3D tracking systems
(device properties and tracking methods)

SGN-5406 Virtual Reality 2012
Atanas Boev

based on material by
Stanislav Stankovic and Ismo Rakkolainen
Outline

3D tracking overview → Device properties → Tracking methods → Motion capture

- Accuracy
- Jitter
- Latency
- Sensor drift
- Update rate

- Mechanical
- Electromagnetic
- AC
- DC
- Time of flight
- Phase
- Inside-out
- Outside-in
- Gyro
- Accelerometer

- Acoustic
- Optical
- Inertial
- Hybrid

Body pose → Facial expression
Overview

WHAT IS 3D TRACKING?
3D tracking

- Tracker - a device which measures position and orientation of an object in 3D space
  - Dedicated hardware device
  - Continuously measures position of tracked objects
  - Works in real time

Mechanical head tracker (1993)

http://hdl.handle.net/2429/2633
Applications of 3D tracking

- Used in some VR systems
  - Used in CAVEs
  - Not needed for VR training environments (e.g. flight simulators)
- Essential for AR systems
- Beneficial for geo-location
  - Positioning (e.g. “you are here”)
  - Tracking (e.g. “where is my iPhone?”)
  - Navigation (e.g. how to get from A to B)
  - Geo-fencing (e.g. turn off alarms in cinema)
VR tracking

• **Target:**
  • Head
  • Hand (e.g. 3D controller)
  • Limbs
  • Body (entire body)

• **Purpose**
  • Viewpoint direction control (field of regard)
  • Viewpoint position control (virtual locomotion)
  • Object manipulation
  • Gesture-based input
  • Avatar control (e.g. VR world, cinema, animation)
AR tracking

- **Registration** – coordinate alignment between real and synthetic objects
  - Virtual objects superimposed over real images (e.g. games, AR maps)
  - Computer generated 3D graphics superimposed on live video stream

- **Real time tracking is critical for AR**
  - Head turn 50 deg/s + system delay <10ms = angular error <0.5 deg
Market considerations

- **Product**
  - Cost (how much people are willing to pay)
  - Social acceptance

- **Performance**
  - Accuracy (tracking precision)
  - Speed (tracking rate)

- **Ease of use**
  - Encumbrance – discomfort for the users, limiting their natural movement
  - Ease of disengagement (how easy is to put on/take off)
  - Interference with the environment (how easy is to install in a given environment)
Degrees of freedom (reminder)

- DoF – Degrees of Freedom.
- Rotation or translation along the axes.
  1. Moving up and down
  2. Moving left and right
  3. Moving forward and backward
  4. Tilting forward and backward (pitching);
  5. Turning left and right (yawing);
  6. Tilting side to side (rolling).
Tracking DoF

- **3D tracking of a point**
  - 3 DoF – Translation along (X,Y,Z)

- **3D tracking of an object**
  - 3 DoF – Translation along (X,Y,Z)
  - 3 DoF – Rotation along (X,Y,Z)
  - 6DoF total

- **More DoF**
  - Tracking of multiple points
  - Tracking of multiple objects
  - Multiple objects in reference to each others
  - 20+ DoF for human body and limbs

- **Motion Capturing**
  - Body posture and position
  - Facial expression
Device properties

ACCURACY, JITTER, LATENCY, DRIFT, UPDATE RATE
Tracker Accuracy

- **Accuracy** - the difference between the object’s actual position and the position reported by tracker measurements
  - Different accuracy for position and rotation.
- **Resolution** - the minimum change that the sensor can detect.
  - Not equal to accuracy
  - Static and dynamic resolution might differ (e.g. sensor drift)
- **Operating range** – the range where the sensor operated with “acceptable” accuracy
  - Expressed as distance from the origin of the reference system of coordinates.
  - Accuracy drops with the distance
- **Repeatability** – expectation for same input to give the same output
  - Same sensor movement to give the same measurements
  - Can be considered as “sensor noise”
  - “Low” sensor noise allows for dynamic sensor calibration
Tracker Jitter

- Jitter - the change in tracker output when the tracked object is stationary
  - Can also be regarded as “tracker noise”
  - A tracker with no jitter gives constant value as output if the object is stationary.
  - Can be minimized using thresholding

Unwanted effects in graphics

- Tremor
- Jumpy virtual objects
- Can be filtered but that increases latency
Tracker Latency

- Latency - the time delay between action and result.

