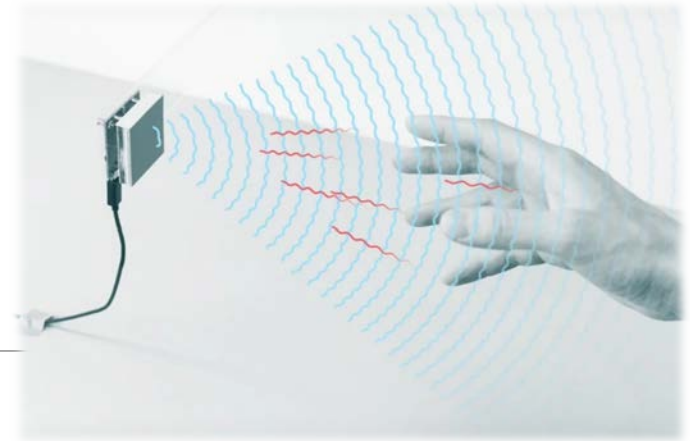
<https://www.youtube.com/watch?v=J54dotTt7k0>

# Other Tracking Techniques

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# Radar

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Tracking with radar is **early stage** technology

No **line of sight** requirements

Most prominent example: Google's **Project Soli**

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

# Pixel 4

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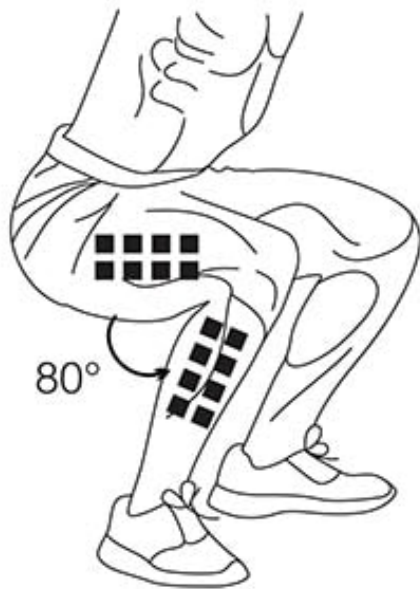
Soli technology first used in Google's Pixel 4 phone, released 10/2019

Motion Sense allows to skip songs, snooze alarms and silence phone calls



# RFID Based Tracking

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Carnegie Mellon University researchers have found ways to track body movements using arrays of **RFID tags**

RFID tags are cheap, battery-free and washable

CMU's system uses a **single**, 900 MHz antenna to monitor an array of tags without any prior calibration

**Arrays** of RFID tags are positioned on either side of the knee, elbow or other joints

By keeping track of the **differences** in when the backscattered radio signals from each tag reach the antenna, it's possible to calculate the angle of a bend in a joint

Demonstrated **millimeter accuracy** in skeletal tracking

# RFID Tracking by CMU

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# Finger Tracking

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# Hybrid Devices: Haptic Feedback Devices

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PHANToM haptic device

Force feedback joystick

Exoskeleton-like devices



Geomagic Touch



LEXOS: Frisoli et. al.,  
Italy



Immersion  
CyberForce



# Pinch Gloves

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- 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](http://www.fakespacelabs.com)

