Course on Virtual Reality

Motion Tracking

Visual Computing Institute
Lehr- und Forschungsgebiet Virtuelle Realität und Immersive Visualisierung
RWTH AACHEN UNIVERSITY

“If I turn my head and nothing happens,

it ain’t VR!”

(Steve Bryson)

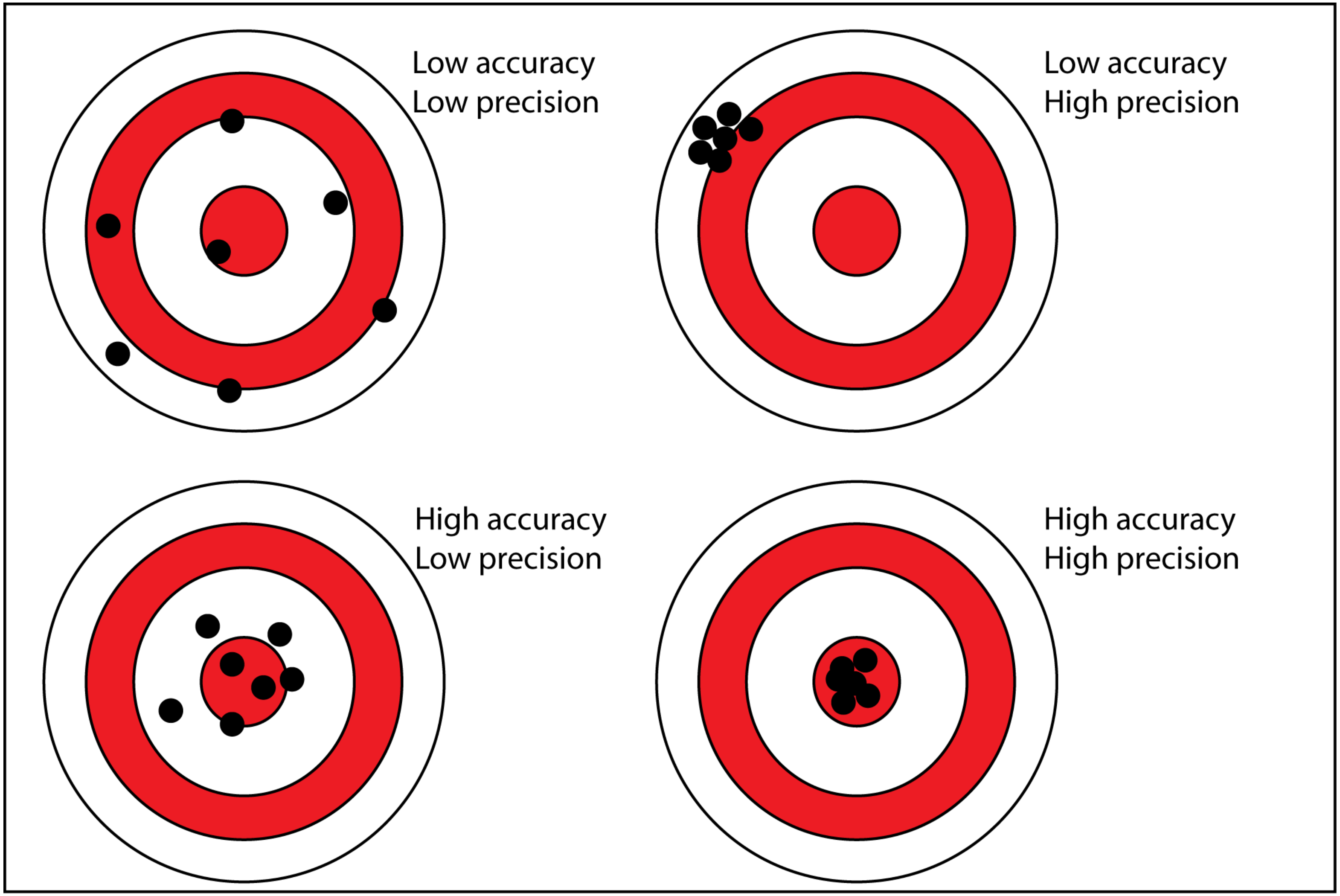
Topics

- Criteria
- Technology
- Opto-electronical Tracking of Body Segments

Criteria

- What is measured (position, orientation, angle, acceleration, distances ...)?
- Dimension (VR: 3-D) and number of tracked segments
- Spatial accuracy (e.g., grasping versus walking)
- Spatial precision

