POLITECNICO DI MILANO

MobiHealth
Wireless Mobile Communication and Healthcare

Motion capture: An evaluation of Kinect V2 body tracking for upper limb motion analysis

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EAI
RESEARCH MEETS INNOVATION

Summary

- Introduction on Movement Analysis and 3D Computer Vision
- Vision systems for Motion Capture
  - Multi-View Stereoscopic system : BTS Smart-DX 7000
  - Time-of-Flight Camera: Microsoft Kinect V2
- Kinematics of the upper limb
  - Experimental Setup
  - Wrist position measurement
  - Elbow angle measurement
- Uncertainty Estimation
  - Wrist position
  - Elbow angle
- Conclusion
- References

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Ospedale Valduce
Villa Beretta

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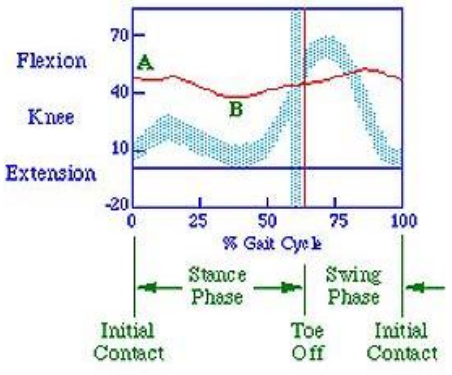
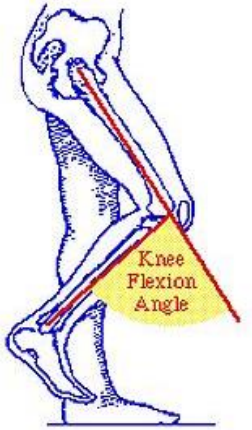
Introduction on Movement Analysis

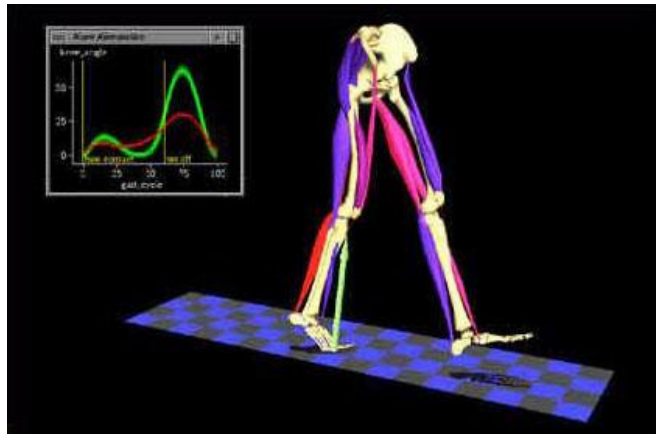
- Study of the capacity of a person to realize a determined movement.
- It analyses of the **kinematics** and/or **dynamics** of the human body.

- **Kinematics** analysis
  - ➢ Range of motion
  - ➢ Absolute position in space
  - ➢ Speed, Acceleration, Jerk





- **Dynamics** related to the movement, using **inertia** and **mass** information and **external forces** measurement
  - ➢ Forces/Moments on the articulation
  - ➢ Forces applied on the muscles



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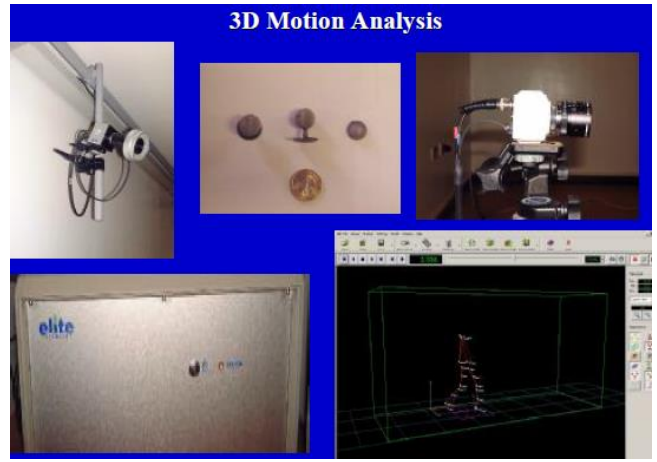
Introduction on Movement Analysis

