GW SCHOOL OF ENGINEERING & APPLIED SCIENCE

Augmented and Virtual Reality

CSCI 3907/6907

Spring 2022

3:30 PM - 6:00 PM, Thursdays

TOM 402

Lecture 4

Dr. Hurriyet Ok

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Oculus VR Device Loan Rules

- First come first served, based on Request Form submissions.
- You will receive emails from the CS Department to confirm whether the requested headset is available to pick up or not at the day and time you requested it.
- You may keep the loaner VR Headset for up to one week only.
- If there is no other pending request, you may renew for an additional week, again making a reservation through the Request Form.
- You will return all equipment and accessories on time and allow at least 15 minutes to process the equipment return.
- You will help with the UVC surface decontamination of your loaned VR device using Cleanbox Technology.

Overview of VR Project Deliverables

01/27: VR Concept Note

02/10: Submit VR development status update

02/24: Publish your VR app and produce a 2 min promo video

03/03: Provide project report & your evaluation of three classmates' VR design

03/03: Present your VR app in the classroom

All due by 3:30 PM

VR Project Deliverables – Feb. 10, 2022

Expected Progress

- Know how to set up and build your VR project on an Oculus or HTC.
- Learn about how users should interact with the virtual world: https://developer.oculus.com/resources/bp-userinput/
- Decide on your VR app locomotion type: https://developer.oculus.com/resources/bp-locomotion/
- Understand handling user input for your VR project, as explained in Chapter ""Interacting with Your Hands" in the textbook "Unity 2020 Virtual Reality Projects" by Jonathan Linowes.

VR App Development and Testing with Oculus

Connect Oculus Device with USB

✓Your own VR Headset: Set your Oculus device into developer mode

https://developer.oculus.com/documentation/native/android/mobile-device-setup/

✓CS Loaner VR Headset: Verify that the Oculus device is in developer mode

https://learn.adafruit.com/sideloading-on-oculus-quest/enable-developer-mode

VR App Development and Testing with Oculus

Install VR App (apk) manually on your Oculus device for testing

- MacOS: Install SideQuest to sideload the apk file

  How To Sideload Content On Oculus Quest Using SideQuest

  https://uploadvr.com/sideloading-quest-how-to/

- Windows PC: Use Android Debug Bridge (ADB) to perform advanced-level testing and debugging activities

  Enable Device for Development and Testing

  https://developer.oculus.com/documentation/unity/unity-enable-device/

Tips for Developing Unity VR App on MacOS

You cannot run Unity VR apps from your Mac and play on Oculus Go/Quest directly, unlike a Windows PC.

Make sure you have installed an Android File Transfer for Mac

https://www.android.com/filetransfer/

This will allow you to browse and transfer files between your Mac computer and Go/Quest.

You may use SideQuest App on Mac to install Unity VR apps (for Android) on Go/Quest and test

https://sidequestvr.com/setup-howto

Tips for Developing Unity VR App on MacOS

More resources:

Unity VR Development Oculus Quest 2021, Getting Started in 15 Mins
https://www.youtube.com/watch?v=JyxbA2bm7os

Oculus Quest 2/Quest/Go Mac SideQuest Guide - Install Any APK/Game/Application, Oculus Sideload
https://www.youtube.com/watch?v=98_Y_Jg151A

How to connect Oculus Quest to Mac: Can you connect Oculus Quest 2 to Apple Mac or MacBook?
https://stealthoptional.com/how-to/how-to-connect-oculus-quest-to-mac-can-you-connect-oculus-quest-2-to-apple-mac-or-macbook/

Getting Started With Unity and Virtual Reality
https://jeffrafter.com/getting-started-with-unity-and-vr/

Developing for VR with Quest 2 & Unity for the First Time – A Step-by-Step Guide
https://www.xrterra.com/developing-for-vr-with-quest-2-unity-for-the-first-time-a-step-by-step-guide/

Do you have another tip or additional resources you found helpful?
Share on Blackboard Discussions

VR Project Showcase on Thursday, March 3

- Submit your VR project report including your evaluations of two classmate VR apps
- Demo your fully functioning VR project (5 minutes incl. Q&A)

IMPORTANT

✓ *Upload your Unity VR app and promo video on Box by 3:30 pm on Thu. Feb. 24*

You will lose points if you turn your project deliverables late or incomplete!

In Class Exercise: VR Project Collaboration

Last Name	First Name	Dev Platform Computer OS	Unity Version	VR Headset	VR App Name
Benevento	Nick	Ubuntu 20.04	2021.2.8f	Quest 2	The Maze
Burnett	Connor	Windows 11/Zorin OS 16	2020.3.26f1	Oculus Quest 2	Undercooked
Bury	Nathaniel	Windows 11	2020.3.25f3	Quest 2	Spiderperson
Chinitz	Noah	Windows 11/Zorin OS 16	2020.3.26f1	Oculus Quest 2	Undercooked
Chulet	Pushpak	Windows 11	2021.2.8f	Oculus Quest 2	VR Collab
Gao	Chengshu	windows 10	2020.3.25f1	Oculus Quest 2	Alchemy Simulator
Gbolahan	Olayinka	macOS Monterey	2020.3.26f1	Oculus Quest 2	Sports Maze Quest
Indla	Lakshmi Kesava Reddy	Windows 10	2020.3.26f1	Oculus Quest 2	Snake and Apples
Jacobs	Jett	macOS Catalina	2020.3.26f1	Oculus Quest	Undercooked
Jaimes	Nelson	Windows 10	2020.3.26f1	Oculus Quest 2	SpatialLearningVR
Kaczorowska	Monika	MacOS Monterey	2020.3.26f1	Oculus Quest2	Where's my gate?
Kanungo	Rishi				
Kim	Dongkun	MacOS Monterey	2021.2.8f	Oculus Quest 2	Gem Runer?
Letavish	Sean	Windows 10	2021.122f1	Oculus Quest 2	A Drive Through the Woods
Li	Luke	Windows 10	2021.2..8f	Oculus Quest 2	Where is my dog?
Li	Zongyao	windows 10	2020.3.25f1	Quest2	Alchemy Simulator
Oh	Saerom	MacOS Monterey	2021.2.7f1	Oculus Quest 2	Finding Coco
Phillips	Lanelle	Mac OS BigSur	2021.2.7f1	Oculus Quest 2	Snakes and Apples
Qin	Kusch	Windows 10	2020.3.26f1	Oculus Quest 2	Finding my classroom simulator
Rice	Neil	macOS Big Sur	2020.3.26f1	Oculus Quest 2	PodDash: Escape from Alienation
Scott	Jamie	macOS Catalina	2020.3.26f1	Oculus Quest 2	Phantasm
Shuai	Tiancheng	Windows 10	2020.3.26f1	Oculus Quest 2	Finding my classroom simulator
Smith	Tanner	macOS Big Sur	2020.3.26f1	Oculus Quest 2	PodDash: Escape from Alienation
Stevens	Sarah	macOS Catalina	2020.3.25f1	Oculus Quest 2	Underwater Treasure Hunt
Wang	Riva	windows 11	2021.2.8f	Oculus Quest 2	Where is my dog?
Zhang	Ruojia	windows 10	2020.3.25f1	Oculus Quest 2	Alchemy Simulator
Zheng	Sonny	Windows 10	2020.3.26f1	Oculus Quest 2	Finding my classroom simulator

Group Discussion: VR Design Experience

Discuss within your group and submit on Blackboard:

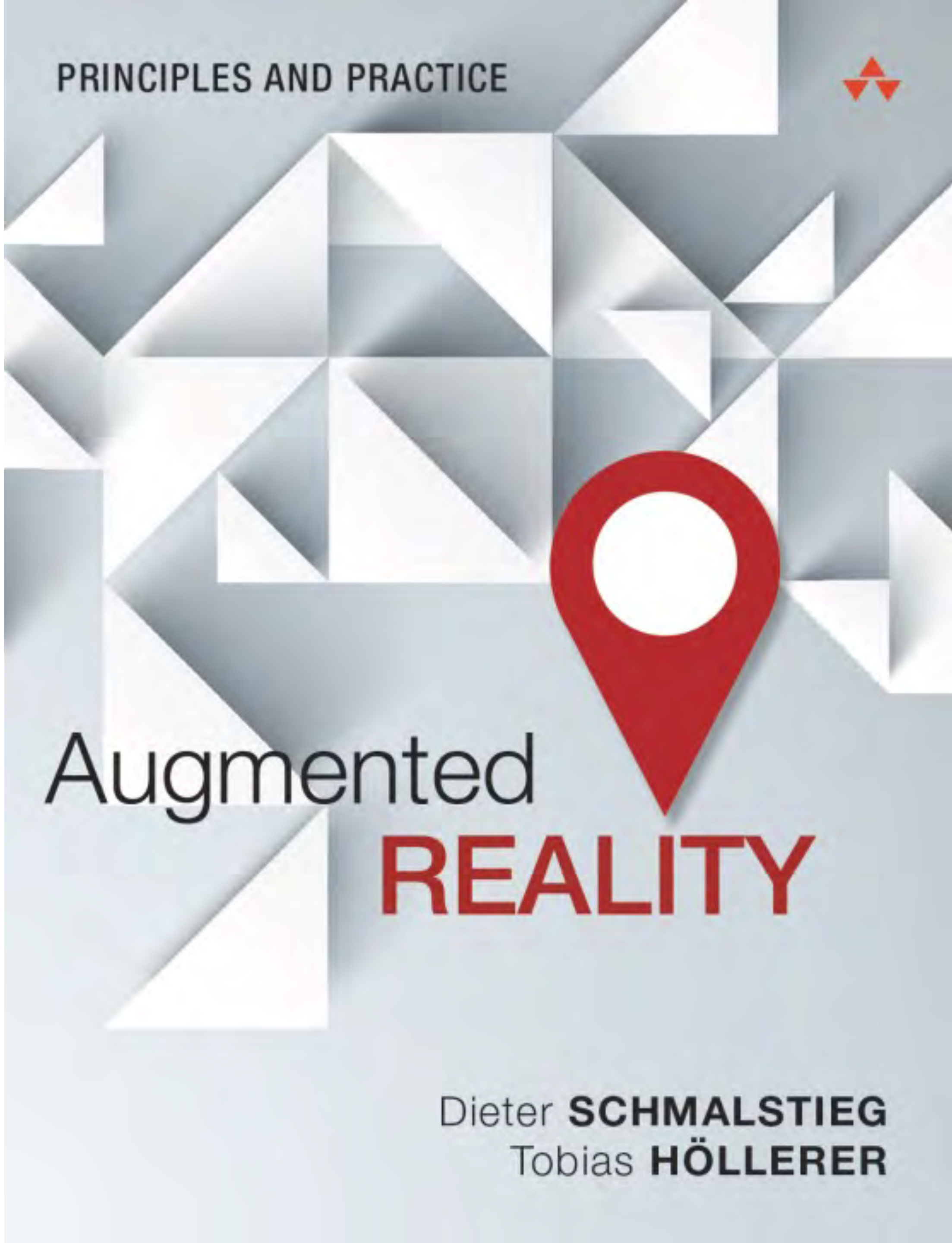
1. What issues you had during VR design and development, so far, and how did you solved them?
   - ✓Be specific about the issues, e.g., installation/configuration, hw/sw compatibility, coding/testing, etc.
   - ✓Provide tips and lessons learned, breakthroughs, “Aha!” moments
2. What are the remaining major challenges?