Accuracy versus Precision



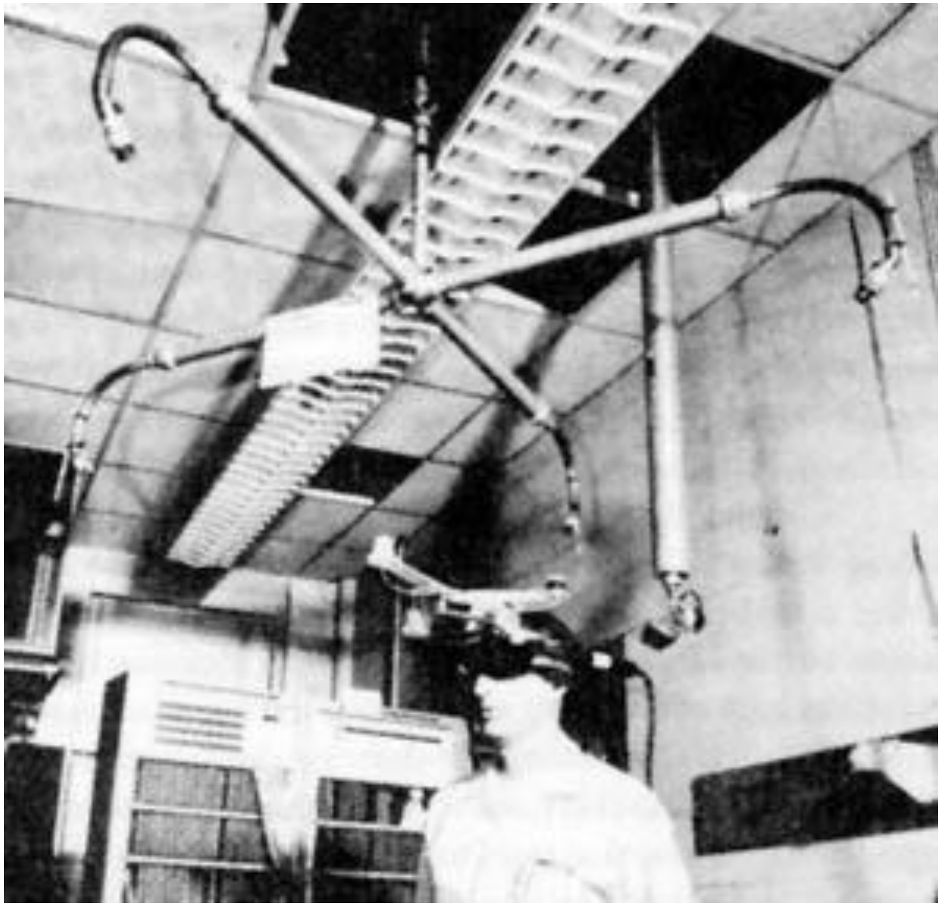
Criteria

- What is measured (position, orientation, angle, acceleration, distances ...)?
- Dimension (VR: 3-D) and number of tracked segments
- Spatial accuracy (e.g., grasping versus walking)
- Spatial precision → Jitter
- Temporal accuracy
  - Response time, latency
- Temporal precision
  - Sample Rate
- Data handling
  - Automatically / manually
  - real time yes / no
- Size of interaction volume
  (often tradeoff between accuracy and size, see, e.g., camera)
- Ergonomics (intrusive / non-intrusive)

Technologies: Overview

- Mechanical
- Electromagnetic
- Ultra sound
- Inertial
- Light
  - Opto-electronical
  - Time of flight
  - Structured light
  - RGB camera(s)
- Satellite, Global Positioning System (GPS)
  - Ubiquitous Computing

Mechanical Tracking – The Ultimate Display



Electromagnetic Tracking - Polhemus

Electromagnetic Tracking - Ascension

Electromagnetic Tracking - Ascension

Bobby Leach Image Courtesy of Film East.

Wireless Cybersuit Image Courtesy of
Ascension Technology Corp.

Electromagnetic Tracking in Military

JSF Simulator Courtesy of Boeing

Electromagnetic Tracking – Pros & Cons

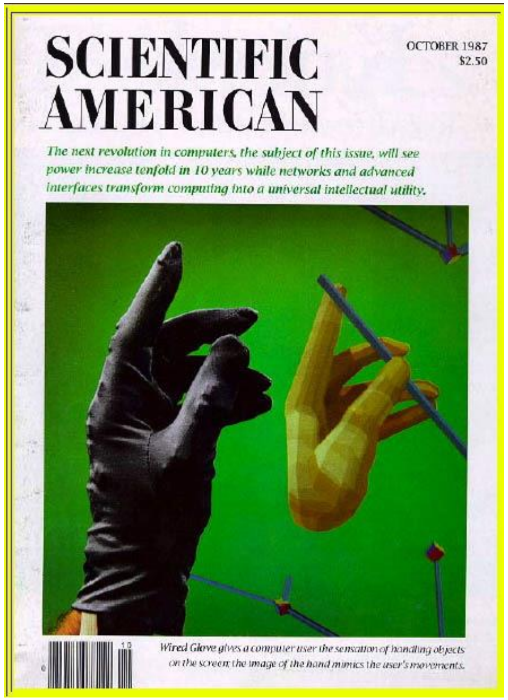
+ Position & orientation
+ No occlusion
- sensitive to ferromagnetic materials in the environment
- Accuracy decreases with growing distance between sender and receiver
- Rather large sensors (1-2 cm)
- Cabling

Instrumented Gloves

- Measures angles between finger segments
- Only makes sense in combination with other trackers
- Different qualities (flexion/extension, adduction/abduction, ...)
- Extremely difficult: Thumb rotation for precision grip

DataGlove:
Optical fibres

CyberGlove:
Resistive strain wires

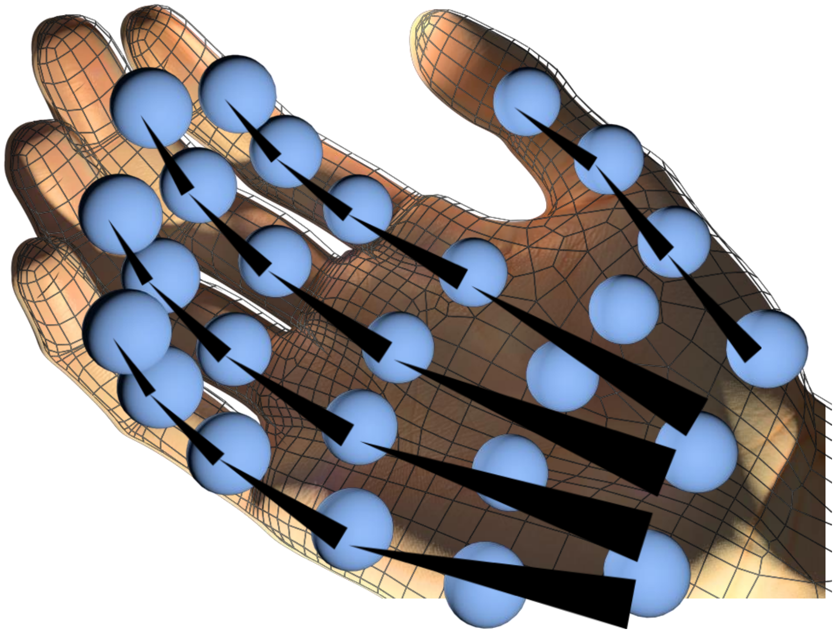


Instrumented Gloves – Pros & Cons

- \+ Allows for natural interaction metaphors
- \+ Number of tracked joints
- \+ No occlusion
- \- Error propagation (position of finger tips?)
- \- Discomfort
- \- Calibration process

Natural Manipulation of Virtual Objects: A Challenge!