- The time between the change in position/orientation of the object and the time the sensor detects the change.

- Several negative effects on the simulation:
  - Spoils the experience, >50 ms: no immersion
  - Introduces discomfort, >10 ms: potential simulator sickness.
Tracker Drift

- **Drift** – increase of the tracker error with time
  - Related to the dynamic sensitivity of the tracker
  - Accumulated (additive) error over time

- **Tracker accuracy decreases with time**
  - Needs (periodic) recalibration
Tracker Update Rate

- **Update rate** - the number of measurements that the tracker reports in an unit of time
  - Larger update rate, better dynamic response of the simulation.
  - Typically 30-240 datasets/s.

- **Multiplexing effect** - If the tracker measures several objects, sampling rate may drop
  - total transfer rate is limited, needs to be shared for multiple objects. With addition of each new object bandwidth per individual object decreases.

![Graph](image)
Tracking technologies

HOW THE OBJECT IS TRACKED?
Tracking technologies

- Mechanical
- Electromagnetic
- Acoustic
  - Ultrasonic
- Optical
  - Videometric
- Inertial
  - Accelerometers, MEMS
- Hybrid
Non-contact trackers

- Non-contact trackers have largely replaced mechanical ones
- 3D measurement technology should not be intrusive and hinder the user’s freedom of motion in the process of tracking

**Technologies:**
- Electromagnetic trackers
- Ultrasound trackers
- Optical trackers
- Accelerometers
- Gyroscopes
Tracking technologies

(ELECTRO-) MECHANICAL TRACKERS
Electromechanical Trackers

- **Contact based tracking**
  - Consists of a serial or parallel kinematic structures interconnected using joints with sensors
- **Accuracy fairly constant over the work envelope of the tracker**
  - Immune to electromagnetic interferences
  - Very low jitter
  - Very low latency
  - Relatively low-cost
- **Tracking of the end of the arm in reference to the coordinate system tied to root of the arm.**
BOOM

- **BOOM (Binocular Omni-Orientation Monitor)**
  - The display is attached to a mechanical arm with a counterbalance.
  - Allows stereoscopic visualization
  - Counterbalanced, highly accurate, motion-tracking support structure for practically weightless viewing

- **Resolution is unsurpassed by any alternative technology**
  - 6 DoF
  - Translation movement accuracy up to 0.16”.
  - Angle resolution 0.1 deg.
Desktop BOOM

- Pushbuttons
- Stereo display
- Graphics signal
- Gimbal sensors
- Tracker signal
- Compliant support
Mechanical motion capture

- **Mechanical trackers in a motion capture suit**
  - High precision
  - Limited comfort

- **Animazoo – Gypsy 7**
  - 14 joint sensors
  - Accuracy (0.125 degrees resolution)
  - Independent digital processing at every joint
  - Low data noise
  - Low data disruption and dropped frames
  - Factory calibrated joint sensors
Mechanical trackers - pros and cons

**Pros:**
- Quite simple and easy to use,
- Accuracy fairly constant over the work envelope of the tracker,
- Immune to electromagnetic interferences,
- Very low jitter,
- Very low latency,
- Relatively low-cost.

**Cons:**
- Limited range - due to dimensions of mechanical arms.
- Restrict the user to a fixed location.
- Long arms increase weight, inertia and mechanical oscillations.
- Reduction in the user’s freedom of motion due to the motion interference from the tracker arm itself.
- Weight of the mechanical tracker.
Tracking technologies

ELECTROMAGNETIC (EM) TRACKERS
Electromagnetic trackers

- A non-contact position measurement device.

- Two components:
  - Transmitter
    - 3 antennas: orthogonal coils wound on a ferromagnetic cube
    - 3 orthogonal electromagnetic fields
  - Receiver – EM Fields generate current in receivers.