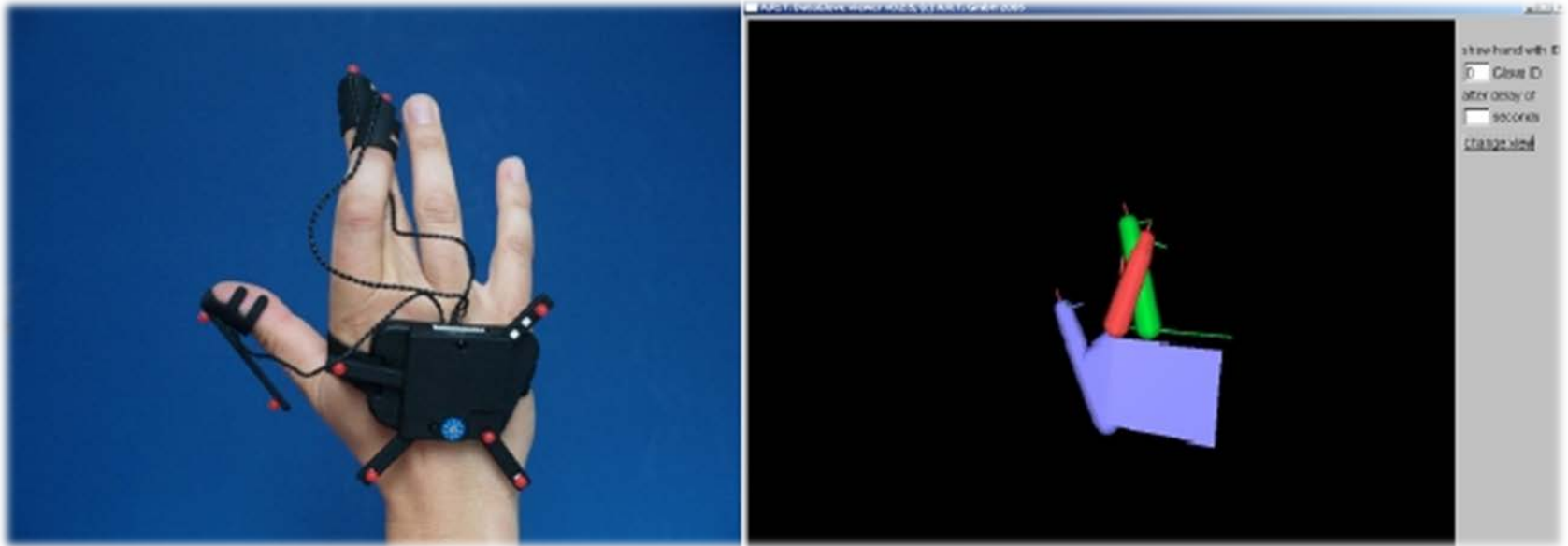


# Optical Finger Tracking

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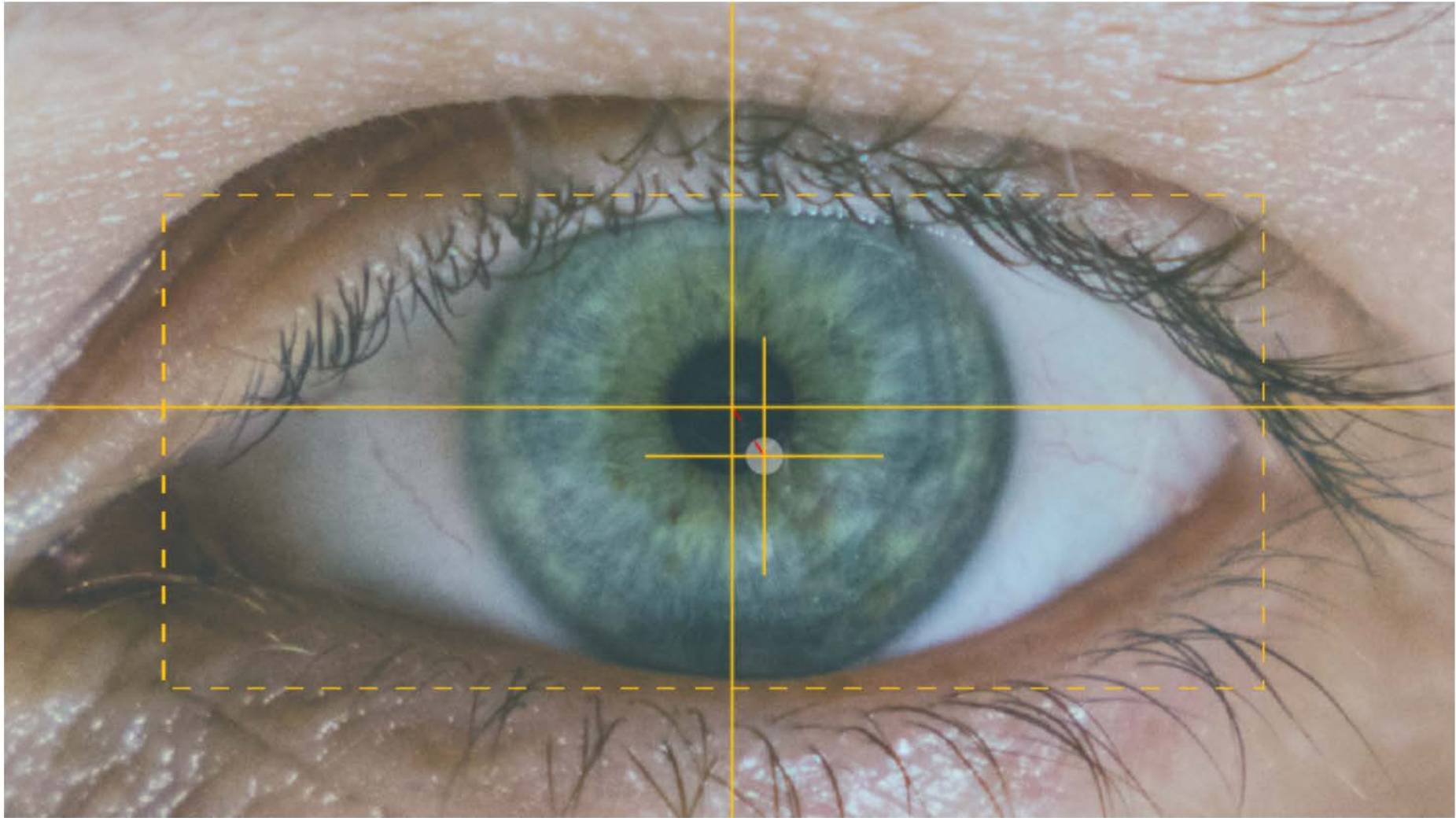
Extension of ART Tracking system