- Geometry-based
  - \+ accurate
  - \- computationally expensive



- Simplified sensor model
  - e.g., spheres
  - \+ easy collision detection
  - \- grasping only at contact points

Grasping_Final.mov

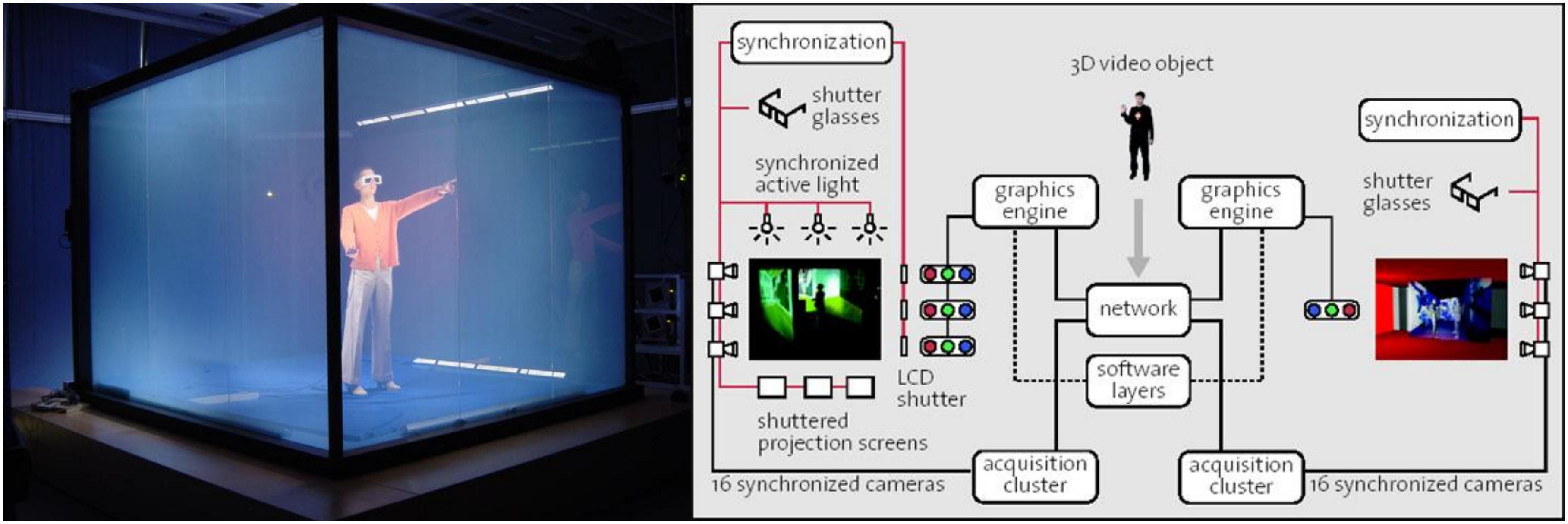
Inertia/Acoustic Tracking - Intersense

- Combination of accelerometers and rotation sensors (gyroscopes)

Computer Vision

- Computer Vision in VR: Stability, accuracy, and latency issues
- Courses held by Prof. Bastian Leibe

- Prominent project on immersive tele-conferencing:
  Blue-C Project at ETH Zurich



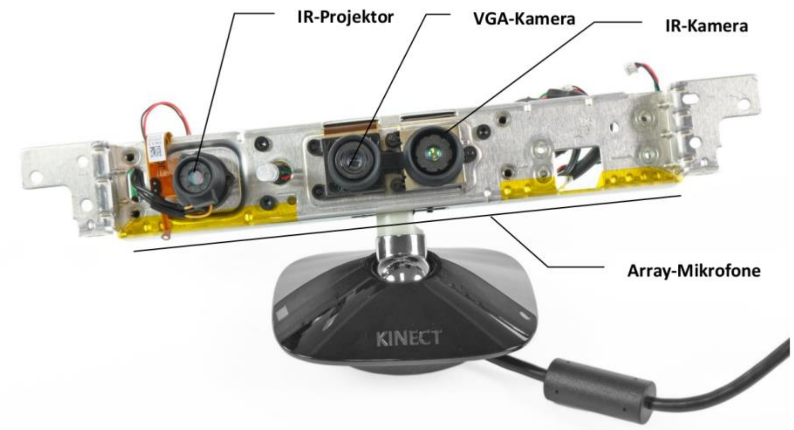
Time of Flight Sensors

- Based on speed of light
- Measure distance between camera and objects
- Similar to Laser Scanning, here: entire image captured
- Resolution: up to 200 x 200 pixels, up to 100 Hz
- Accuracy: ~ 1 cm
- Components:
  - Illumination unit (e.g., infrared laser light)
  - Optics incl. band pass filter
  - Image sensor
  - Driver electronics: Measure time in picoseconds resolution

