Advanced Topics in Virtual Reality

Tracking Devices

Anton L. Fuhrmann
2019

Tracking

VR needs tracking for

- user (head, eyes, body)
- input devices (bat, wand, glove, PIP, …)
- environment (occlusion, interaction, ambient intelligence, …)

to deliver

- position & orientation data (6DoF)
- object identification
- geometric information

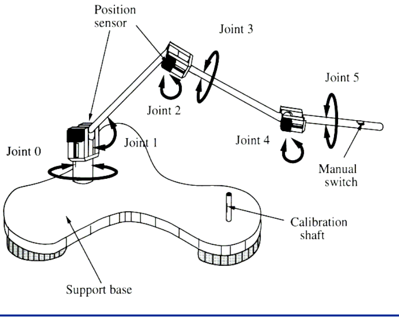
Tracking Methods

- mechanical
- magnetical
- optical
- inertial
- ultra-sound
- radio

Mechanical Tracking

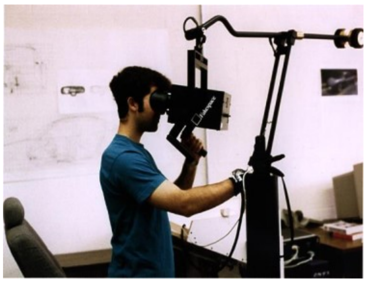
Mechanical mount for input device, output device, users head, etc ...

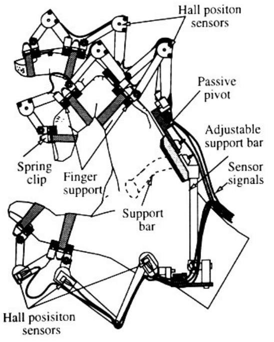
delivers information using angle and/or translation sensors (e.g. on optical basis)



angular sensors:

Mechanical Tracking Examples





Fakespace boom   Dextrous Master glove

Mechanical Tracking Examples

phantom tracking & haptic feedback device

Mechanical Tracking

Advantages

- fast (300 – 1000 samples/s)
- short lag (<5ms)
- precise (depending on set-up)

Disadvantages

- tethered (→restriction of movement)
- expensive

Shape Tracking

Principle:

- flexible tape with curvature sensors
- can be used like mechanical tracker

Shape Tracking

Full body motion capture:

Shape Tracking

Advantages

- wireless
- rugged
- delivers skeletal data

Disadvantages

- mediocre precision
- relative measurements only

Magnetical Tracking

Uses magnetic fields produced by

- geomagnetic field:
  inexpensive orientation sensor,
  used in gaming HMDs, cellphones

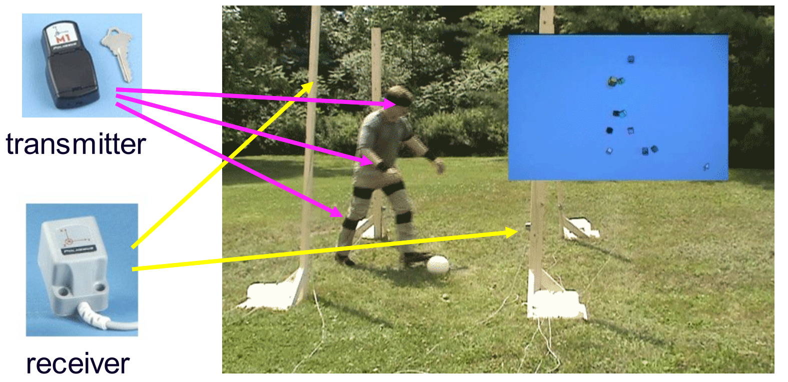
  2DoF (rotational)
- special transmitter:
  creates three orthogonal fields
  6DoF (t & r)

Magnetical Tracking: Polhemus

Uses AC magnetic fields, sensitive to ferromagnetic material.