- **Valduce Hospital "Villa Beretta"**
  - Rehabilitation Centre
  - Costa Masnaga (LC)
  - Gait and Movement Analysis Laboratory
    - Dynamic EMG / 3D Motion analysis
    - Evaluates causes of walking and related movement problems
    - Analyses muscle function and dexterity
    - Focuses on patients with nervous system damage,
    - Provides Basis for corrective physical, medical and surgical therapies



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Introduction on 3D Computer Vision

Vision systems are **non contact optical** measurement techniques

\+ **With no loading effect** on the measured system (unlike IMUs)

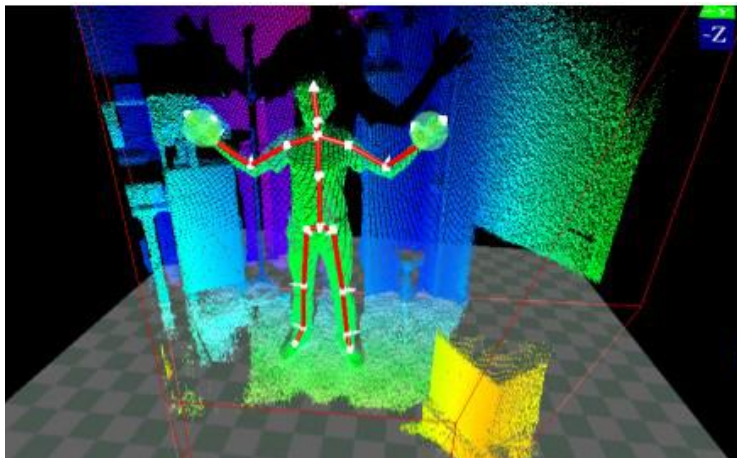
\+ **With no damage** on the measured system

\+ **Remotely** measures **simultaneous points**

– Sensible to **occlusion, material reflection** and **light conditions**

3D Vision systems:

- Permits the measurement of **the position of points in a scene**
- Deals with **point clouds**: a set of 3D points, that can be:
  - **Dense** and structured
    → Matrix of points
  - **Sparse** and unstructured
    → Small array of points
- Allows **body recognition** and **position estimation** in 3D



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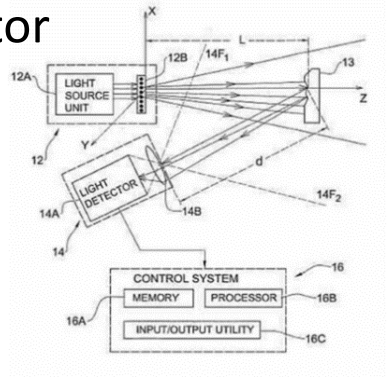
Introduction on 3D Computer Vision

Different techniques exist:

- **Multi-View Stereoscopy:**
  - 2 or more cameras
  - Sparse point cloud reconstruction

- **Active triangulation:**
  - Single camera with structured light projector
    - Laser blade for static scene
    - Codified light pattern for dynamic scene



- **Time of Flight camera (TOF):**
  - Light echo measurement (LiDAR)
  - Time between emission of modulated light and its reception
  - Diffused light
  - Dense point cloud reconstruction