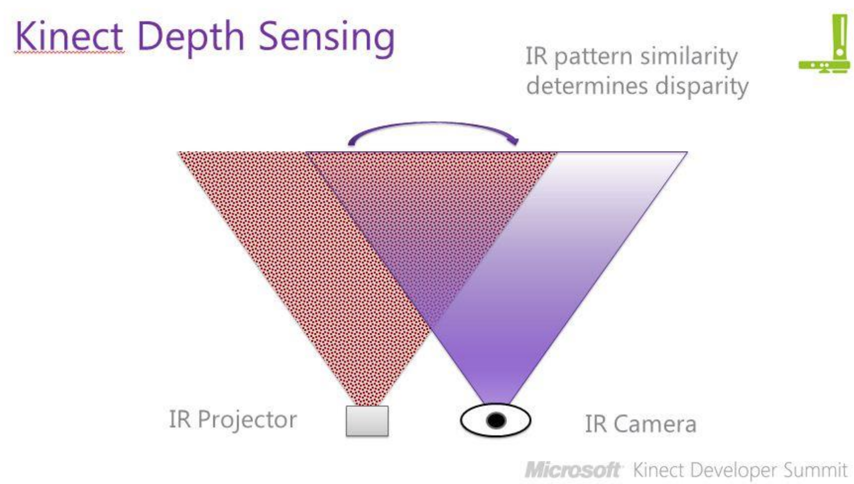
European ARTTS Project

Structured Light: Microsoft Kinect

Pictures: Michael Weyrich, Univ. Siegen

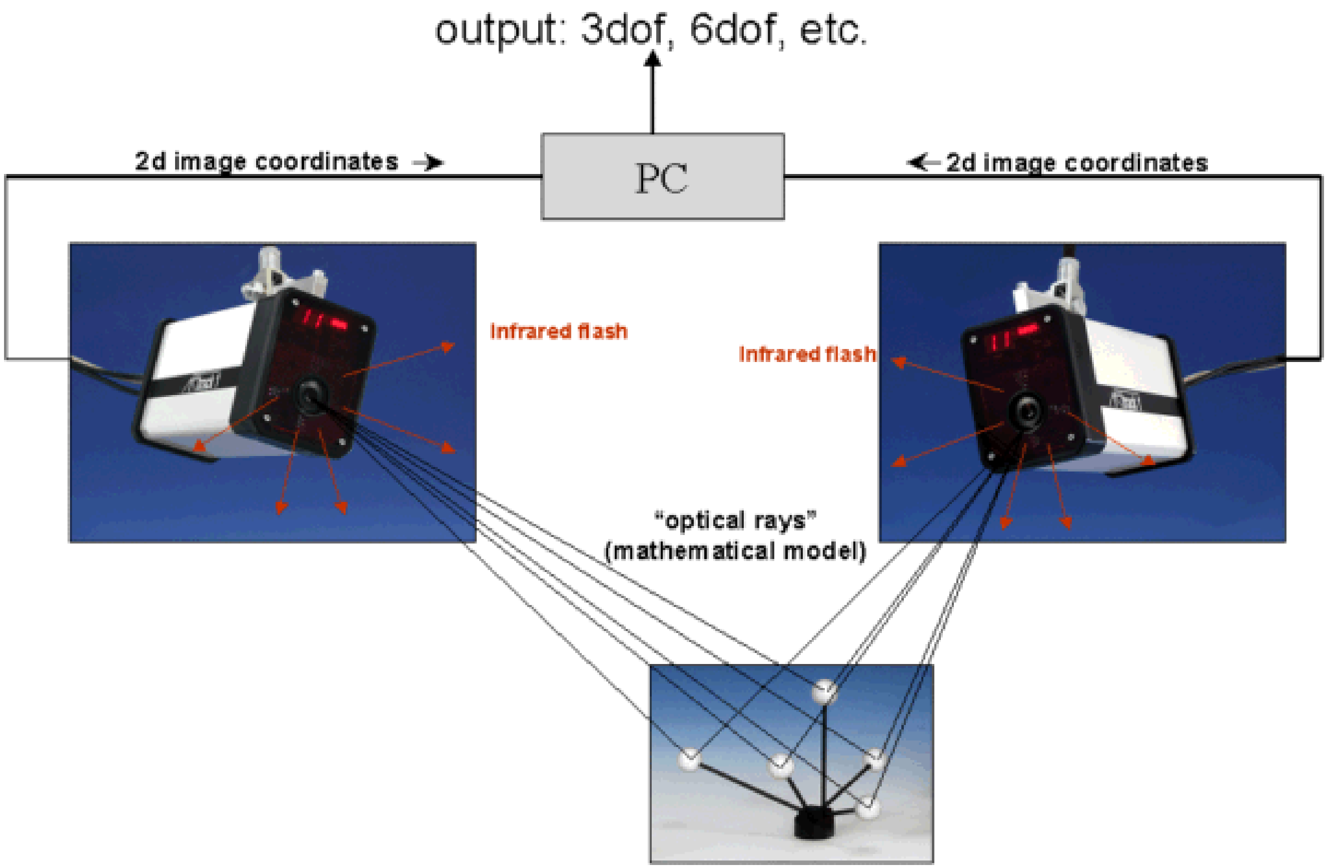


- Infrared laser projector emits a pre-defined matrix of points
- Pattern of deformed point matrix captured by IR camera
- Conversion to 3D coordinates by triangulation
- Resolution: 640 x 480 pixels, 30 Hz
- VGA camera allows for texture mapping



Opto-electronical Tracking – A.R.T.