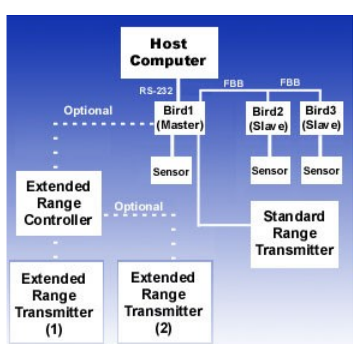
Polhemus LIBERTY™ LATUS™

Wireless version: wireless transmitters; wired receivers:



Magnetical Tracking: Ascension

Uses „DC“ magnetic fields, not sensitive to ferromagnetics

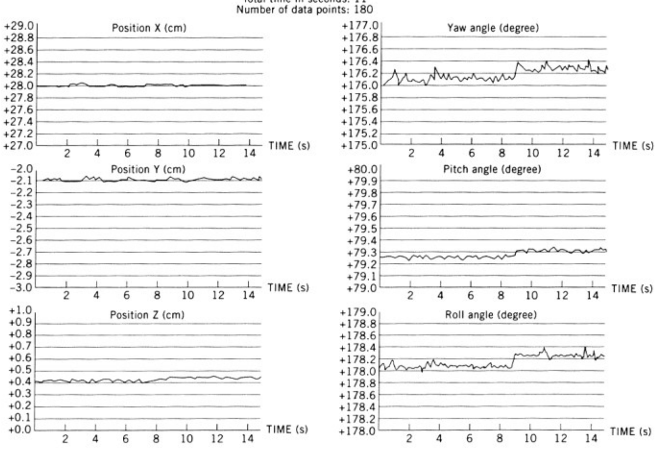


Magnetical Tracking Comparison

SPECIFICATION	FASTRACK	FLOCK OF BIRDS
Operation radius	30" (120" with red. acc.)	36" (96" optional)
Angular range	all-attitudes	±180° Azimuth&Roll ±90° Elevation
Transl. accuracy	0.03" RMS	0.1" RMS
Transl. resolution	0.0002"/inch range	0.03" RMS
Angular accuracy	0.15° RMS	0.5° RMS
Angular resolution	0.025° RMS	0.1° RMS at 12"
Update rate (measurements/sec)	120	144
Outputs	Cartesian coord. & orient. angle (selectable direction cosines and quaternions; English/metric units)	Cartesian coord. & orient. angle (selectable rotation matrix)
Interface	RS-232 (selec. baud rates to 115,200 or IEEE-488 up tp 100 kbaud/sec)	RS-232 (selec. baud rates to 115,200) or RS-422/485 (selec. baud rate to 310,000)
Data format	ASCII of Binary	Binary
Modes	Point or stream	Point or stream

Magnetical Tracking Noise

Polhemus



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Advanced Topics in VR

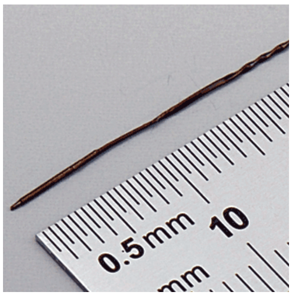
Magnetical Tracking: Aurora (NDI)

Used mainly for medical applications, high precision, small working volume (50cm radius), extremely small probes

System Control Unit (SCU)

transmitters
(different versions)

Aurora 5DOF Sensor,
0.5 mm x 8 mm



Magnetical Tracking: Aurora (NDI)

Electromagnetic spatial measurement systems determine the location of objects that are embedded with sensor coils. When the object is placed inside controlled, varying magnetic fields, voltages are induced in the sensor coils.

These induced voltages are used by the measurement system to calculate the position and orientation of the object. As the magnetic fields are of a low field strength and can safely pass through human tissue, location measurement of an object is possible without the line-of-sight constraints of an optical spatial measurement system.

www.ndigital.com

Magnetical Tracking: Aurora (NDI)

Aurora Accuracy Performance - Planar Field Generator

The following metrics apply to the Aurora V2 System released in April 2011. The Aurora V2 System achieves 20% higher accuracy performance than previous Aurora Systems.

	Cube Volume		Dome Volume	
	RMS	95% CI	RMS	95% CI
	Accuracy - 5DOF Sensors*			
Position	0.70 mm	1.40 mm	1.10 mm	2.00 mm
Orientation	0.20°	0.35°	0.20°	0.40°
	Accuracy - 6DOF Sensors*			
Position	0.48 mm	0.88 mm	0.70 mm	1.40 mm
Orientation	0.30°	0.48°	0.30°	0.55°

*All data collected with the Aurora V2 System in an environment free of electromagnetic disturbances.
Accuracy depends on tool design and the presence of metal. Note: Results based on more than 300 random positions and orientations distributed throughout the characterized volume.

www.ndigital.com

Magnetical Tracking: conclusion

Advantages

- inexpensive (starting at 2.000€)
- no occlusion problems

Disadvantages

- (tethered → restriction of movement)
- sensitive to magnetic distortion
- noisy
- limited range (1-3m)

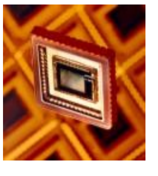
Optical Tracking

Using a variety of methods:

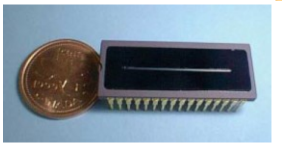
- active or passive markers
- marker-less
- inside-out
- outside-in

Optical Tracking

Using a variety of sensors:



- 2D: cameras (CCD array)



- 1D: CCD lines
- 0D: photo-diodes

- “2D”: lateral-effect photodiodes

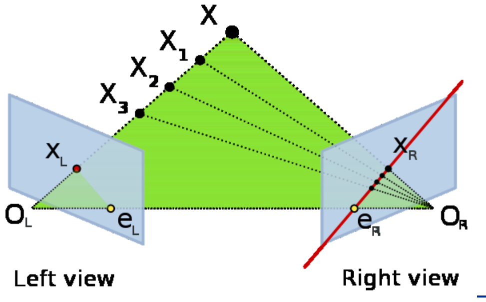
Epipolar Geometry

Epipolar geometry is the geometry of **stereo vision**.

When two cameras view a 3D scene from two distinct positions, there are a number of geometric relations between the 3D points and their projections onto the 2D images that lead to constraints between the image points.

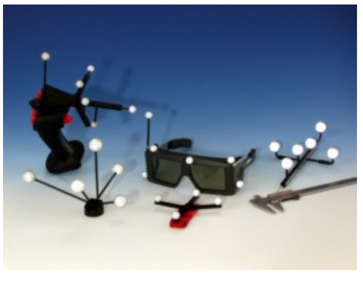
These relations are derived based on the assumption that the cameras can be approximated by the **pinhole camera model**.

http://en.wikipedia.org/wiki/Epipolar_geometry



Passive Markers, Multiple Cameras (A.R.T.)

camera contains IR-flash and image-processor



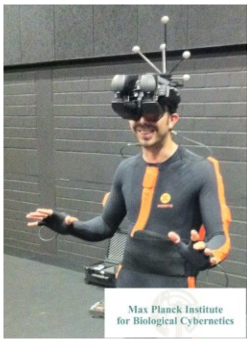
targets use retro-reflecting markers in geometric constellations

http://www.ar-tracking.de/

http://www.iotracker.com/

Passive Markers, Multiple Cameras (OptiTrack)

camera contains IR-flash and image-processor

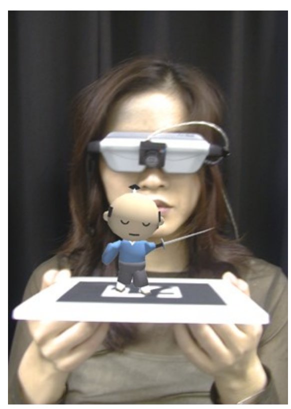


targets use retro-reflecting markers in geometric constellations

http://www.naturalpoint.com/optitrack

Passive Markers, Single Camera (AR-Toolkit)

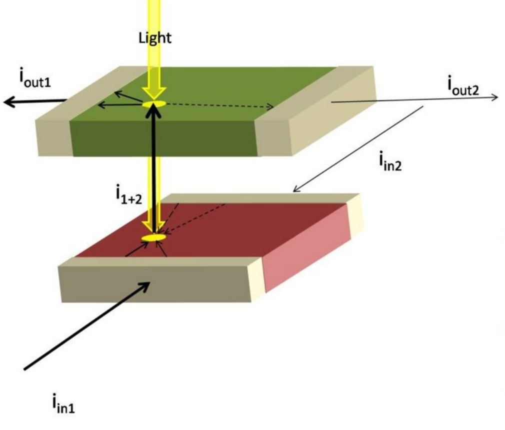
single camera tracks b/w marker images inside/out



Active Markers, LAPD (HiBall)

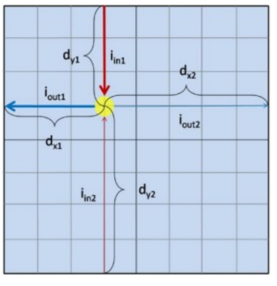
- active markers (IR-LEDs) stationary on ceiling
- 6 lateral-effect photodiodes move

Duo Lateral-Effect Photodiode



$$X = \frac{i_{out2} - i_{out1}}{i_{out2} + i_{out1}}$$

$$Y = \frac{i_{in2} - i_{in1}}{i_{in2} + i_{in1}}$$



http://hades.mech.northwestern.edu/index.php/Lateral-Effect_Photodiode

Active Markers, 1D sensors (CODA)