- Two basic types:
  - AC – alternating EM field (coils)
  - DC – static EM filed (static magnets)
General information

• **Common properties**
  - Widely used
  - Sensors are triads of orthogonal magnetic transducers.
  - AC or DC are about the same size.
  - Computer calculates position and orientation from the sensory information

• **Pros**
  - Relatively accurate
  - Allows wireless operation
  - No need for line-of-sight

• **Cons**
  - Limited range (1-5 meters)
  - Accuracy drops fast
  - Latency from the calculation and filtering
Accuracy

- **Calibration is a constant concern:**
  - Component drift due to temperature and age while measuring very small signals must be calibrated out continuously while the trackers operate.
  - Moving metallic/magnetic objects in the environment induce magnetic fields.
  - Wooden structures are often used in CAVEs.

- **Accuracy range of millimeters in position, and milliradians in orientation.**

- **Depending on e.g., speed and accuracy, current prices range from:**
  - low at about $2,000 - $3,000
  - moderate at $6,000 - $10,000
  - with some special purpose systems of high sensor count and greater range running more expensive at $15,000 -$50,000 and higher
AC EM Trackers

- Alternating magnetic fields, 7-14 kHz
- 3 orthogonal coils in the receiver, one for each axis.
- Two approaches – Time multiplexed and Frequency multiplexes

- **Time multiplexed:**
  - Three windings are driven at different times
  - A single frequency is used on all three (X,Y,Z) of its axes.
  - Only one at a time can be energized in order to know precisely where the field originates.

- **Frequency multiplexed:**
  - Three frequencies are used.
  - All three can be driven simultaneously.
  - Has many advantages but also increases complexity and cost.
## Case study: Polhemus Fastrek

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees-of-Freedom</td>
<td>6DOF</td>
</tr>
<tr>
<td>Number of Sensors</td>
<td>1-4</td>
</tr>
<tr>
<td>Update Rate</td>
<td>120 Hz (divided by number of sensors)</td>
</tr>
<tr>
<td>Static Accuracy Position</td>
<td>0.03in RMS</td>
</tr>
<tr>
<td>Static Accuracy Orientation</td>
<td>0.15° RMS</td>
</tr>
<tr>
<td>Latency</td>
<td>4ms</td>
</tr>
<tr>
<td>Resolution Position at 30cm range</td>
<td>Resolution Position per inch of source and sensor separation</td>
</tr>
<tr>
<td>Resolution Orientation</td>
<td>0.025°</td>
</tr>
<tr>
<td>Range from Standard TX2 Source</td>
<td>Up to 5 feet or 1.52 meters</td>
</tr>
<tr>
<td>Extended Range Source</td>
<td>Up to 15 feet or 4.6 meters</td>
</tr>
<tr>
<td>Interface</td>
<td>RS-232 or USB (both included)</td>
</tr>
<tr>
<td>Host OS compatibility</td>
<td>GUI/API Toolkit 2000/XP</td>
</tr>
</tbody>
</table>

---

**Image Description:**
- A photograph of the Polhemus Fastrek device showing its physical form factor and design details.
- The device appears to be a compact piece of equipment, likely designed for ease of use and integration into various applications.
# Case study: Polhemus  Liberty

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees-of-Freedom</td>
<td>6DOF</td>
</tr>
<tr>
<td>Number of Sensors</td>
<td>1-16</td>
</tr>
<tr>
<td>Update Rate</td>
<td>240 Hz per sensor</td>
</tr>
<tr>
<td>Static Accuracy Position</td>
<td>0.03in</td>
</tr>
<tr>
<td>Static Accuracy Orientation</td>
<td>0.15° RMS</td>
</tr>
<tr>
<td>Latency</td>
<td>3.5ms</td>
</tr>
<tr>
<td>Resolution Position at 30cm range</td>
<td>0.00015in 0.0004cm</td>
</tr>
<tr>
<td>Resolution Orientation</td>
<td>0.0012°</td>
</tr>
<tr>
<td>Range from Standard TX2 Source</td>
<td>Up to 5 feet or 1.52 meters</td>
</tr>
<tr>
<td>Extended Range Source</td>
<td>Up to 15 feet or 4.6 meters</td>
</tr>
<tr>
<td>Interface</td>
<td>RS-232 or USB (both included)</td>
</tr>
<tr>
<td>Host OS compatibility</td>
<td>GUI/SDK 2000/XP</td>
</tr>
</tbody>
</table>
## Case study: Polhemus Patriot