Picture: A.R.T. GmbH

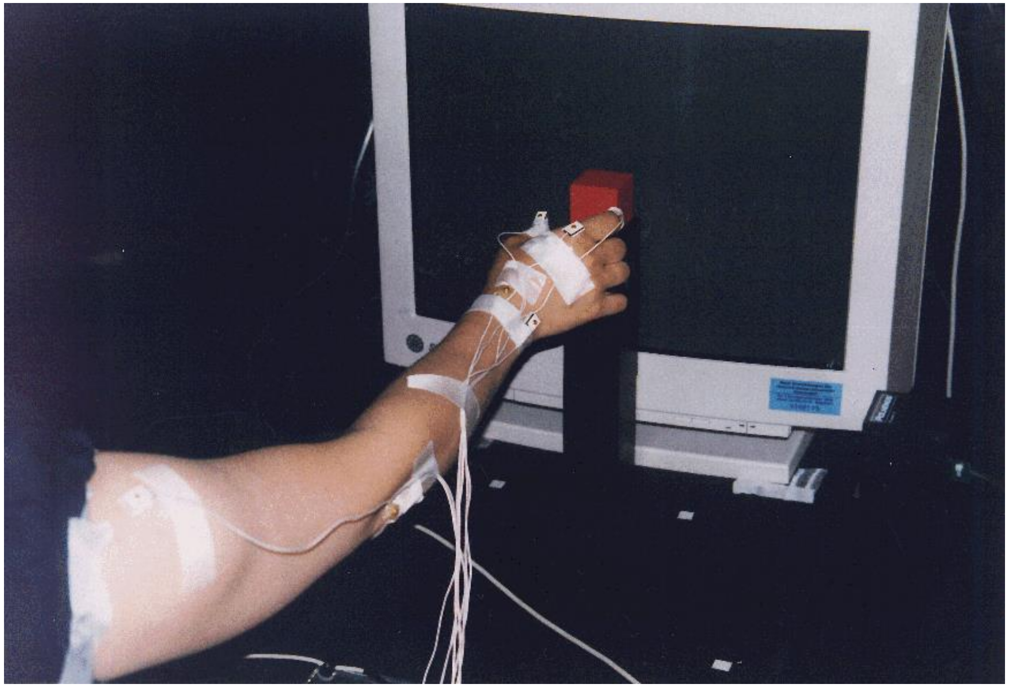


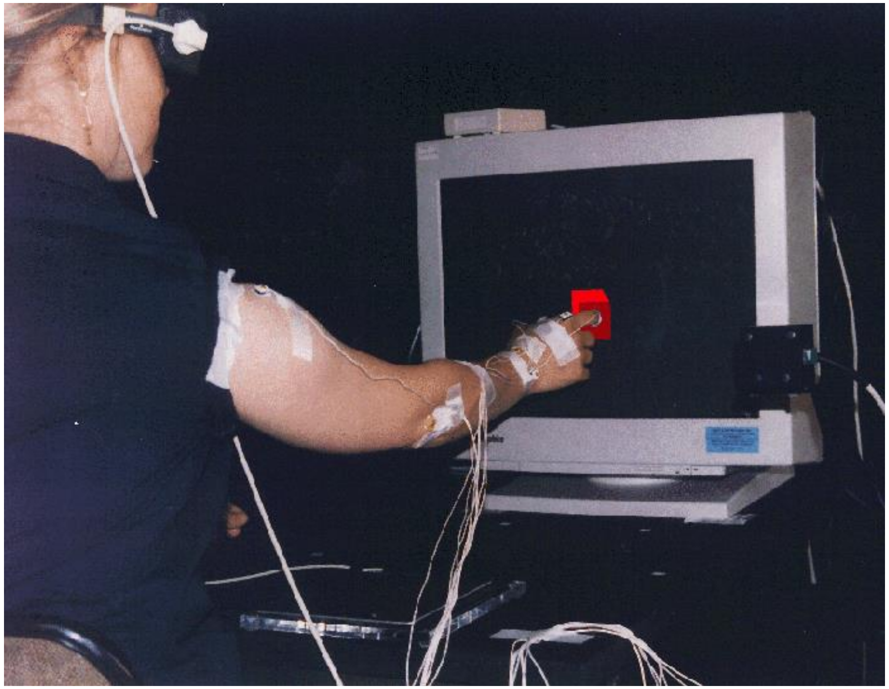
Opto-electronical Tracking

- 2 or more (Infrared) cameras track the 2-D position of markers attached to the human body
- Calculate 3-D positions from 2-D images, e.g., via Direct Linear Transformation (DLT)

  - passive: IR light reflecting markers
  - active: IR light emitting markers
    - \+ Sequential activation: Trivial identification of single markers
    - \- Cabling

Opto-electronical Tracking – Selspot





Experiment (from 1997): Grasping real objects versus gasping virtual objects (University Hospital Düsseldorf & RWTH VR Group)

Finger Tracking – A.R.T.

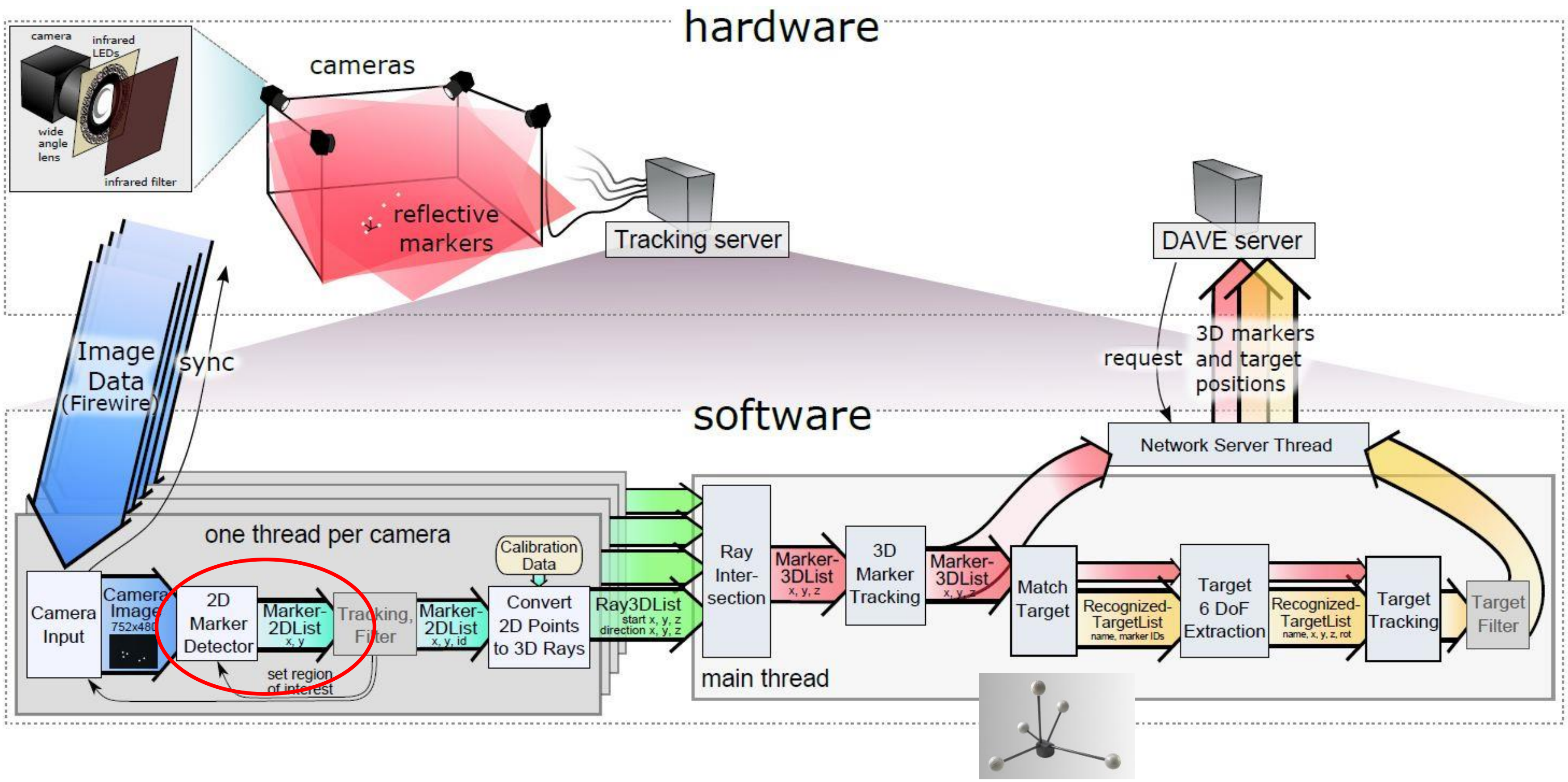
Picture: A.R.T. GmbH

Opto-electronical Tracking – Pros & Cons

+ Accuracy, latency sample rate (of today's systems)
+ Passive markers: No cabling, nearly non-intrusive
- Occlusion
- No orientation (combine 3 non-collinear markers, see later)
- Calibration process (rather comfortable in today's systems)

Optical Tracking Processing Pipeline

[M. Lancelle, PhD. Thesis, 2011]



2D Marker Detection

[M. Lancelle, PhD. Thesis, 2011]