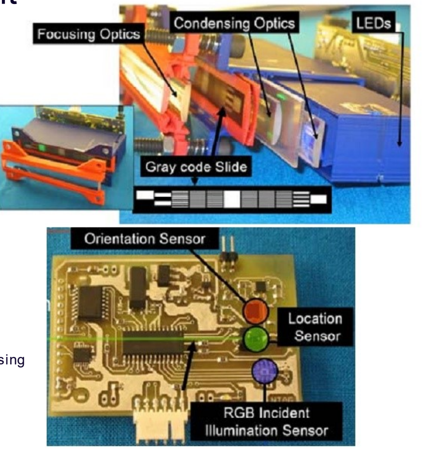
- IR-LED targets
- three linear CCDs

Active Markers, „0D“ sensors (ReActor)

- IR-LED targets on suit
- 544 photodiodes on frame
- uses light distribution over frame

MIT „Second Skin"

- IR-sensors targets on suit
- Simple „slide-projectors" in environment project time multiplexed angle information
- Additionally measures illumination & orientation

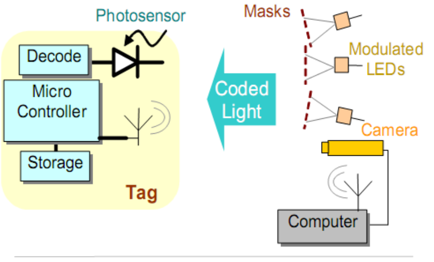


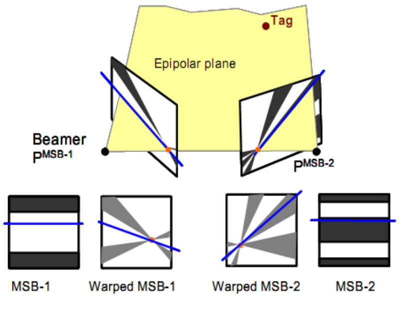
Prakash et.al.: "Lighting-Aware Motion Capture Using Photosensing Markers and Multiplexed Illumination"; SIGGRAPH 2007
http://web.media.mit.edu/~raskar/LumiNetra/

MIT „Second Skin"

Projectors produce binary-coded „fan", which allow a sensor to determine one angle around proj.-center

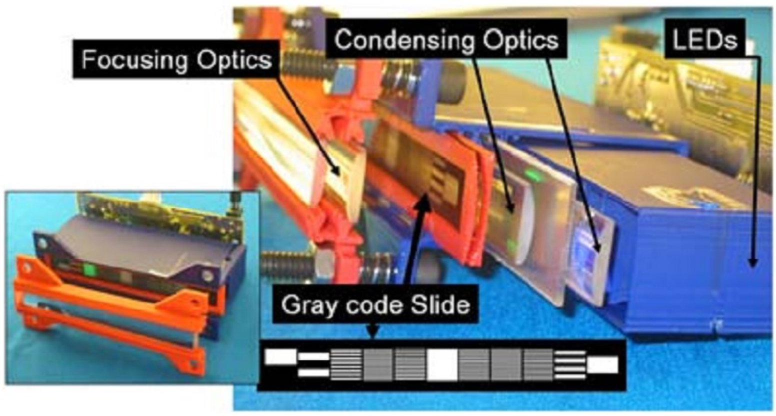
→ 3 projectors determine position unambiguously





MIT „Second Skin“

Projectors produce time-multiplexed, gray-coded „fan” by projecting different LEDs through a static slide:



MIT „Second Skin“

Advantages

- Inexpensive projectors & sensors
- Perfect identification of sensors
- HF modulated IR light → insensitive to sun etc.
- Coarse orientation from directionality of sensor

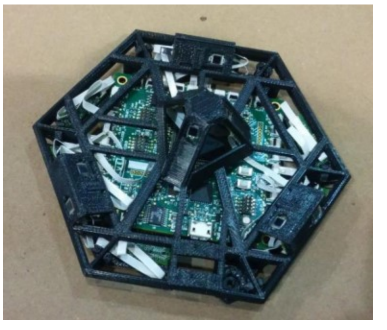
Disadvantages

- Time-multiplex → limited # of projectors
- Small working volume (at the moment)

"Lighthouse" Tracking

Developed by Valve

similar to “2nd skin”, uses sweeping laser lines to determine angles to photodiode constellation:



http://www.hizook.com/blog/2015/05/17/valves-lighthouse-tracking-system-may-be-big-news-robotics