SCHOOL OF ENGINEERING & APPLIED SCIENCE

Chapter 3: Tracking

Augmented Reality – Principles and Practice

http://www.augmentedrealitybook.org

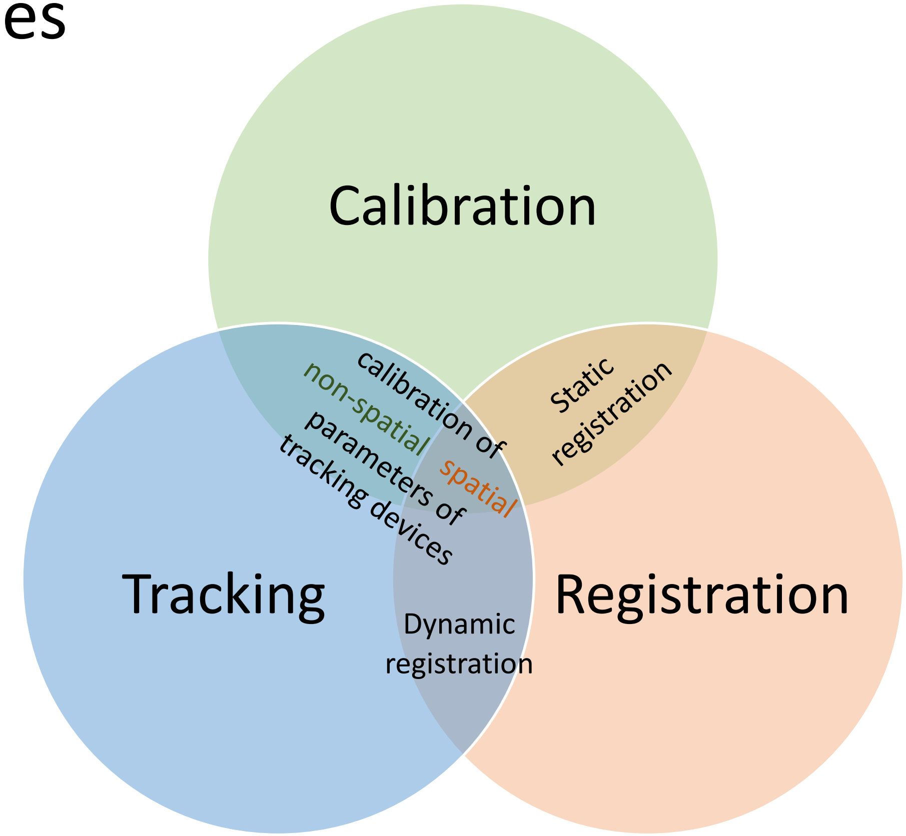


Agenda

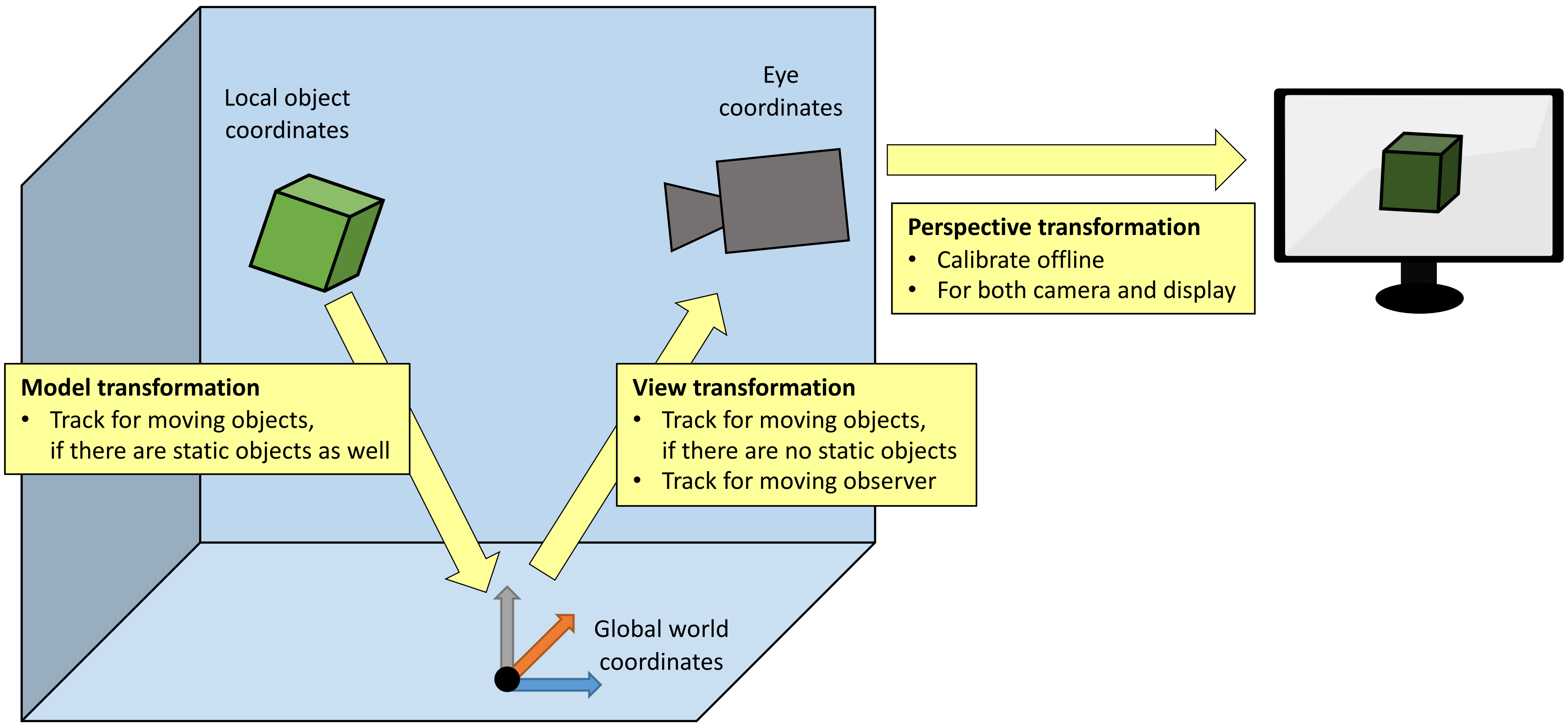
- Tracking, Calibration, and Registration
- Coordinate Systems
- Characteristics
- Stationary Tracking Systems
- Mobile Sensors
- Optical Tracking
- Sensor Fusion

Tracking, Calibration, and Registration

- Registration = alignment of spatial properties
- Calibration = offline adjustment of measurements
  - Spatial calibration yields static registration
  - Offline: once in lifetime or once at startup
  - Alternative: autocalibration
- Tracking = dynamic sensing and measuring of spatial properties
  - Tracking yields dynamic registration
  - Tracking in AR/VR always means “in 3D”!