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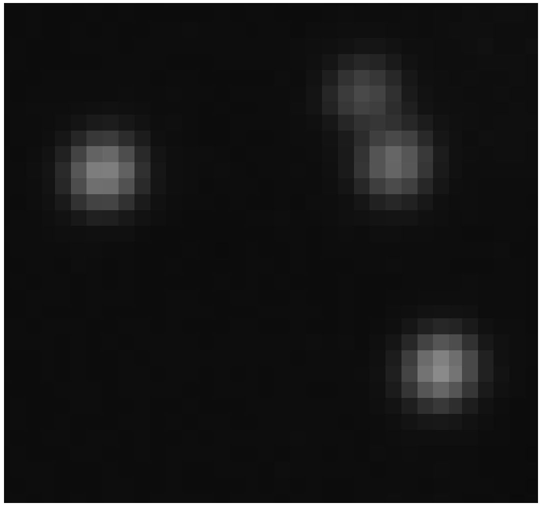
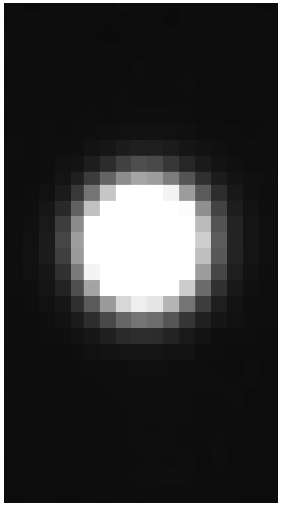
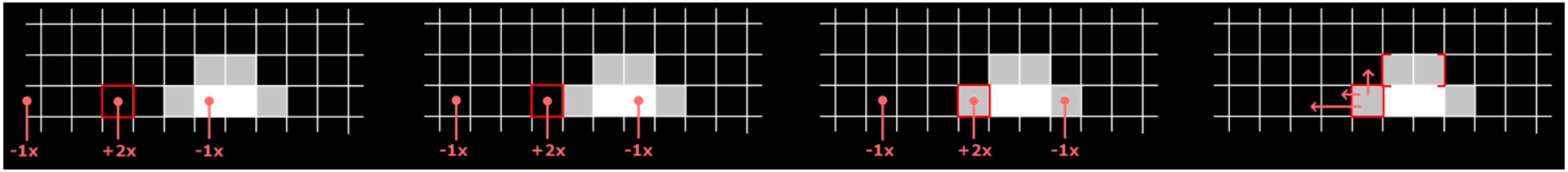






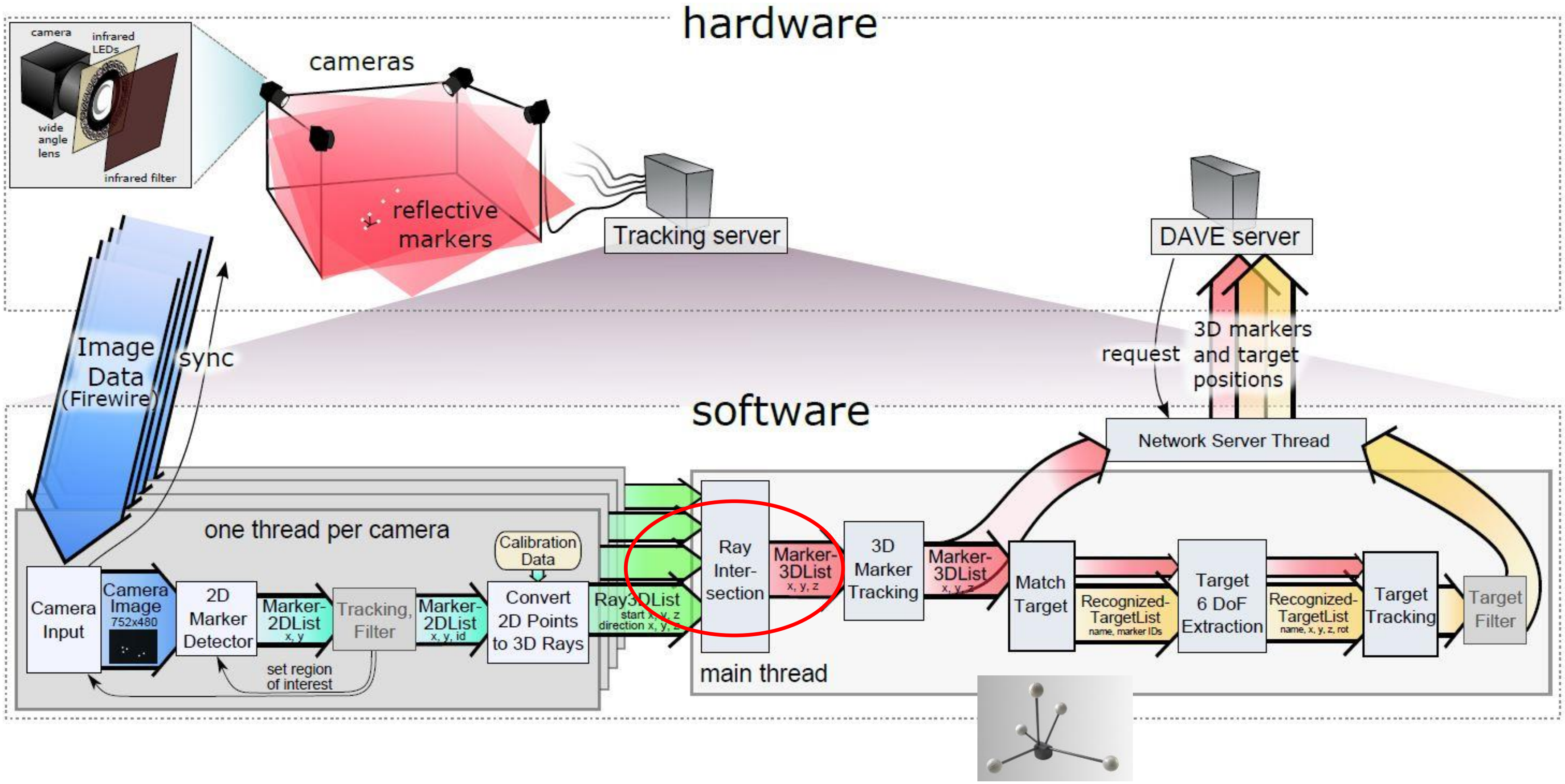
2D Marker Detection

[M. Lancelle, PhD. Thesis, 2011]