Tracks three fingers and the hand with IR LEDs



# Eye Tracking

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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

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Add-on for VR headsets



**A QUICK GUIDE  
TO CREATING CONTENT  
WITH TOBII EYE TRACKING**

# Vive Pro Eye

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Vive Pro with built-in eye tracking

Video with use cases for eye tracking:



# FOVE

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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



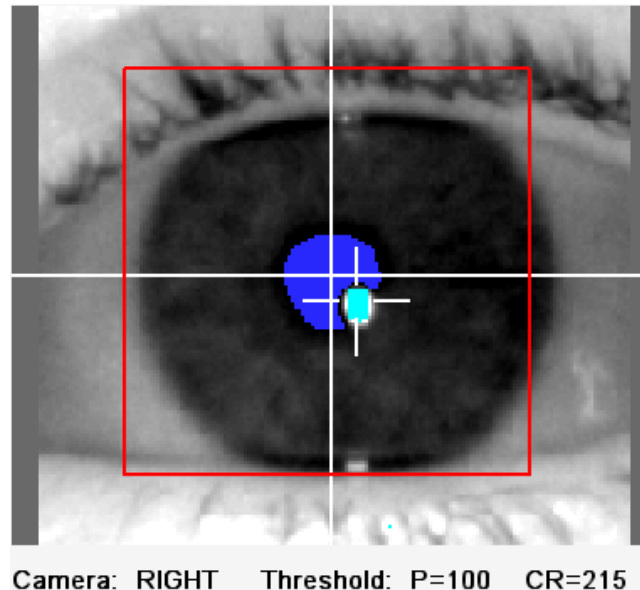
# Eye Tracking Challenges

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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

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# Outside-In Tracking

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Cameras or markers are placed around the room

Examples:

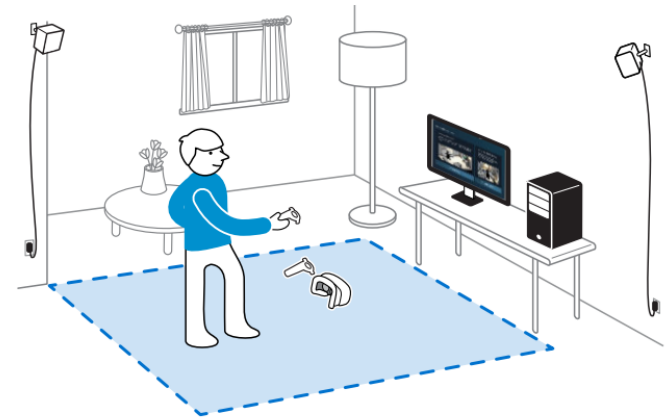
- Oculus Rift, HTC Vive

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

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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