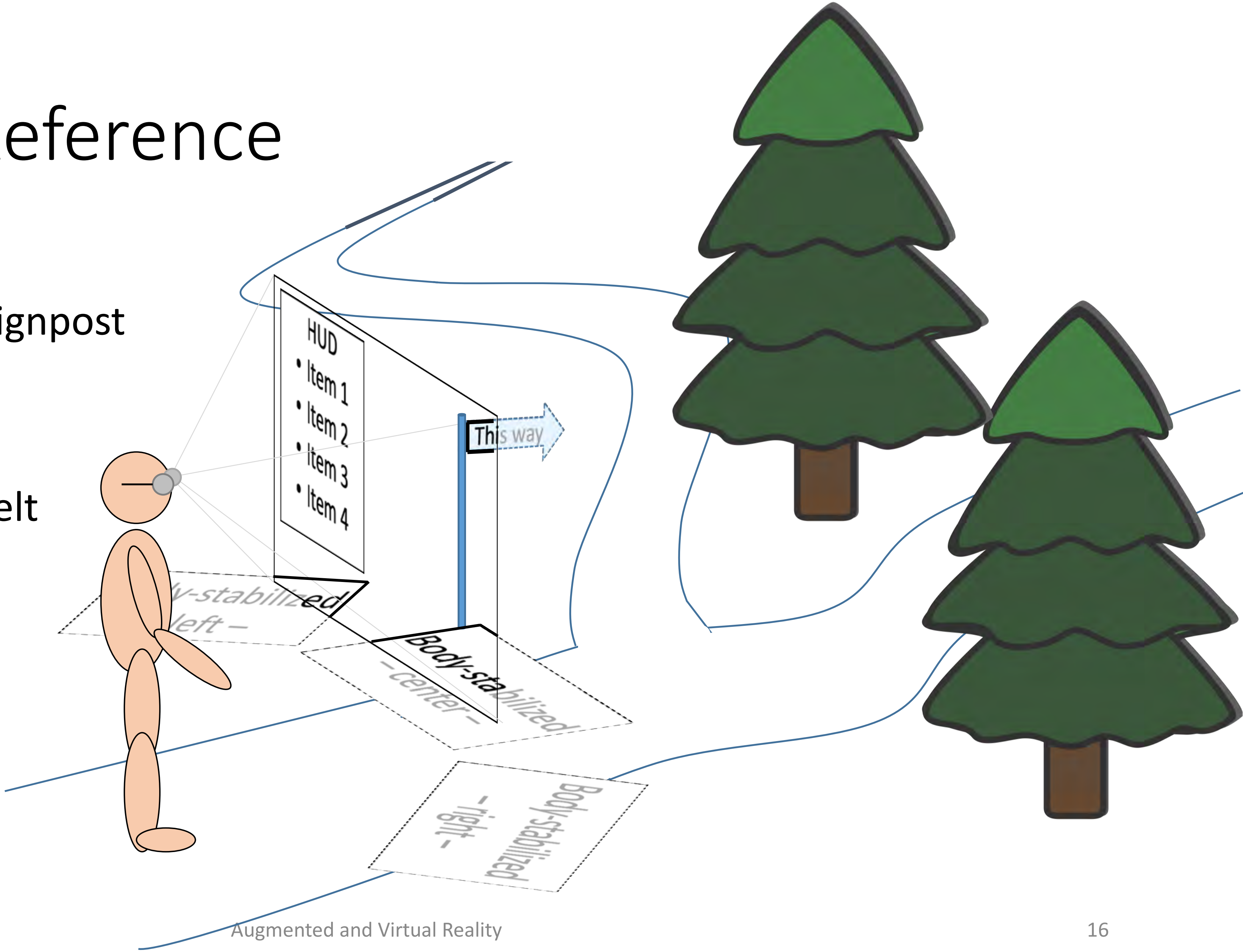


Coordinate Systems



Frames of Reference

- Word-stabilized
  - E.g., billboard or signpost
- Body-stabilized
  - E.g., virtual tool-belt
- Screen-stabilized
  - Heads-up display

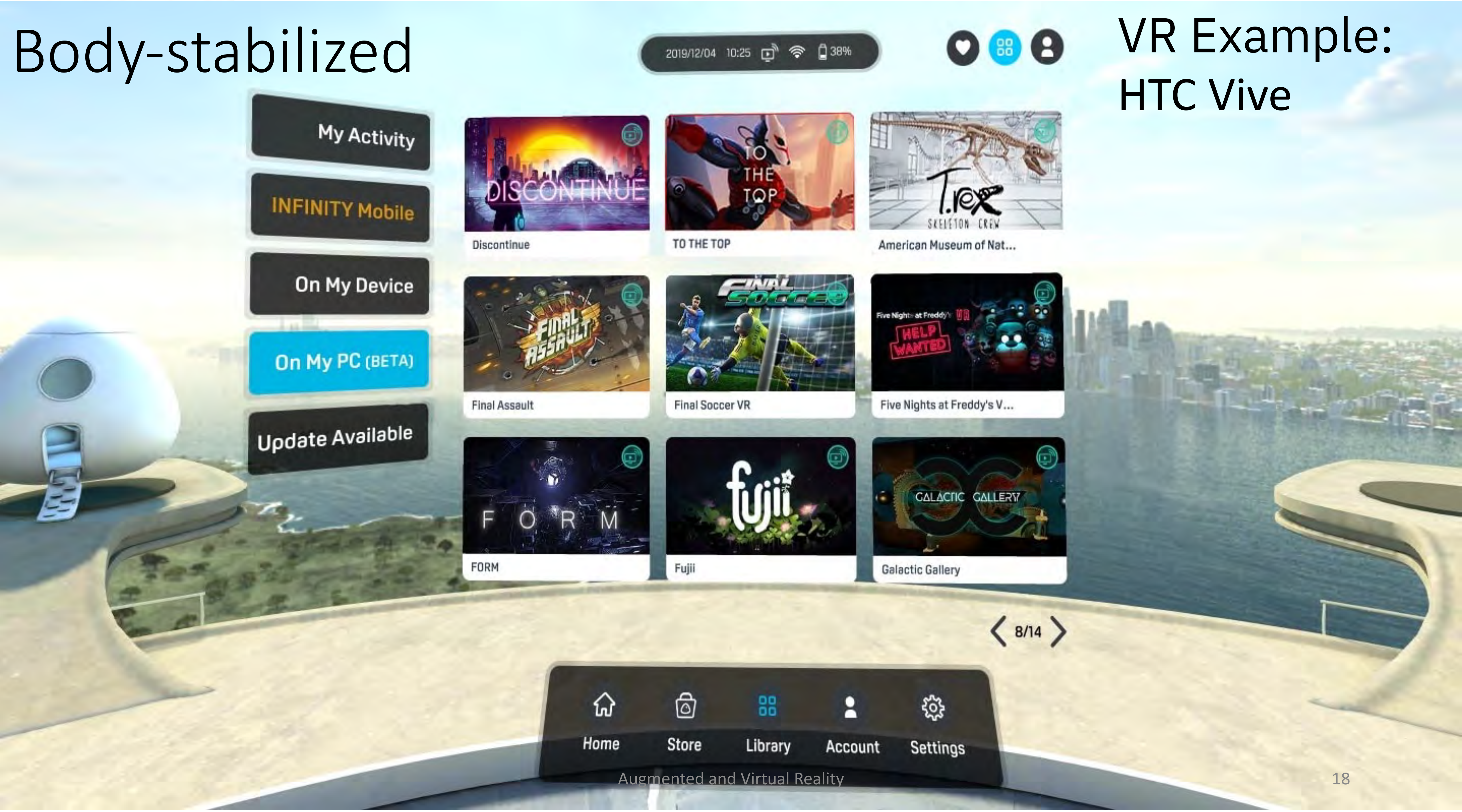


Body-stabilized

VR Example:
Oculus Home on
Oculus Quest

Body-stabilized

VR Example: HTC Vive



Measurement Coordinates

- Global vs. local measurements
  - Global → larger (or unlimited) workspace
  - Local → better accuracy
- Absolute vs. relative measurements
  - Absolute → coordinate system defined in advance
  - Relative → incremental sensing

Physical Phenomena

- Electromagnetic radiation
  - Visible light
  - Infrared light
  - Laser light
  - Radio signals
  - Magnetic flux
- Sound
- Physical linkage
- Gravity
- Inertia

Measurement Principle

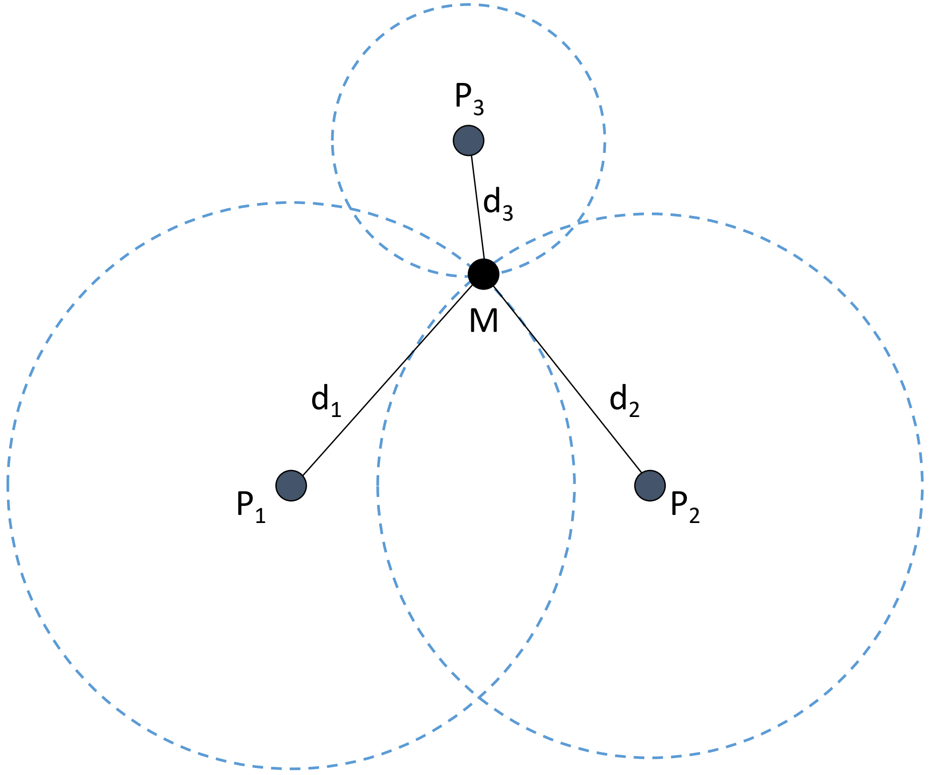
- Signal strength
- Signal direction
- Time of flight
  - Absolute time
  - Signal phase
  - Requires synchronized clocks

Degrees of Freedom (DOF)

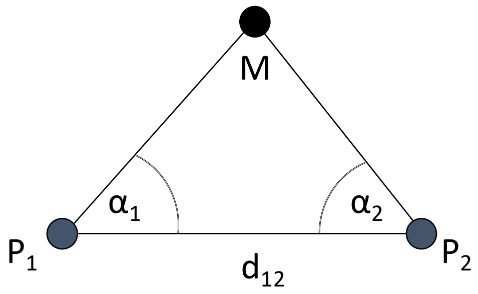
- DOF = independent dimension of measurement
- Full tracking requires 6DOF
  - 3DOF position (x, y, z)
  - 3DOF orientation (roll, pitch, yaw)
- Some sensor deliver only a subset
  - E.g., gyroscope → 3DOF orientation only
  - E.g., tracked LED → 3DOF position only
  - E.g., mouse → 2DOF position only

Measured Geometric Property

- Trilateration: 3 distances



- Triangulation: 2 angles, 1 distance



Sensor arrangement

- Multiple sensors in rigid geometric configuration
  - E.g., stereo camera rig
- Sparse or dense sensors
  - E.g., digital camera is dense 2D array of intensity sensor with know angles
- Advanced technical issues
  - Sensor synchronization
  - Sensor fusion