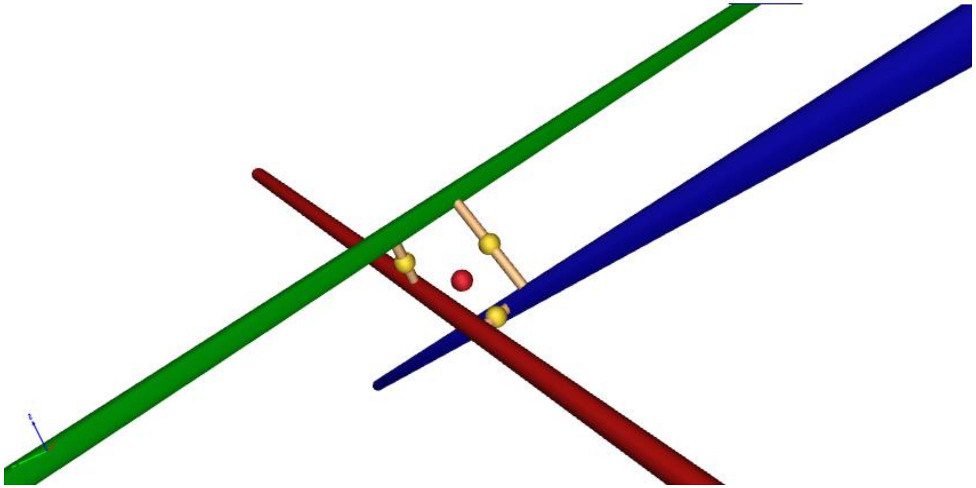
```
const int hDist = 3; // horizontal distance of samples
const int threshold = 30; // absolute threshold for detection
for (each line/row y in the region of interest) {
  for (each column x in the region of interest minus a hDist pixel wide border) {
    float value = 2*img(x, y) - img(x - hDist, y) - img(x + hDist);
    if (value > threshold) {
      if (does left pixel belong to a known-marker?) {
        m = known-marker; // yes, use that marker
      } else {
        // it's a new marker in this line
        if (does it touch a known-marker in the previous line?) {
          m = known-marker; // yes, use that marker
        } else {
          // add new marker
          MarkerStruct m = {0, 0, 0, false};
          tMarkers.push_back(m);
          if (maximum number of blobs exceeded) return;
        }
      }

      weight = value - 0.95*threshold;
      m.posSumX += x * weight;
      m.posSumY += y * weight;
      m.weightSum += weight;
      if (marker touches image border) m.touchesBorder = true;
    }
  }
}

for (each marker m) {
  m.posSumX /= m.weightSum;
  m.posSumY /= m.weightSum;
  if (m.touchesBorder) m.erase(); // remove from list
}
```

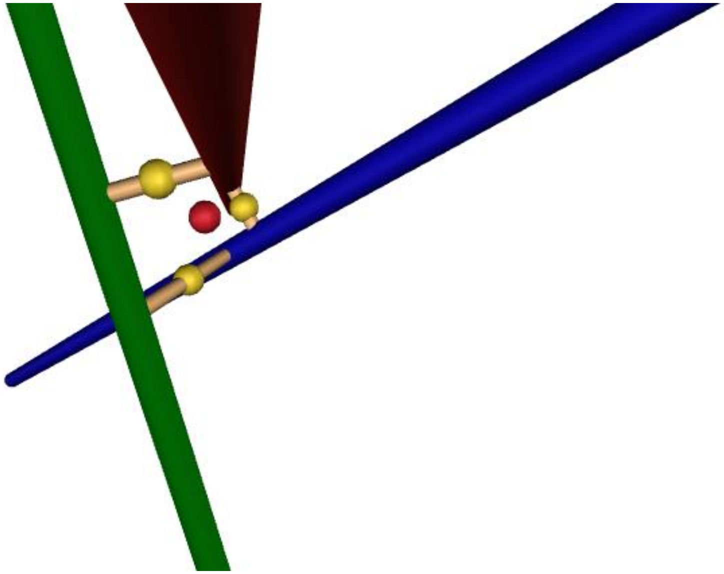
Optical Tracking Processing Pipeline

[M. Lancelle, PhD. Thesis, 2011]