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees-of-Freedom</td>
<td>6DOF</td>
</tr>
<tr>
<td>Number of Sensors</td>
<td>1-2</td>
</tr>
<tr>
<td>Update Rate</td>
<td>60Hz per sensor</td>
</tr>
<tr>
<td>Static Accuracy Position</td>
<td>0.06in RMS</td>
</tr>
<tr>
<td>Static Accuracy Orientation</td>
<td>0.40° RMS</td>
</tr>
<tr>
<td>Latency</td>
<td>Less than 18.5ms</td>
</tr>
<tr>
<td>Resolution Position at 12in range</td>
<td>0.00046in</td>
</tr>
<tr>
<td></td>
<td>0.00117cm</td>
</tr>
<tr>
<td>Resolution Orientation at 12in range</td>
<td>0.00381°</td>
</tr>
<tr>
<td>Range from Standard TX2 Source</td>
<td>Up to 5 feet (1.52 meters)</td>
</tr>
<tr>
<td>Extended Range Source</td>
<td>n/a</td>
</tr>
<tr>
<td>Interface</td>
<td>RS-232 or USB (both included)</td>
</tr>
<tr>
<td>Host OS compatibility</td>
<td>GUI/SDK XP/Vista/Win7 (32-bit and 64-bit) Linux: Open-source application available</td>
</tr>
</tbody>
</table>
DC Magnetic Trackers

- Pulsed DC magnetic fields
- Always time multiplexed
- Affected by Earth’s magnetic field
  - DC signals such as the earth’s field must be measured and subtracted from the sensor outputs.

Fig. 2.10  DC magnetic tracker block diagram. Adapted from Blood [1989]. © Ascension Technology Co. Reprinted by permission.
Environmental Magnetic Issues

- Interference from metallic materials and magnetic fields.
- CRT, Speakers, sources of magnetic fields.
- Magnetic fields induced in ferromagnetic materials.
- Steel and iron reinforcement in architectural structures, concrete.
### Case study: Ascension MotionStar

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees of freedom</td>
<td>6 (Position and Orientation)</td>
</tr>
<tr>
<td>Translation range</td>
<td>±3.05m in any direction with one transmitter; ±4.88m with dual transmitters</td>
</tr>
<tr>
<td>Angular range</td>
<td>All Attitude: ±180° Azimuth &amp; Roll, ±90° Elevation</td>
</tr>
<tr>
<td>Static Accuracy Position</td>
<td>0.76cm RMS at 1.52m range, 1.5cm RMS at 3.05m range</td>
</tr>
<tr>
<td>Static Accuracy Orientation</td>
<td>0.5° RMS at 1.52m range, 1.0° RMS at 3.05m range</td>
</tr>
<tr>
<td>Static Resolution Position</td>
<td>0.08cm at 1.52m range, 0.25cm at 3.05m range</td>
</tr>
<tr>
<td>Static Resolution Orientation</td>
<td>0.1° RMS at 1.52m range, 0.2° RMS at 3.05m range</td>
</tr>
<tr>
<td>Measurement rate</td>
<td>Up to 144 measurements/second</td>
</tr>
<tr>
<td>Outputs</td>
<td>X, Y, Z positional coordinates and orientation angles, rotation matrix, or quaternions</td>
</tr>
<tr>
<td>Interface</td>
<td>Ethernet, RS-232C</td>
</tr>
</tbody>
</table>
## AC trackers vs. DC trackers

<table>
<thead>
<tr>
<th></th>
<th>AC</th>
<th>DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>very high</td>
<td>medium high</td>
</tr>
<tr>
<td>Resolution</td>
<td>very high</td>
<td>medium</td>
</tr>
<tr>
<td>Speed</td>
<td>very high</td>
<td>low</td>
</tr>
<tr>
<td>Latency</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>Range</td>
<td>short, medium</td>
<td>short</td>
</tr>
<tr>
<td>Noise</td>
<td>in-bands, signal</td>
<td>power lines, earth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>magnetic field</td>
</tr>
<tr>
<td>Cost</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>System size</td>
<td>small</td>
<td>medium</td>
</tr>
<tr>
<td>Environment distortions</td>
<td>good conductors</td>
<td>ferromagnetics</td>
</tr>
<tr>
<td>Multiple systems</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
Tracking technologies
ACOUSTIC TRACKERS
Acoustic Trackers

- Ultrasonic signal produced by a stationary transmitter to determine the real-time position of the sensor.
  - Transmitter + several microphones
  - Brief ultrasonic pulses.