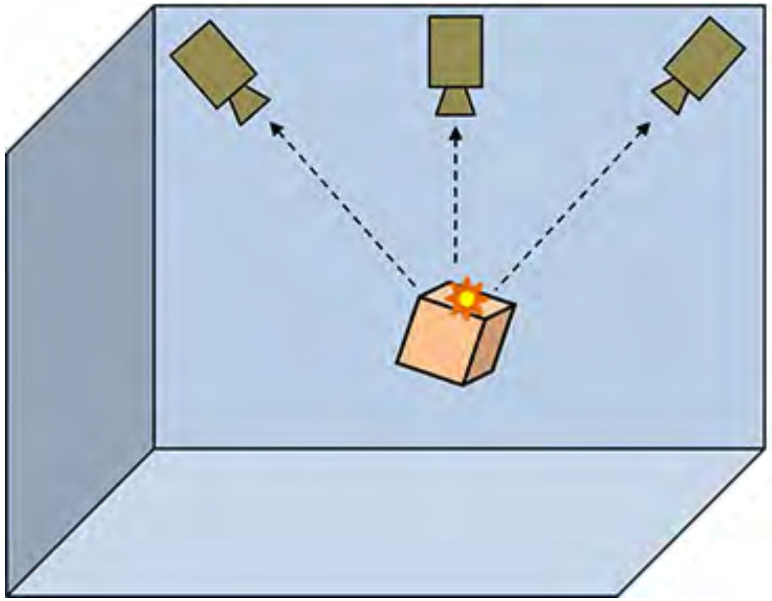
Sensor Group Arrangement

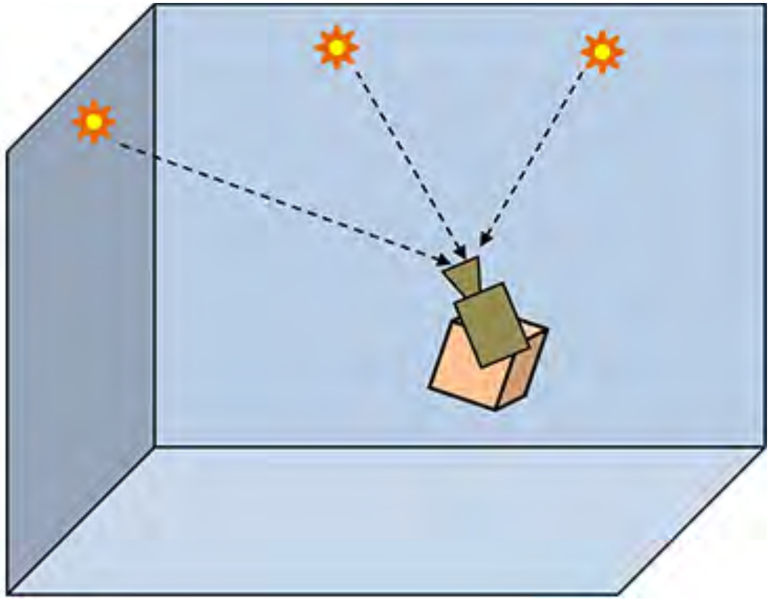
Outside-in

- Stationary mounted sensors
- Good position, poor orientation

Inside-out

- Mobile sensor(s)
- Good orientation, poor position





Oculus Insight technology

https://tech.fb.com/the-story-behind-oculus-insight-technology/

In Class Group Exercise

- Read the article

  How Oculus squeezed sophisticated tracking into pipsqueak hardware

  https://techcrunch.com/2019/08/22/how-oculus-squeezed-sophisticated-tracking-into-pipsqueak-hardware/

- Discuss and answer these questions
  1. What are the pros and cons of “outside-in” vs. “inside-out” tracking?
  2. What are the main factors help achieving Quest-like untethered HMD?
  3. What are the limitation of Quest?

READING REVIEW & CLARIFICATIONS

What are the pros and cons of “outside-in” vs. “inside-out” tracking?

How Oculus squeezed sophisticated tracking into pipsqueak hardware
https://techcrunch.com/2019/08/22/how-oculus-squeezed-sophisticated-tracking-into-pipsqueak-hardware/

The article Explanation:

- ✓ Sensors in the room, watching the devices and their embedded LEDs closely — looking from the outside in.
- ✓ Sensors on the headset itself, which watches for signals in the room — looking from the inside out.

Inside-out is better for wireless system, since no need to send signals between the headset and the computer doing the actual position tracking, which can add latency to the experience.

AR Textbook Explanation:

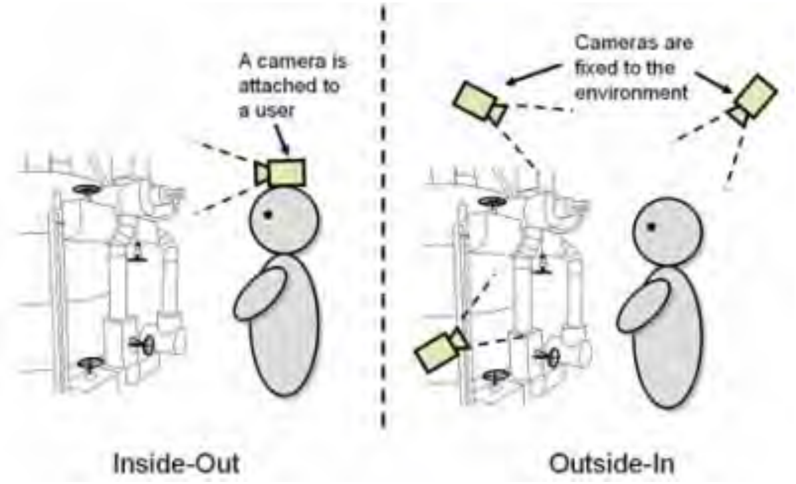
- ✓ Outside-in tracking means that sensors are mounted stationary in the environment and observe a moving target, such as a head-worn display.
- ✓ Inside-out tracking means that sensors move with the tracked object and observe stationary references in the environment.

ATTENTION! VR Textbook by by Jonathan Linowes (see Section “Headpose Tracking”) defined these terms reversed:

- ❖ Outside-in positional tracking: Two or more dumb laser emitters are placed in the room and an optical sensor on the headset reads the rays to determine your position (e.g. HTC VIVE)
- ❖ Inside-out positional tracking: An array of (invisible) infrared LEDs on the HMD are read by an external optical sensor (infrared camera) to determine your position. You need to remain within the view of the camera (e.g. Oculust Rift)

We will accept the AR Textbook/Article definition as the correct way to explain “outside-in” and “inside-out” tracking.

Inside-Out vs. Outside-in Tracking



In inside-out positional tracking, the camera or sensors are located on the device being tracked (e.g. HMD)

https://xinreality.com/wiki/Inside-out_tracking

Outside-in VR tracking uses cameras or other sensors placed in a stationary location and oriented towards the tracked object (e.g. a headset) that moves freely around a designated area defined by the intersecting visual ranges of the cameras

https://xinreality.com/wiki/Outside-in_tracking

Case Study: How does Hand Tracking work?

Oculus Quest 2 and Quest Hand Tracking

- Allows you to use your hands in place of your touch controllers.

How does hand tracking works?

- By using the inside-out cameras on Oculus Quest 2 and Quest.
- Your headset will detect the position and orientation of your hands and the configuration of your fingers.
- Once detected, computer vision algorithms are used to track the movement and orientation of your hands.

https://support.oculus.com/articles/headsets-and-accessories/controllers-and-hand-tracking/index-controllers-hand-tracking/

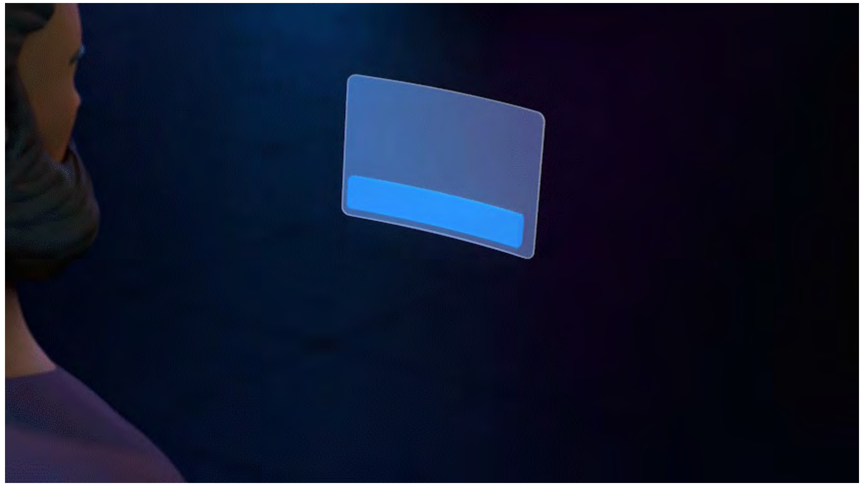
Hand Tracking for Oculus Quest 2 and Quest currently supports the following gestures:

Gestures	What it's used for	How to do it
Point and Pinch	To select something.	When the cursor appears, point your hand at what you want to select. Then, pinch your thumb and finger together to select.
Pinch and Scroll	Scrolling up, down, left, or right	Pinch your fingers inward. While still pinched inward, move your hand up, down, left or right to scroll. When you’re done scrolling, release.
Palm Pinch	Brings you back to your Oculus Home menu.	Look at your palm at eye level, then hold your thumb and index finger together until the Oculus icon fills up, then release.