Triangulation by Ray Intersection

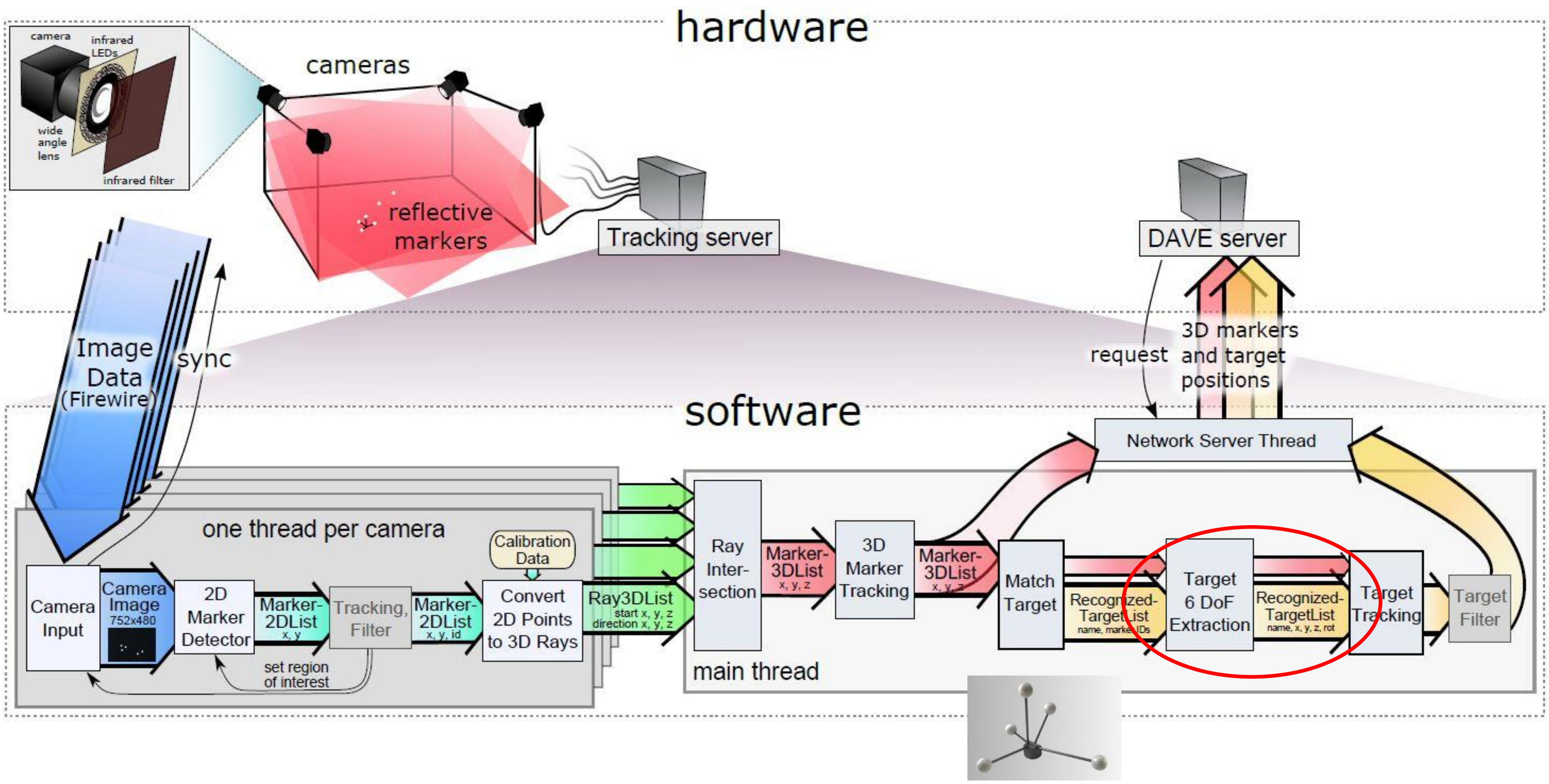




The shortest connection between two skew lines is shown as thin yellow cylinder. Its center is the assumed real intersection position (yellow sphere) of these two rays. For more than two rays, the average position of all yellow spheres is used (red sphere).

Optical Tracking Processing Pipeline

[M. Lancelle, PhD. Thesis, 2011]

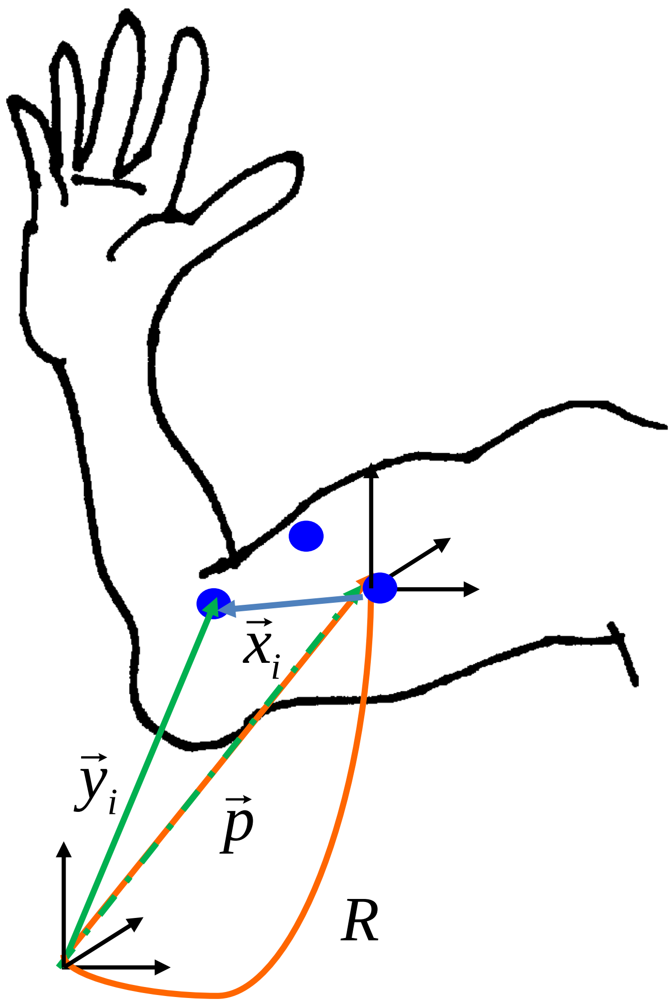


Position & Orientation of Body Segments

- Here:
  Place markers arbitrarily on the segment
- Reference measurement necessary to get $\vec{x}_i$
- Basic equation:

$$\vec{y}_i = R\vec{x}_i + \vec{p}$$

- Given (directly measured): $\vec{y}_i$
- We are looking for Rotation Matrix R
- … and $\vec{p}$ as accurate as possible
- Approach: Least Squares Method



Position & Orientation: The Algorithm

For the details, see VR II course

1. $$\vec{x}_m = \frac{1}{n}\sum_{i=1}^{n}\vec{x}_i, \qquad \vec{y}_m = \frac{1}{n}\sum_{i=1}^{n}\vec{y}_i$$

2. $$X = \left[(\vec{x}_1 - \vec{x}_m),(\vec{x}_2 - \vec{x}_m),\ldots,(\vec{x}_n - \vec{x}_m)\right],$$
$$Y = \left[(\vec{y}_1 - \vec{y}_m),(\vec{y}_2 - \vec{y}_m),\ldots,(\vec{y}_n - \vec{y}_m)\right]$$

3. $C = Y \cdot X^T$ Covariance Matrix

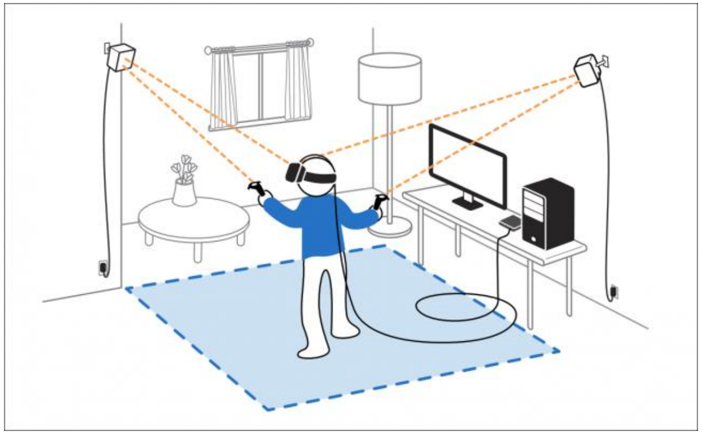
4. $C = U \cdot W \cdot V^T$ Singular Value Decomposition

5. $$R = U \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & \det\left(UV^T\right) \end{pmatrix} \cdot V^T \qquad \vec{p} = \vec{y}_m - R\vec{x}_m$$

Tracking in the HTC Vive: “Lighthouse”

- Two basis stations:
  - Arrays of infrared LED lasers
- IR light sensors in the HMD front
- Time differences → position & orientation

[Tracking with just one basis station possible
within a limited view angle]



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Tracking in the Oculus Rift

- Rotation: Intertia - combination of gyrometer and accelerometer,
- Translation: IR LEDs attached to the HMD, IR camera