- Pros
  - Low-cost – a cheaper alternative to magnetic trackers
  - Error-prone - environment, noise, reflections.

- Cons
  - Not very accurate.
  - Requires line-of-sight
  - Not suitable for tracking hands due to frequent occlusions.
Acoustic tracking methods

- **Two approaches:**
  - Time difference,
  - Phase difference

- **Time-of-flight (TOF):**
  - All current commercial systems
  - Time that sound pulse travels is proportional to the distance from the receiver.
  - Problem: differentiating the pulse from noise.
  - Each transmitter works sequentially – increased latency.

- **Phase coherent approach (Sutherland 1968):**
  - No pulse, but continuous signal (~50 kHz)
  - Many transmitters on different frequencies
  - Sent and received signal phase differences give continuously the change in distance, no latency,
  - Only relative distance, cumulative & multi-path errors possible.
Acoustic tracking principles

- Measurements are based on triangulation
  - Minimum distances at transmitter and receiver required.
  - Can be a problem if trying to make the receiver very small.

- Each speaker is activated in cycle and 3 distances from it to the 3 microphones are calculated.
  - 9 distances total.

- Tracking performance can degrade when operating in a noisy environment.

- Update rate about 50 datasets/s
  - Time multiplexing is possible
  - With 4 receivers, update rate drops to 12 datasets/s
Extending the range

- Certain applications require larger user motion volume than a transmitter can cover.
  - Several transmitters multiplexed with one receiver.
  - Only one transmitter works at a time.
  - The computer switches the transmitters.
Case study: Logitech Head Tracker

- Transmitter is a set of three ultrasonic speakers - 30cm from each other
  - Rigid and fixed triangular frame

- Receiver is a set of three microphones Placed at the top of the HMD
  - May be part of 3D mice, stereo glasses, or other interface devices

- Range typically about 1.5 m
  - Direct line of sight required
Tracking technologies

OPTICAL TRACKERS
Optical Trackers

- **Optical tracker** - A non-contact measurement device that uses optical sensing to determine the real-time position/orientation of an object
  - CCD or CMOS camera
  - Photodiode
  - Photo-sensor

**Pros**
- Immune to metal interference
- Update rates much higher and latency smaller than in ultrasonic trackers
- Larger working environment

**Cons**
- Requires direct line of sight
- Requires “visible” optical markers
Tracker configurations

a) Outside-in: Static sensors, markers on objects.

b) Inside-out: Static markers, mobile sensors.
Outside-in

- Light sensors or cameras surrounding the tracked object observe it.
- Position of the sensor is fixed.

- Markers or light beacons are typically placed on the object:
  - Passive reflectors or fiduciary markers.
  - Active IR-transmitters.
Vision-based tracking

- In the general case should work with no "special" markers
  - Analysis of Video signal
  - Ultimate Computer Vision goal
  - Computationally expensive
  - Image filtering, segmentation, contour finding
  - Feature extraction, object recognition

- Easier task if optical markers are present
  - Specific color (green room, blue room)
  - Specific time (flashes “between frames”)
  - Infrared light (not to interfere with image)
Video tracking

- A single camera can be used for 2D tracking
- Usually multiple cameras needed for 3D tracking
- Several dots are needed to acquire the orientation
- The positions of the light dots in the image give the directions of the objects as seen from the camera
- The operation range can be very large
Case study: Sony Move

- Video Tracking.

- RGB LCD Light Ball as a marker.

- Optical ball tracking.

- 3 Axis linear accelerometer.
- 3 Axis angular rate sensor.
- Magnetometer for calibration.