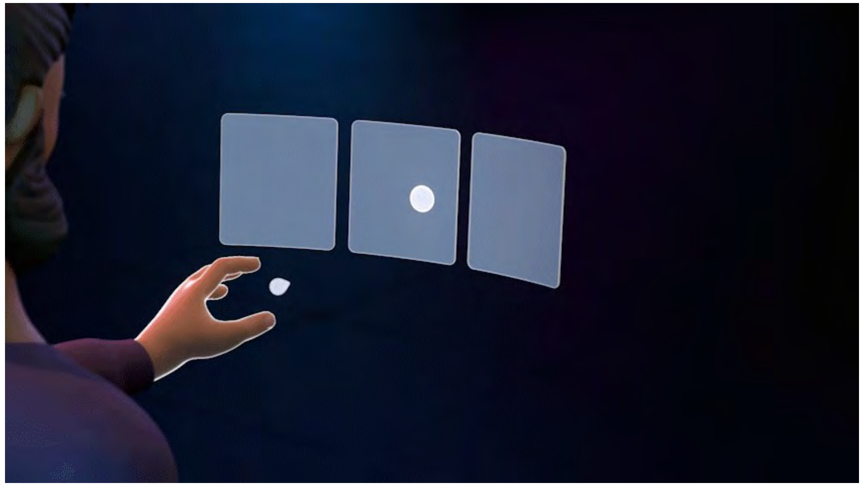
https://support.oculus.com/articles/headsets-and-accessories/controllers-and-hand-tracking/index-controllers-hand-tracking/

What gestures can I use with Hand Tracking?

Point and Pinch



Pinch and Scroll



Palm Pinch

Signal Sources

- Passive sources
  - Natural signals
  - E.g., natural light, earth magnetic field
- Active sources
  - Electronic components producing physical signal
  - Can be direct or indirect (reflected)
  - E.g., acoustic, optical, radiowaves
  - Most forms require open line of sight
- No sources
  - Most important example: inertia

Measurement error

- Accuracy
  - How close is measurement to true value
  - Affected by systematic errors
  - Can be improved with better calibration
- Precision
  - How closely do multiple measurements agree (random error, noise)
  - Varies per type of sensor
  - Varies per degree of freedom
  - Can be improved with filtering (more computation, more latency)
- Resolution
  - Minimum difference that can be discriminated between two measurements
  - Cannot be reached in practice because of noise

Temporal Characteristics

- Update rate:
  - Number of measurements per time interval
- Measurement latency
  - Time it takes from occurrence of physical event to data becoming available
- End-to-end latency
  - Time it takes from occurrence of physical event to presentation of a stimulus

Stationary Tracking Systems

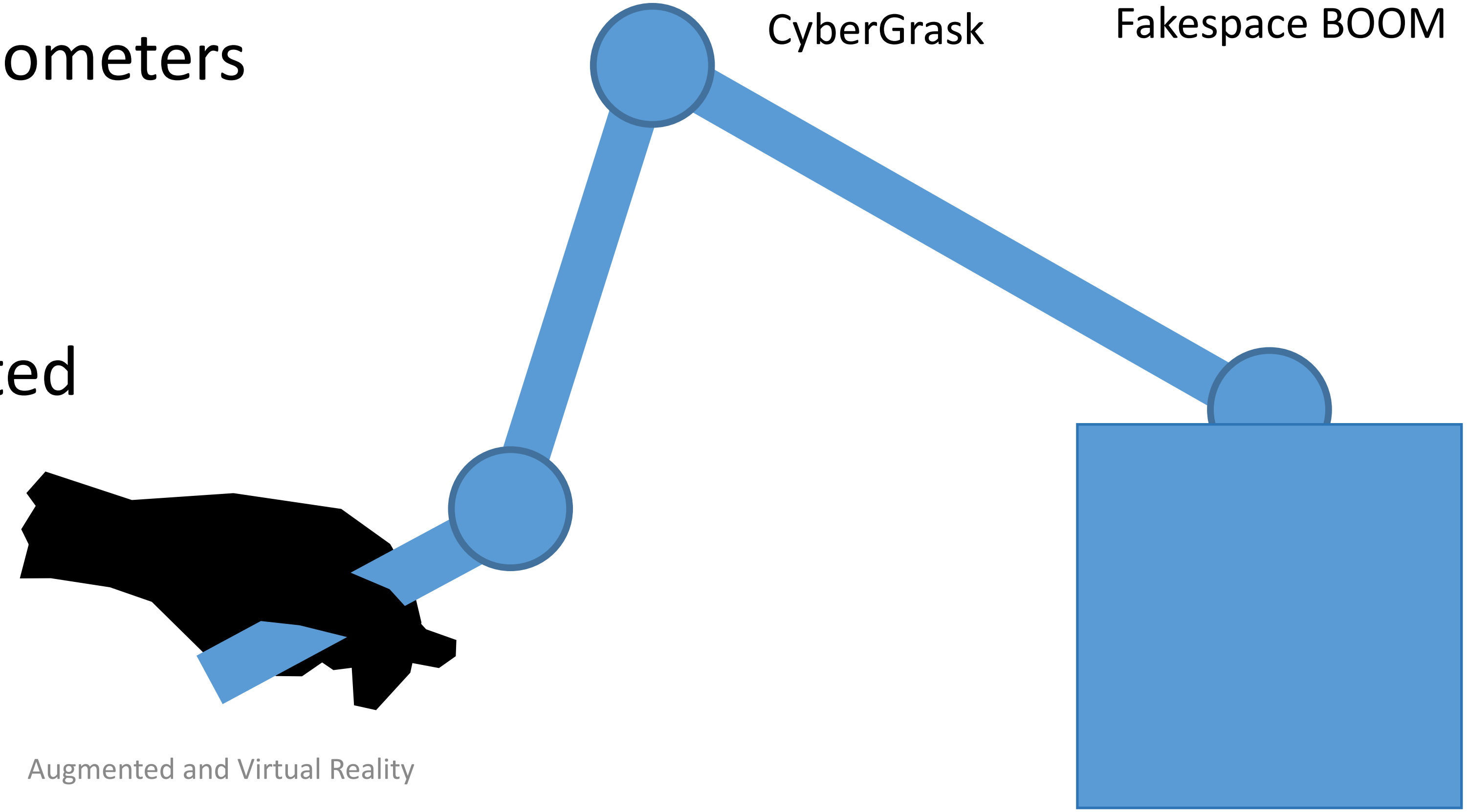
- Mechanical Tracking
- Electromagnetic Tracking
- Ultrasonic Tracking

Mechanical Tracking

- Track end-effector of articulated arm
- Joints with 2 or 3 DOF
- Rotary encoders or potentiometers
- High precision
- Fast
- Freedom of operation limited

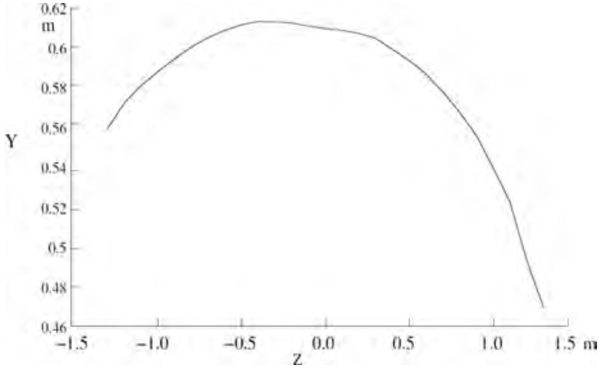
CyberGrask

Fakespace BOOM



Electromagnetic Tracking

- Stationary source produces three orthogonal magnetic fields
- Current induced in sensor coils
- Measurement of strength and phase of signal
- Signal strength falls off quadraticaly with distance
- Working range: half-sphere with 1-3m radius
- Problems with electromagnetic interference



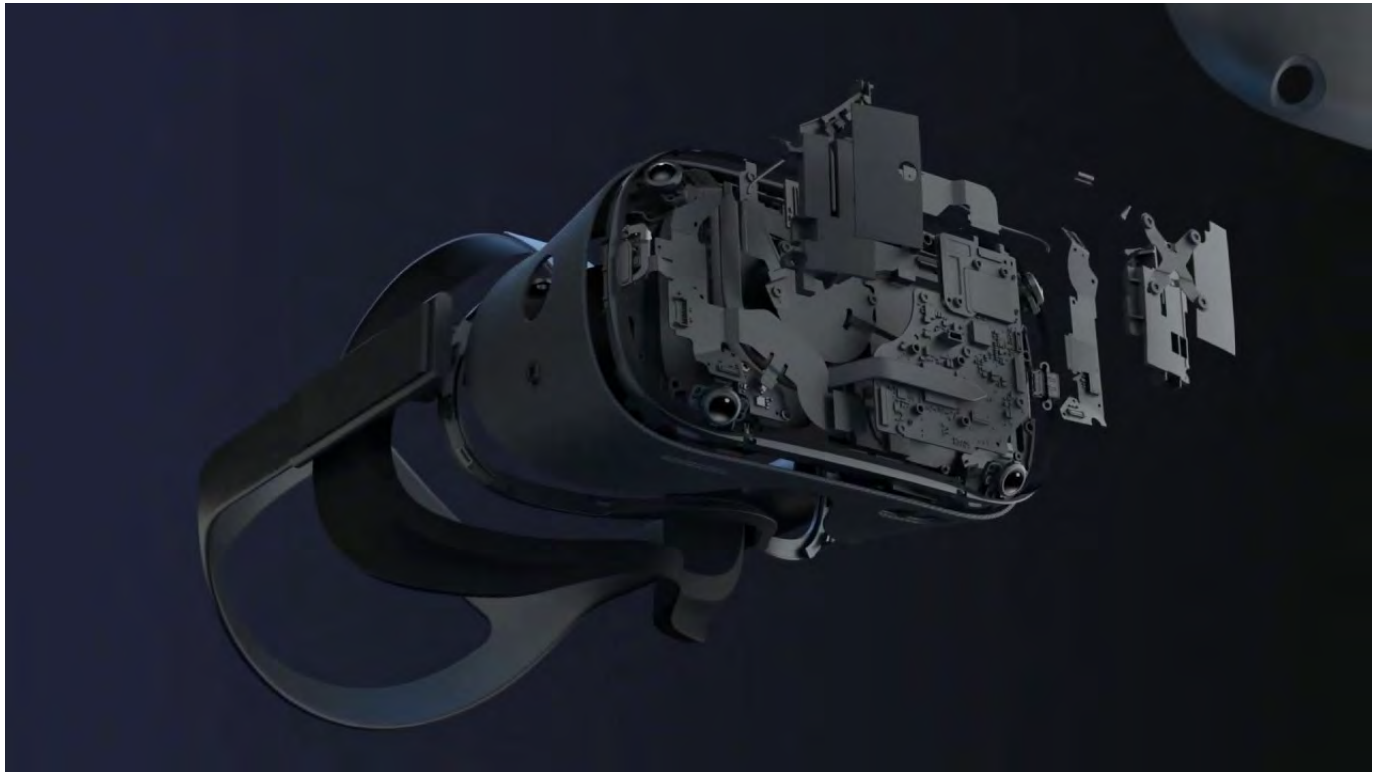
Razer Hydra

Ultrasonic Tracking

- Measures time of flight of sound pulse
- Trilateration of 3 measurements
  - Requires synchronized time (cables) or more than 3 measurements
- Low update rate (10-50Hz) due to slow speed of sound
  - Possible fusion with fast inertial sensors (e.g., InterSense IS-600)
- Requires open line of sight
- Suffers from noise or change of temperature
- Wide-area configuration, e.g., AT&T BAT system
  - Microphones mounted in ceiling