"Lighthouse" Tracking

One global sync pulse, followed by two angle-dependent pulses:

https://i.kinja-img.com/gawker-media/image/upload/s--wsP3xmPN--/1259287828241194666.gif

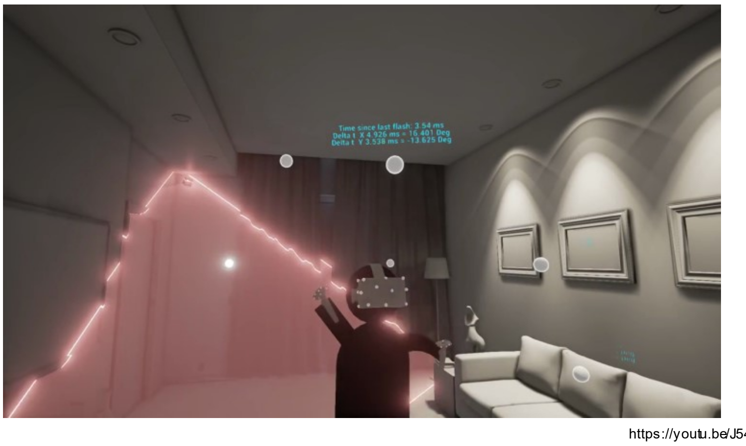
"Lighthouse" Tracking

One global sync pulse:

https://youtu.be/J54dotTt7k0

"Lighthouse" Tracking

followed by a vertical sweep:



https://youtu.be/J54dotTt7k0

"Lighthouse" Tracking

and by a horizontal sweep:

https://youtu.be/J54dotTt7k0

"Lighthouse" Tracking Video

https://youtu.be/J54dotTt7k0

"Lighthouse" Tracking

Simple time measurement give angles:

http://www.hizook.com/blog/2015/05/17/valves-lighthouse-tracking-system-may-be-big-news-robotics

Optical Tracking: conclusion

Advantages

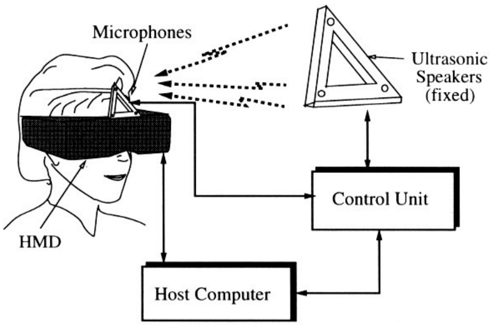
- precise
- wireless

Disadvantages

- occlusion
- environment lighting sensitive (outdoor!)
- Precise and large range systems still expensive

Ultrasound Tracking

Measures time of flight or phase difference



Ultrasound Tracking

Logitech

Specifications:

- 6 degrees of freedom
- 250 dpi resolution/ 3D mode
- 400 dpi resolution/ 2D mode
- Update Rate: 50 reports/sec
- Tracking Speed: 30 inches/sec
- Tracking Space: 5 ft. long, 100 degree cone
- Host Interface: RS-232 serial, 9 or 25 pin connector
  Power Supply: external 115VAC (230VAC available)

Ultrasound Tracking

Advantages

- inexpensive
- works underwater

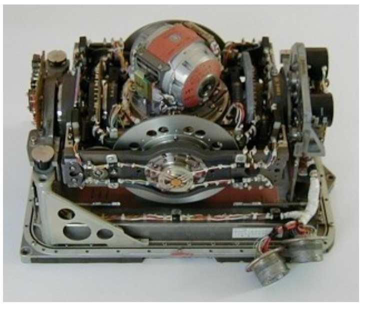
Disadvantages

- Measures only distances, needs multiple beacons for 6DoF
- sensitive to air pressure & humidity
- imprecise

Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform



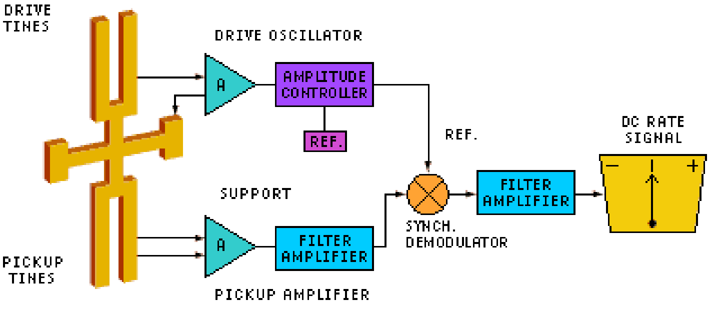
Inertial Tracking

measures linear & angular accelerations and integrates position & orientations:

(Old) inertial navigation platform

Inertial Tracking

micro-mechanical „tuning fork“:



Inertial Tracking: Xsens

commercial inertial tracking

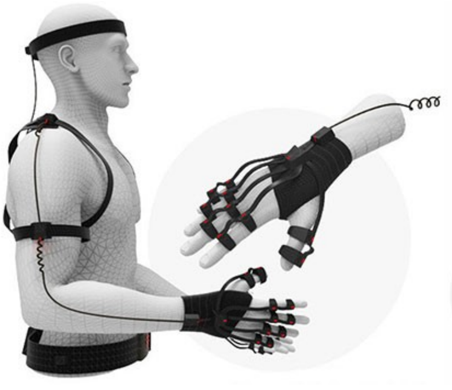
Inertial Tracking: Intersense

commercial inertial tracking

„Inertiacube“
uses ultrasound
for absolute
measurement

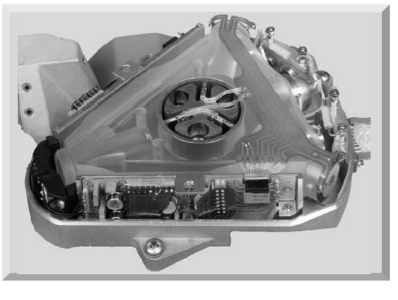
Inertial Tracking: Perception Neuron

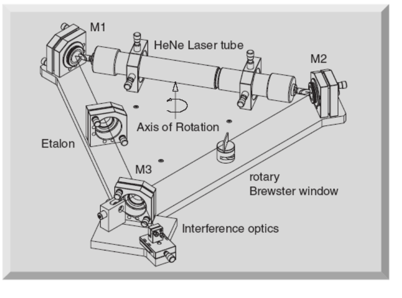
commercial inertial full-body tracking



Inertial Tracking

laser gyro:





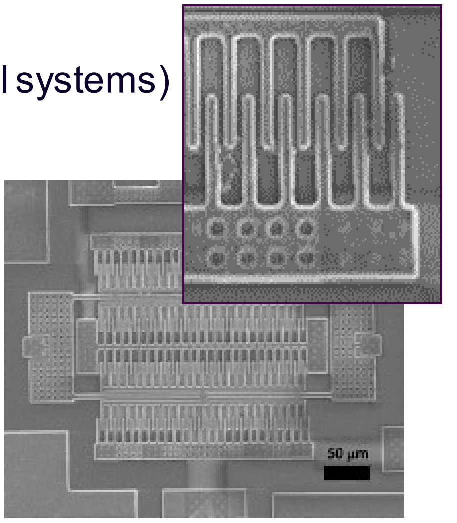
Inertial Tracking

MEMS
(Microelectromechanical systems)

deliver linear & angular acceleration in compact packages:

phones

game controller



Inertial Tracking: conclusion

Advantages

- source-less
- no occlusion
- delivers accelerations! (→prediction)

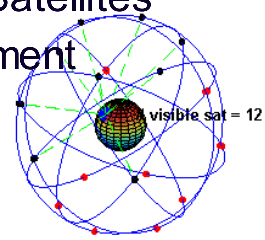
Disadvantages

- drift
- relative measurements only

Global Positioning System - GPS

A **space-based satellite navigation** system that provides location and time information, anywhere on or near the Earth where there is an unobstructed line of sight to at least four Satellites

Maintained by the US government



Alternative systems:

GLONASS (Russia)

Planned for 2014: Galileo (EU)

…

Global Positioning System - GPS

Principle:

Satellites deliver extremely precise synchronized time

Receiver measures the time differences between different satellites' signals:

$$L_1 = c(t - t_1) = \sqrt[2]{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2}$$

$$L_2 = c(t - t_2) = \sqrt[2]{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2}$$

$$L_3 = c(t - t_3) = \sqrt[2]{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2}$$

$$L_4 = c(t - t_4) = \sqrt[2]{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2}$$

Solution (x, y, z, t) of the receiver

minimal 4 equations for 4 variables → more satellites higher precision

Global Positioning System - GPS

Advantages:

Works globally

Precise timing information for synchronization purposes (~100ns)

Inexpensive & small receivers

Relative precise: <10m
(enhanced by carrier phase and differential measurement: <10cm)

Advantages:

Works only within line-of-sight of sky

Prone to errors when reflections occur (multipath signals)