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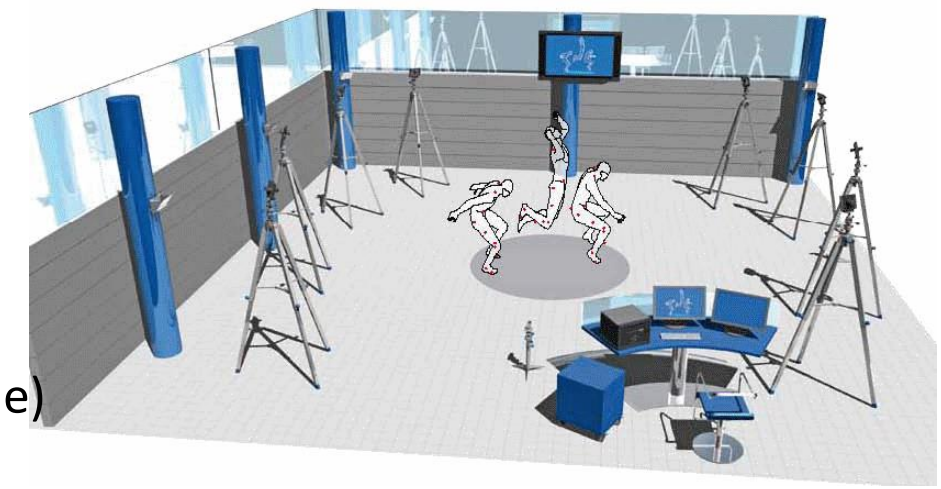
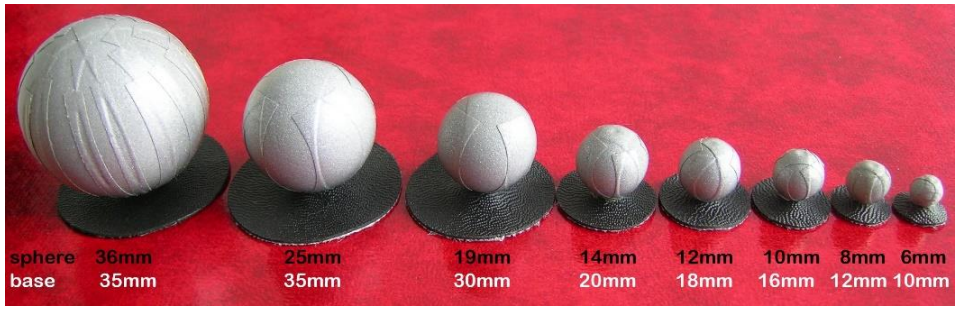
Vision systems for Motion Capture

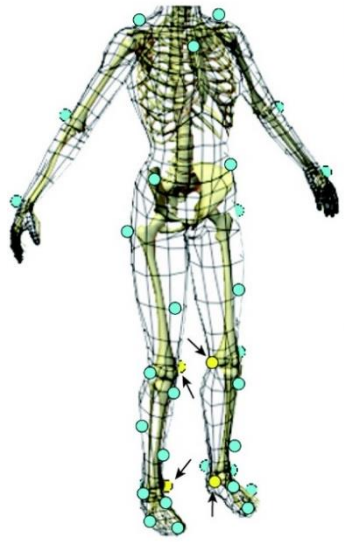


Stereoscopic system

- **BTS Smart-DX 7000**
  - Up to 16 cameras
  - Resolution of 2048 x 2048 pixels
  - Up to 2000 fps (500 fps at full frame)
  - Precision under 0.1 mm
  - Volume of 6 x 6 x 3 m
  - Strobe wavelength of 850 nm (IR light)

- **Set of reflective markers** fixed on the body





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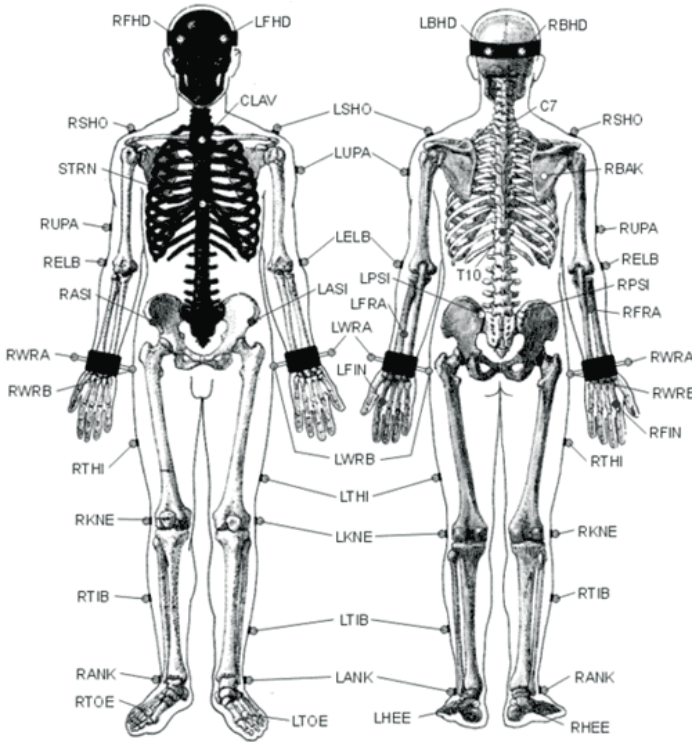
Vision systems for Motion Capture