Image: Joseph Newman

Inside Oculus Quest Hardware: The Sensors Which Track Head And Hand Movement



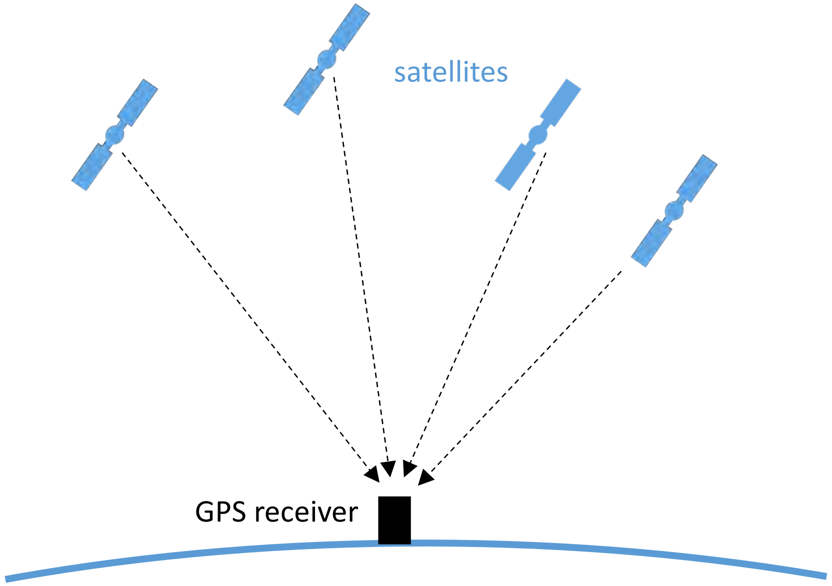
https://youtu.be/AZ7ufYef-dM

Mobile Sensors

- Global Positioning System
- Wireless Networks
- Magnetometer
- Gyroscope
- Linear Accelerometer
- Odometer

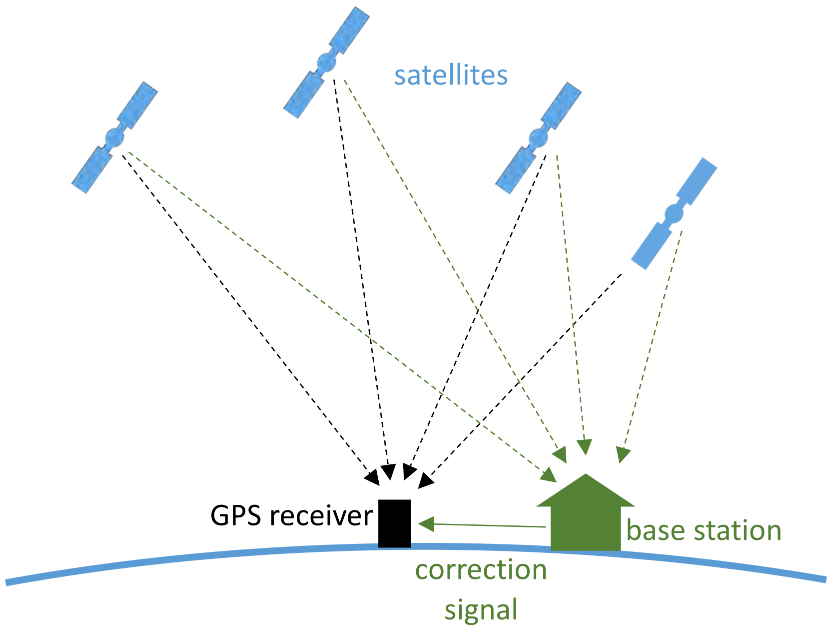
Global Positioning System

- Planet-scale outside-in radiowave time-of-flight
- Requires clock synchronization
- Must receive signals from at least 4 satellites



Differential GPS

- Compensate for atmospheric distortion
- Receive correction signal from base station via network
- Real-Time Kinematics (RTK) Differential GPS also uses signal phase

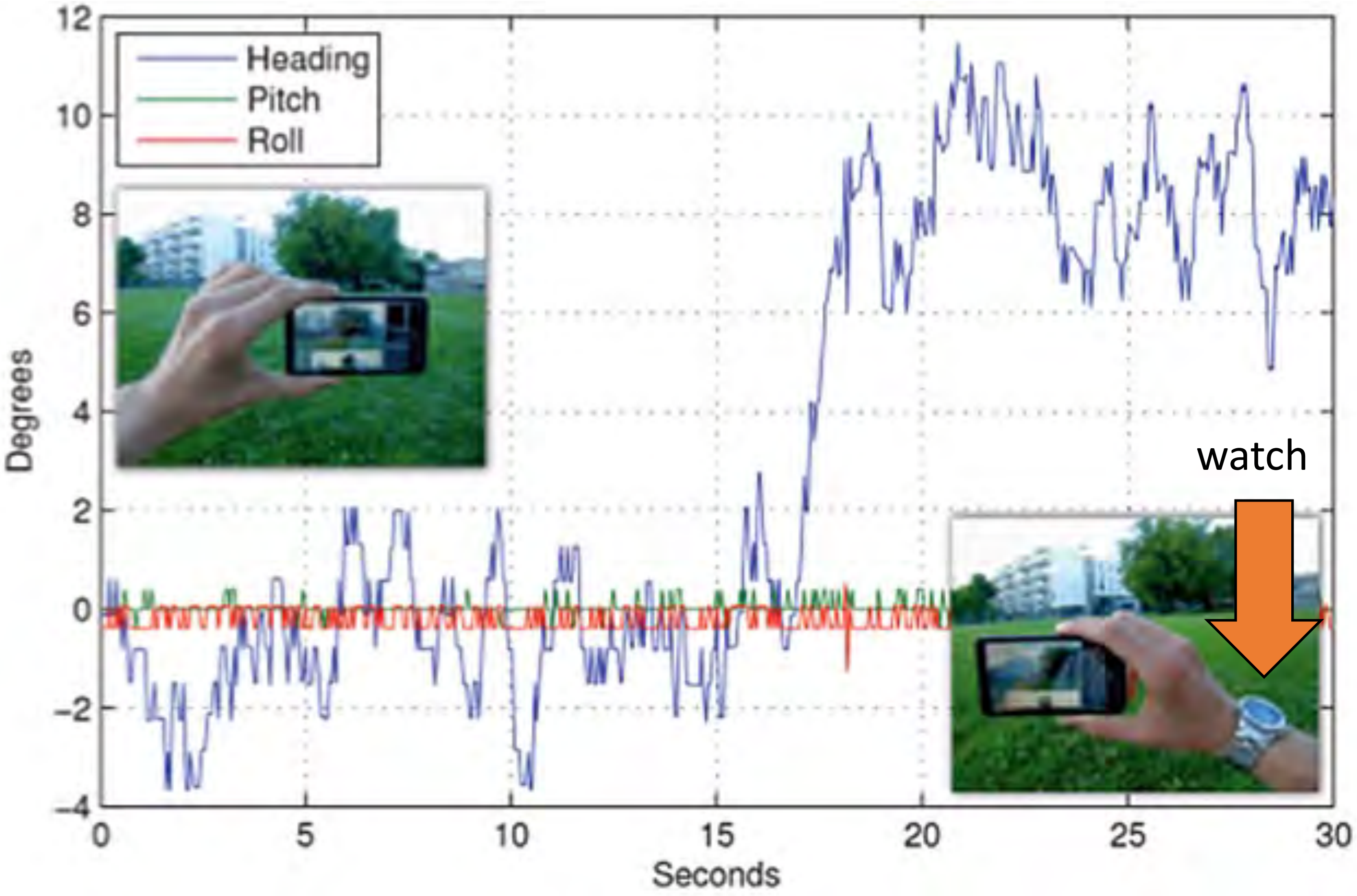


Wireless Networks

- Measure signal strength from WiFi, Bluetooth, mobile phone towers
- Potential trilateration/triangulation
- Mostly only good for coarse location (e.g., based on WiFi SSID)
- Fingerprinting: carefully map the signal reception in a given area
  - Recent use: Bluetooth iBeacon in department stores
- Assisted GPS: accelerate GPS initialization using WiFi or GSM id
  - Skyhood, Google, Broadcomm etc.