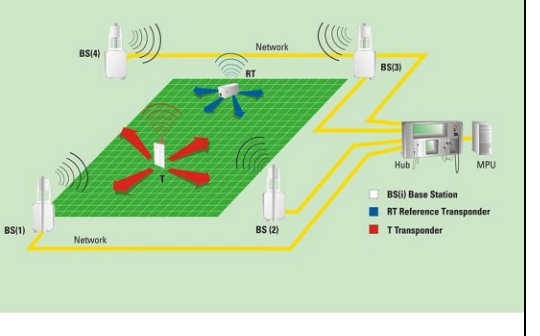
Radio Tracking

Principle:

“Das Echtzeit-Netzwerk ist mit mehreren Basis-Stationen (Mess-Stationen) verbunden. Jedes zu messende Objekt wird über einen Transponder individuell angesprochen und antwortet mit einem bestimmten Signal.

Die Basis-Stationen empfangen die Signale des Transponders und des Referenztransponders und detektieren deren Ankunftszeiten. Die Daten werden dann in Echtzeit über das Netzwerk an den Zentralrechner weitergeleitet, der daraus die aktuellen 3D-Positionsdaten errechnet.

Die 3D-Positionsdaten in x, y, z und der Geschwindigkeitsvektor werden vollautomatisch der Anwendungssoftware übergeben und dargestellt. Zusätzlich können über einen eigenen Telemetriekanal Daten wie z.B. Herzfrequenz, Temperatur usw. mitgesendet werden.”



Radio Tracking

hub

basis
station

transponder

Radio Tracking

Advantages

- large volume of operation (500m x 500m)
- rugged (e.g. inside soccer ball)
- up to 16.384 transponders

Disadvantages

- 6DoF only with multiple transponders
- only ±5cm precision (at best)

“Geometric” Tracking

Instead of tracking only transformations of rigid bodies, the tracker reconstructs scene (and user) geometry in real-time

- Delivers typically a point cloud
- Tracks everything in sight
- Needs post-processing for meaningful data

“Geometric” Tracking

Typically, the devices work like a laser scanner, but with much higher update rates.

Methods include:

- Stereo cameras
- Phase (“Time-of-Flight”) cameras
- Structured light scanners

“Geometric” Tracking: stereo camera

Two (or more) cameras are mounted with a known offset, from the images a depth map is constructed:

Example:
Point Grey “BumbleBee”
1024×768 @20fps

“Geometric” Tracking: stereo camera

Using fast CPUs or GPUs, one can construct a dense depth map from most* stereo images:

Example:
“Stereo Vision on GPU”
R.Yang, 2006
http://www.cs.unc.edu/~welch/media/pdf/Yang2006EDGE-stereovision.pdf

*depends on content: without detectable features, the algorithm does not work

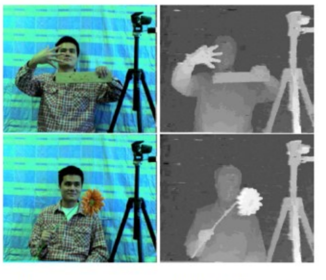


Figure 1: Two sample images and their depth maps from our live system on a 3.0GHz PC with an ATI's Radeon XL1800 graphics card. With this quality, we can achieve 43 fps with 320×240 input images and 16 disparity levels.

“Geometric” Tracking: ToF camera

Phase cameras measure the phase (~time of flight) of light impulses:

Example:
PMDtec sensor

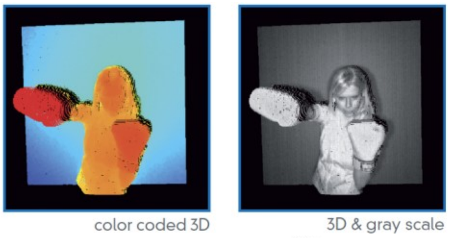
200×200 @60Hz

~1mm depth resolution

0.3-7m range

60° Field of View

http://www.youtube.com/watch?v=iXZYuboaeSM
http://en.wikipedia.org/wiki/ToF_camera