- Requires constant calibration.
Case study: Microsoft Kinect

Developed by PrimeSense for Microsoft

- **Components:**
  - RGB camera
  - Range camera
  - IR light source
  - Multi-array microphone

- **Range Camera extracts depth information and combines it with a video signal**
Case study: Microsoft Kinect

- IR light source continuously projects infrared structured light pattern.
- Range camera captures IR image.
- Depth information is calculated based on the geometric deformations of projected light pattern.
- If human shape is detected, this information is used to articulate a virtual skeleton.
- Motion Capturing.
Inside-out

- Video sensor on the tracked object
- System analyzes images and trying to detect markers
  - Does not work with flat or defocused surfaces (e.g. optical mouse)
  - Multiple reference points needed
- Often used in augmented reality systems
- Single camera can give 6 DoF
  - Optical mouse – 2 DoF
Case study: Wiimote

- Primary input device for Nintendo Wii console.
- Introduced in Nov. 2006.
- "Motion Sensing":
  - Position – relative to screen.
  - Orientation – relative to screen.
  - Motion – relative to previous position.
- Detailed specs:
  http://wiibrew.org/wiki/Wiimote
1. Motion (relative to previous position of device) – acceleration along X, Y, Z-axes – using ADXL 330 Accelerometer (Analog Devices).

2. Orientation – using ”sensor bar”.

Wiimote Sensors
Wiimote: Sensors bar

- Not a sensor at all.
- Source of IR light – any source of IR light will suffice.
- Detection – CMOS Optical sensor on Wiimote (PixArt).
- Essentially the same like in a webcam.
- Accurate up to 5m.
- Distance from ends of sensor bar calculated by triangulation.
Optical markers

- Location and mutual positions of markers must be known in advance:
  - e.g. length of Wiimote sensor bar for example.

- Landmark color and shape different from surroundings:
  - e.g. adjustable color of Sony Move ball.

- Special easily distinguishable patterns:
  - e.g. IR pattern used by Kinect.
Case study: Optical markers for camera tracking

Camera pose tracking

http://youtu.be/0L34HsXXU00
Tracking technologies

INERTIAL TRACKERS
Inertial trackers

- Self-contained sensors that measure the rate of change in an object orientation, object translation velocity or acceleration
- Measures relative values
  - Only changes from previous noticed, not the absolute value.
- Solid-state structures that use microelectro-mechanical systems (MEMS) technology.

- **Pros:**
  - Self-contained units that require no complementary components.
  - Integrated into most mobile phones.
  - No range limitations.
  - Fairly inexpensive.

- **Cons:**
  - Noise
  - Sensor drift (especially large)
MEMS

- MEMS = MicroElectroMechanical Systems
- Spring-supported load
- Created using semiconductor device fabrication process
- Reacts to gravity and inertia
- Changes its electrical parameters (e.g. capacity)
Measurement principles

- The rate of change in object orientation or angular velocity is measured by Coriolis type gyroscopes.

- **Three gyroscopes on orthogonal axes**
  - Measure yaw, pitch and roll angular velocities.
  - Orientation angle determined by integration over time.

- **Three accelerometers machined coaxially with the gyroscopes.** Needed to measure body-referenced accelerations.
Specifics

- Rapidly accumulating errors.

- Error in position increases with the square of time.
  - Cheap units can get position drift of 4 cm in 2 seconds.
  - Expensive units have same error in 200 seconds.

- Not good for measuring location.

- Inertial trackers are often used together with other types of trackers.

- Periodically reset the output of inertial ones.
Types of inertial trackers

**Gyroscopes**
- The rate of change in object orientation or angular velocity is measured.

**Accelerometers**
- Measure acceleration.
- Can be used to determine object position, if the starting point is known.

**Inclinometer**
- Measures inclination, "level" position.
- Like carpenter’s level, but giving electrical signal.
Case study: iPhone orientation sensors

- **Three-axis accelerometer**
  - Gives direction acceleration – affected by gravity and movement

- **Three-axis gyroscope**
  - Measures translation and rotation moment – affected by movement

- **Three axis magnetometer**
  - Gives (approximate) direction of magnetic north

- **GPS**
  - Gives geolocation - multiple samples over time can be used to detect direction and speed

iPhone app: sensor monitor
Tracking technologies

HYBRID TRACKERS
A hybrid tracker is a system that utilizes two or more position/orientation measurement technologies.

Tracks objects better than any single technology alone would allow.