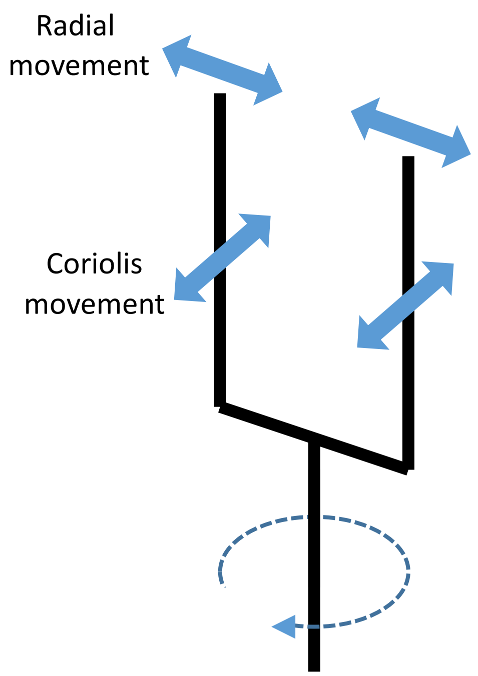
Magnetometer

- Electronic compass
- Measure direction of Earth magnetic field in 3D
- Principle: magnetoresistance (Hall effect)
- Often very distorted measurements

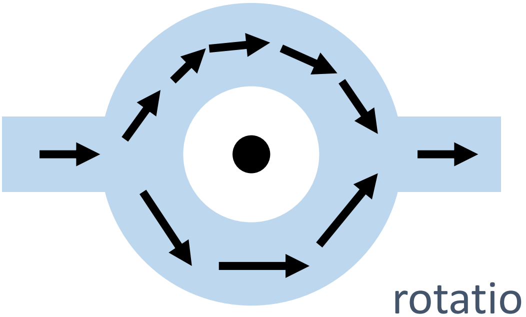


Gyroscopes

Image: Hideyuki Tamura

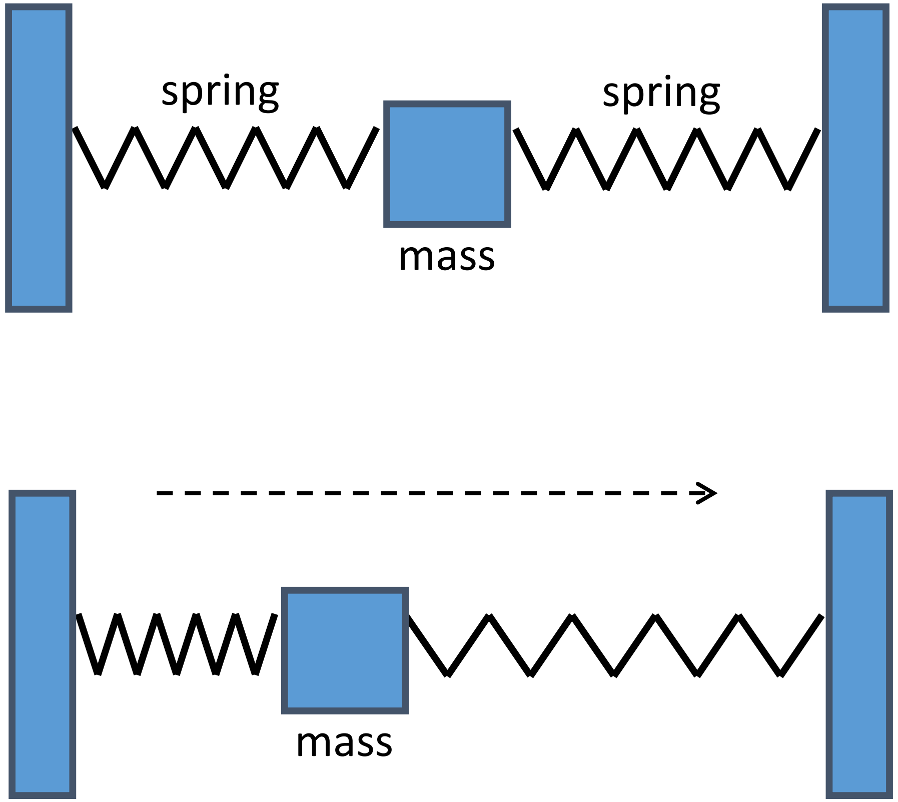


- Determines rotational velocity
- Electronic gyro
  - Measures Coriolis force of small vibrating object
  - Micro-electromechanical system (MEMS)
  - High update rate (1KHz)
  - Only relative measurements
  - Must integrate once to determine orientation → drift
- Laser gyro (fiber-optic gyro)
  - Measures angular acceleration based on light interference
  - Large, expensive, used in aviation



Linear accelerometer

- MEMS device
- Displacement of small mass
- Measures
  - Change of electric capacity, or
  - Piezoresistive effect of bending
- Subtract gravity (the difficult part!)
- Integrate twice numerically to get position
- Drift problems
- Combine lin.acc., gyro + compass into *inertial measurement unit* (IMU)



Odometer

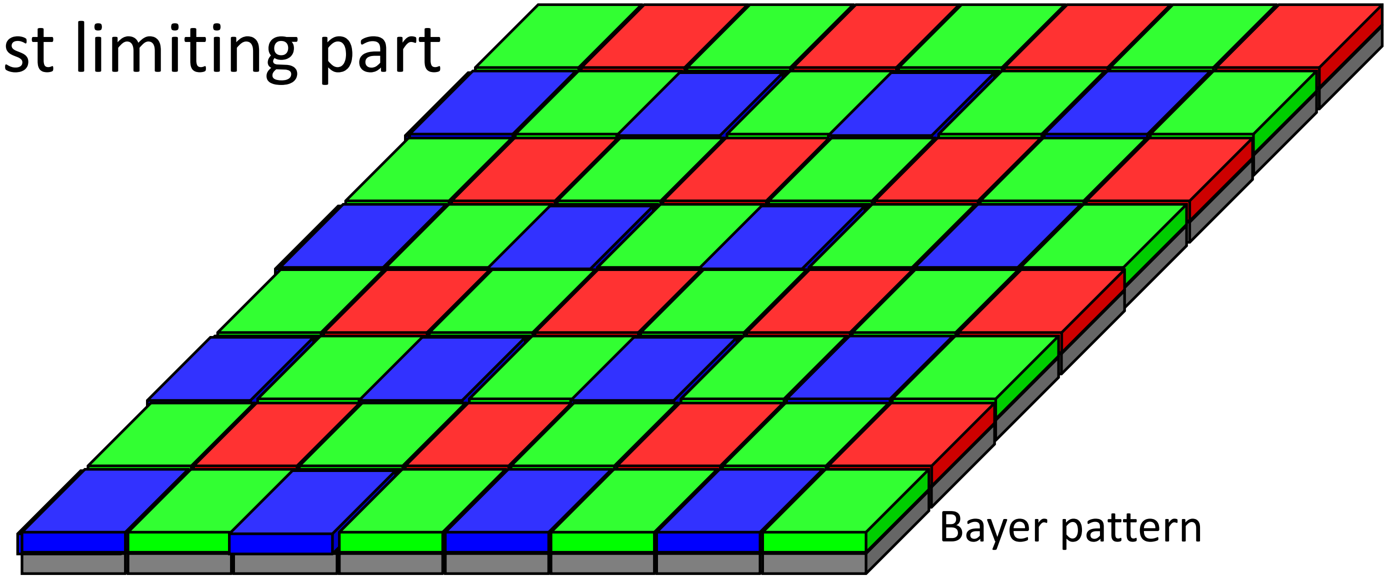
- Mechanical or opto-electrical wheel encoder
- E.g., traditional ball mouse

Optical Tracking

- Optical sensors
- Model-Based versus Model-Free Tracking
- Illumination
- Markers versus Natural Features
- Target Identification

Optical Sensors

- Digital cameras are cheap and powerful
  - CCD (charge coupled devices) – professional photography
  - CMOS (complementary metal oxide semiconductor) – fast and cheap
- Computer vision techniques improve with Moore's law
- Lenses are becoming the most limiting part



Bayer pattern

Model-Based versus Model-Free Tracking

Model-based

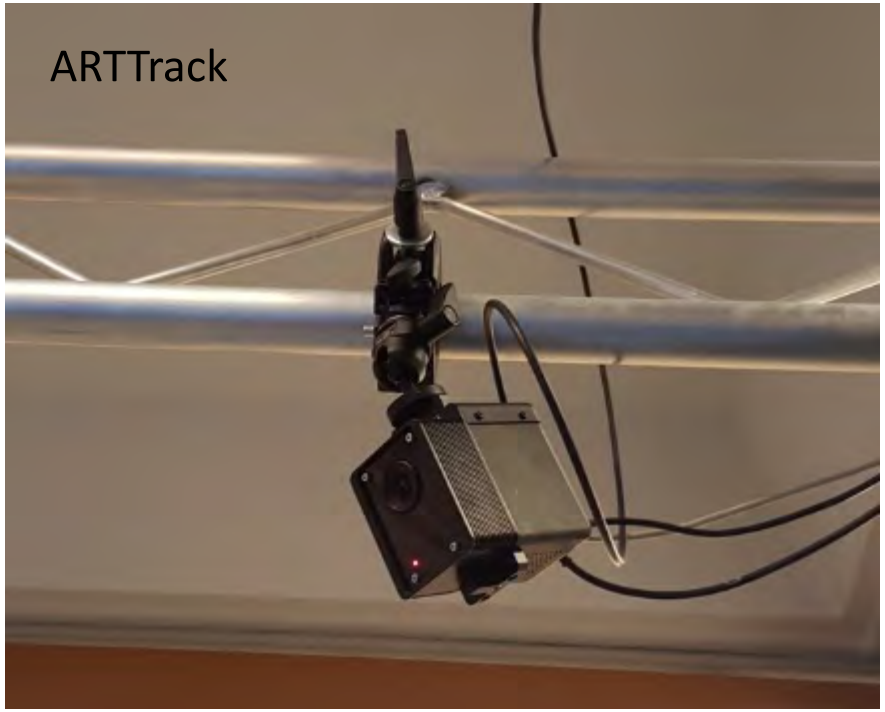
- A tracking model representing the 3D world is available
- Compare the model to observations in the images

Model-free

- At start-up, no tracking model is available
- Most build a temporary tracking model while tracking
- Measurements only relative to starting point

Illumination

- Passive illumination
  - Natural (or existing) light sources
  - Visible spectrum 380-780nm
  - Cannot track when it is too dark (mostly indoors)
- Active illumination
  - Often infrared spectrum
  - LED beacons
  - Camera with infrared filter delivers high contrast
  - Not suitable with sunlight
- Structured light
  - Project a known pattern into the scene
  - Projector with regular light or laser
  - Laser ranging
    - Measure time of flight taken by laser pulse
    - Steerable MEMS mirror for scanning laser
    - LIDAR (light radar): long range laser used in surveying