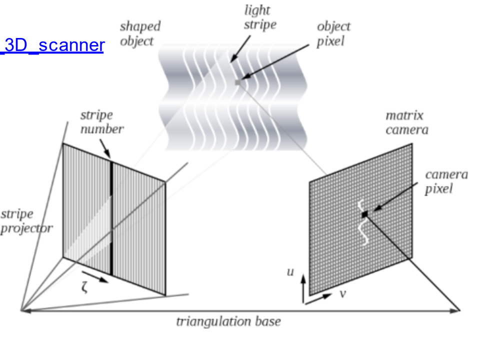


color coded 3D   3D & gray scale

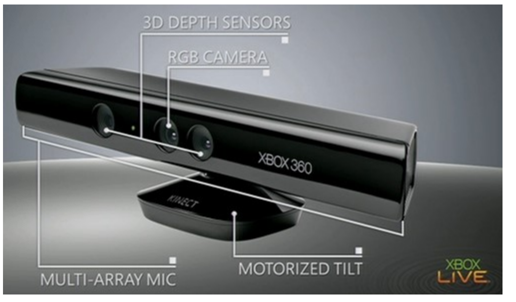
“Geometric” Tracking: structured light

A pattern is projected on an object and captured from a different angle (→*epipolar geometry*):

http://en.wikipedia.org/wiki/Structured-light_3D_scanner



“Geometric” Tracking: structured light

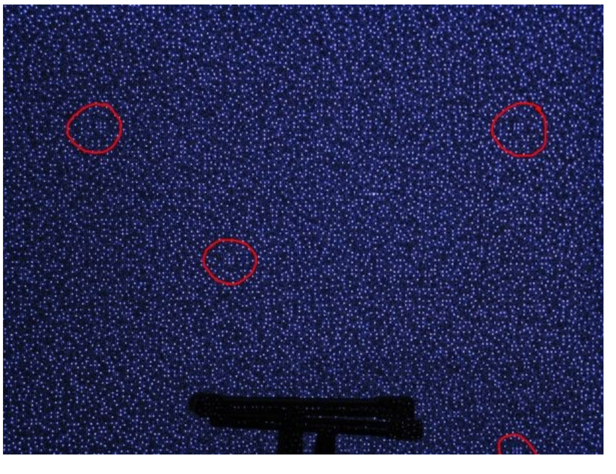


Example:

Microsoft Kinect

Projects pseudo-random IR point pattern & captures IR @QVGA and visible light @VGA (depth with high latency)

“Geometric” Tracking: structured light

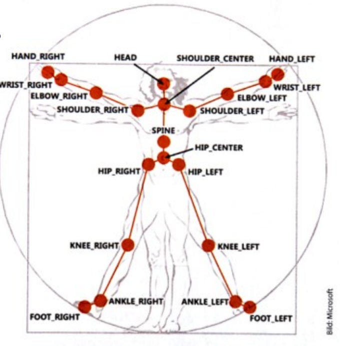


"Geometric" Tracking: segmentation

Depending on which data is needed, costly post-processing routines have to be applied:

- Segmentation in user/background
- Segmentation of user into limbs

e.g. Kinect-SDK:
skeleton with 20 nodes



"Geometric" Tracking

Advantages

- No special markers needed
- Delivers scene model (e.g. for occlusion handling)

Disadvantages

- Point data must be post-processed (skeleton-based segmentation, time-consuming)
- Occlusion (when only using one sensor)
- Fine-grained data like finger position or hand- and head-orientation are difficult or impossible to extract

cellphone revisited: tracking

contain enough sensors for many AR applications:

A-GPS

2 DoF compass

3 DoF acceleration

camera(s)

Hybrid Tracking

Using a combination of two or more methods two improve:

- precision
- speed
- reliability

e.g.: Intersense:
inertial (relative & fast) +
ultrasound (absolute & slow)

Hybrid Tracking

inertial tracking has an inherent advantage:

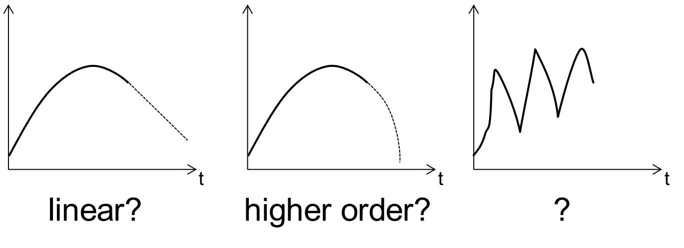
since it directly measures acceleration, it can be used for higher-order extrapolation

→ prediction!

Prediction

To compensate for the ***system delay***, we have to use the ***predicted future state*** of our system to generate the virtual environment.

But how to predict?



Prediction: Kalman Filter

The **Kalman** filter is a set of mathematical equations that provides an efficient computational (recursive) means to estimate the state of a process, in a way that minimizes the mean of the squared error. The filter is very powerful in several aspects:

it supports estimations of past, present, and even future states, and it can do so even when the precise nature of the modeled system is unknown.

Welch, G. et.al., "An introduction to the Kalman Filter", SIGGRAPH 2001, Course Notes