One solution: adding solid-state magnetometers with gyroscopes to determine the local magnetic north.
- Used to compensate the drift
- Common in mobile phones

Methods needed for compensating the error in location:
- GPS + WiFi triangulation
Motion capture

BODY POSE
Motion Capture

- Technique of digitally recording the movements of real things
- Human movements most often
- Tracks position of several points at the same time
- A tool for creating realistic animation
- Can be based on any tracking method
- Optical tracking used quite often
- Sometimes not real time – post processing of prerecorded video
Case study: movie industry

The Matrix

http://youtu.be/-6fa_lyOKVk
Case study: Ascension ReActor 2

- Ascension ReActor 2
- IR based Optical tracking
- 42 active IR markers on the special suit
- 544 IR detectors in bars of the framework
- http://www.inition.co.uk/3D-Technologies/ascension-reactor-2-0
Case study: OptiTrack

- IR based Optical tracking.
- Suite with active IR markers.
- Special wide field of view IR cameras.
- http://www.naturalpoint.com/optitrack/
Case study: Animazoo Gypsy-7

- Mechanical motion capture system.
- Exoskeleton based.
- 15 joint sensors.
- Accuracy (0.36 degrees resolution).
- Low data noise.
- Factory calibrated.
- Limitless capture area.
Case study: Ascension MotionStar

- Electromagnetic motion capturing system.
- DC based tracking system.
- Ferrous metal in floors, walls and ceilings as well as noise sources in the motion-capture area can adversely affect measurements.
- Electromagnetic transmitters placed on strategic points on special suit.
Case study: Quma Motion Capture Figure

- A puppet which can be manipulated to control the position of virtual character.
- Type of mechanical tracker.
- Sensors in joints.
- 1DoF at each joint.
Motion capture

FACIAL EXPRESSION
Face tracking

- **Face Tracking - Real Time detection of a human face in video signal.**
  - Face tracking = face recognition + object tracking
  - Face recognition – distinguish human face in images
  - Object tracking – follow object (e.g. face) movement over time

- **2D face tracking:**
  - Detects and follows faces (more or less) perpendicular to the line of sight of camera.
  - Can’t detect the orientation of the face.
  - Robust solutions exist.

- **3D face tracking:**
  - Fits a 3D facial model
  - Detects facial orientation
  - Used in iPhoto, Picasa

http://www.lysator.liu.se/~eru/research/
Viola-Jones Face Tracker

- The classical face detection algorithm
  - Used in most cases (e.g. Facebook)
  - Part of OpenCV library
  - Real Time.
  - Very Robust.

- A pyramid of weak Haar-like detection filters.
  - Can’t detect orientation of the face.
  - Needs to be executed for separate facial orientations
  - Check the demo at [http://vimeo.com/12774628](http://vimeo.com/12774628)
How to confuse Viola-Jones

If you don’t want your face to be automatically tagged on Facebook…

Images from cvdazzle.com
Case study: Polar Rose Recognizer

- Allows attaching profile information to face

http://youtu.be/0QBLKBYrgvk
Facial Motion Capture

- Facial Motion Capture - the process of electronically converting the movements of a person's face into digital form.

- A facial motion capture describes the coordinates or relative positions of reference points on the actor's face.
  - Most often optically

- 2D or 3D based methods.
  - 2D methods with single camera. Can't detect head rotation.
  - 3D methods with multiple cameras.

- Applications in film and animation.
- Potential future use as a computer input. If we manage to make computers recognize human facial expressions.
Facial Motion Capture

- Early methods included markers.
  - Up to 350 passive markers, placed on actors face.
  - Markerless solutions are common now.

- Cartoons require exaggerated expressions.
- Problem with capturing eye motion.
- Danger of uncanny valley.
Case study: movie industry

Avatar – using markers

http://youtu.be/1wK1Ixr-UmM

LOTR - markerless

http://youtu.be/_vMqSP-00Rg
Case study: Zign Creations' Zign Track

- Cheap 2D tracking system -160$.
- Single webcam or DV camera.
- No markers.
Case study: Faceware

Image Metrics:
- [http://www.image-metrics.com/Faceware-Software/Overview](http://www.image-metrics.com/Faceware-Software/Overview)

- Markerless facial motion capture.
- Image analysis based 3D method.
- Employed by major video game companies.