Leap Motion

- 2 cameras, 3 infrared LEDs
- Short-distance reflection of the hands

ultraleap

ultrahaptics LEAP MOTION

Leap Motion – Demo Video

Intro

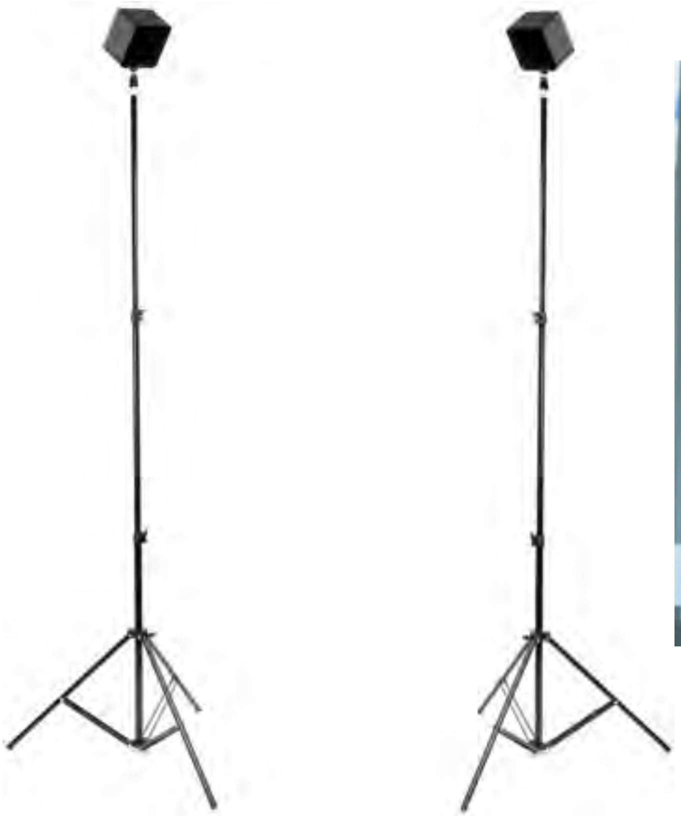
https://www.youtube.com/watch?v=_d6KuiuteIA

Orion

https://www.youtube.com/watch?v=rnlCGw-0R8g

Valve/HTC Vive

- “Lighthouses” = two scanning infrared lasers
- Photodiodes on head pick up lasers



How the Vive Lighthouse Works
https://youtu.be/oqPaaMR4kY4

Markers vs Natural Features

- Fiducials markers
  - Artificial tracking targets
  - Square shapes yield 4 points (enough for pose)
  - Circular shapes yield only 1 point
  - Digital marker model exists first,
    marker manufactured second (e.g., printing)
- Natural feature tracking
  - Existing visual features in the environment
  - Physical features exist first,
    tracking model reconstructed second

Image: Daniel Wagner

Image: Andrei State, UNC Chapel Hill

Flat Marker Designs

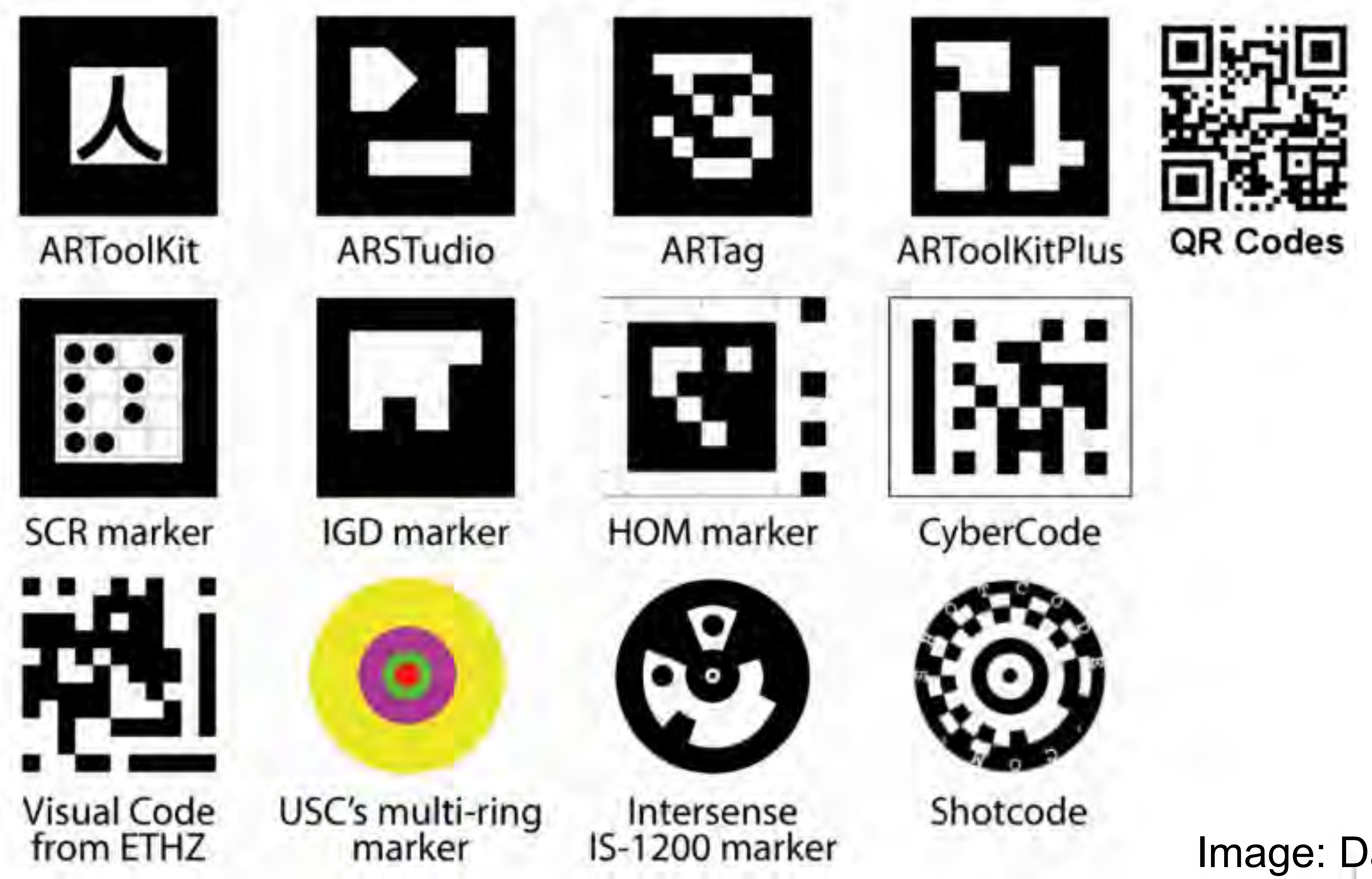


Image: Daniel Wagner

Retro-Reflective Ball Markers

- Light reflected towards light-source
- Illuminate with infrared LED flash
- Infrared camera observes bright blobs
- 4 or more spheres in known configuration to recover 6DOF pose
- Multiple targets distinguished by their geometric configuration

Advanced Realtime Tracking GmbH

Natural Features

- Detect salient interest points in image
  - Must be easily found
  - Location in image should remain stable when viewpoint changes
  - Requires textured surfaces
  - Alternative: can use edge features (less discriminative)
- Match interest points to tracking model database
  - Database filled with results of 3D reconstruction
  - Matching entire (sub-)images is too costly
  - Typically interest points are compiled into "descriptors"

Image: Martin Hirzer

Image: Gerhard Reitmayr

Marker Target Identification

- More targets or features → more easily confused
- Must be as unique as possible
- Square markers
  - 2D barcodes with error correction
  - E.g., 6x6=36 bits (2 orientation, 6-12 payload, rest for error correction)
  - Marker tapestries
- Spherical targets
  - 5 spheres in different geometric configurations
  - Can distinguish 10-20 targets
- Pulsed LEDs

Image: Mark Fiala

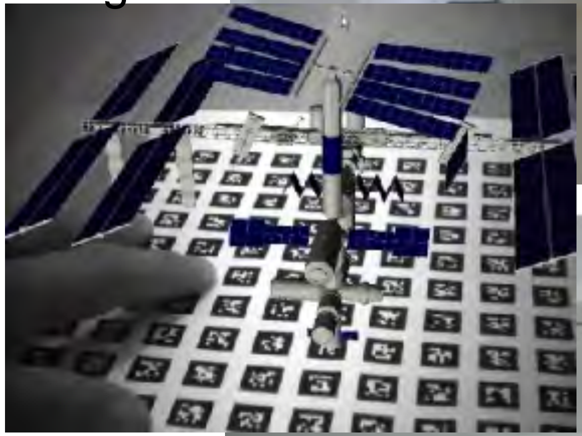


Image: Greg Welch, UNC Chapel Hill

Natural Feature Target Identification

- Individual natural interest points too easily confused
- Rely on co-occurency of interest points for detection
- Probabilistic search methods used to deal with errors
  - Vocabulary trees
  - Random sampling consensus

Image: Martin Hirzer

Complementary Sensor Fusion

- Combining sensors with different degrees of freedom
- Sensors must be synchronized (or requires inter-/extrapolation)
- E.g., combine position-only and orientation-only sensor
- E.g., orthogonal 1D sensors in gyro or magnetometer are complementary

Competitive Sensor Fusion

- Different sensor types measure the same degree of freedom
- Redundant sensor fusion
  - Use worse sensor only if better sensor is unavailable
  - E.g., GPS + pedometer
- Statistical sensor fusion (see next slide)

Statistical Sensor Fusion

- Important form of competitive fusion for higher quality
- Combine measurement to improve quality
- Establish statistical estimate of the true system state
- Predict future system state ←→ Correct from observation (measurement)
- Extended Kalman filter for Gaussian error distribution
- Unscented Kalman filter for highly non-linear systems
- Particle filter for systems with multiple state hypothesis
- E.g., maintain estimate with fast IMU + update when slow computer vision results come in

Cooperative Sensor Fusion

- Primary sensor relies on information from secondary sensor to obtain its measurements
  - E.g., A-GPS combines celltower + GPS
- Combination of inside-out + outside-in
- Stereo cameras with known epipolar geometry
- Non-overlapping cameras (e.g., 360°)
- Indirect sensing (cont’d)

PointGrey LadyBug

Image: Georg Klein

Cooperative Sensor Fusion for Indirect Sensing

"Track around the corner"