Stereoscopic system

- It exists **plenty of Marker Placement**
  - Body Segment CM
  - Plug-in-Gait
  - Helen Hayes (Davis)
  - Cleveland Clinic Model
  - Golfer Full-Body
  - ….



- **Main drawbacks:**
  - Measurements need to be realized on the **skeleton**, not on marker fixed on **soft tissues** that are not even rigid respect to the skeleton.
  - **Markers** are numerous, complicated and fastidious to fix, and results depend entirely on how these marker are fixed.
  - **Expensive** (>200 k€)

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Vision systems for Motion Capture

TOF Systems

- **Microsoft Kinect V2**
  - RGB-D camera
  - 512 x 424 pixels, up to 30 Hz
  - Range from 0.5 to 4.5m - Field of view 70 ° x 60 °
  - Precision around 2 mm for the point cloud reconstruction
    - A. Corti, S. Giancola, G. Mainetti, R. Sala, "**A metrological characterization of the Kinect V2 time-of-flight camera",** *Robotics and Autonomous Systems*, vol. 75, pp. 584-594, 2016.

- **Integrated software for markerless human-motion capture**
  - Human body seen with 25 joints
  - On-line elaboration for real-time application
  - Machine learning black box feed with thousands of bodies (adults)
    - J. Shotton, T. Sharp, A. Kipman, A. Fitzgibbon, M. Finocchio, A. Blake, M. Cook, R. Moore, **"Real-time human pose recognition in parts from single depth images"**, *Communications of the ACM*, vol. 56, no. 1, pp. 116-124, 2013.

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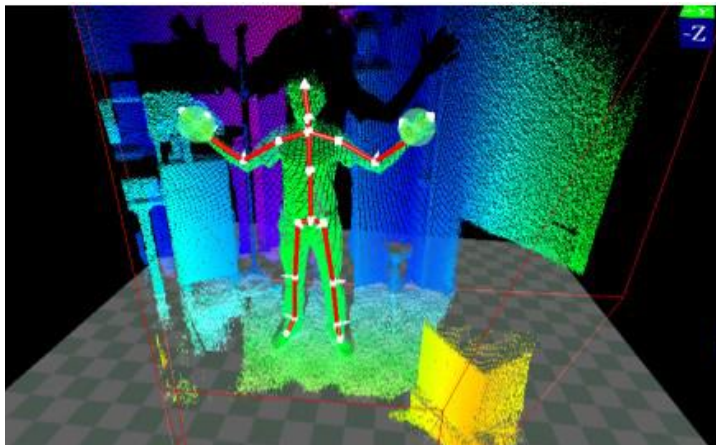
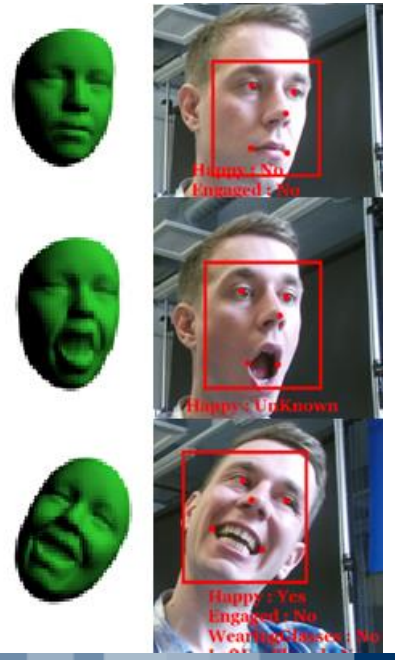
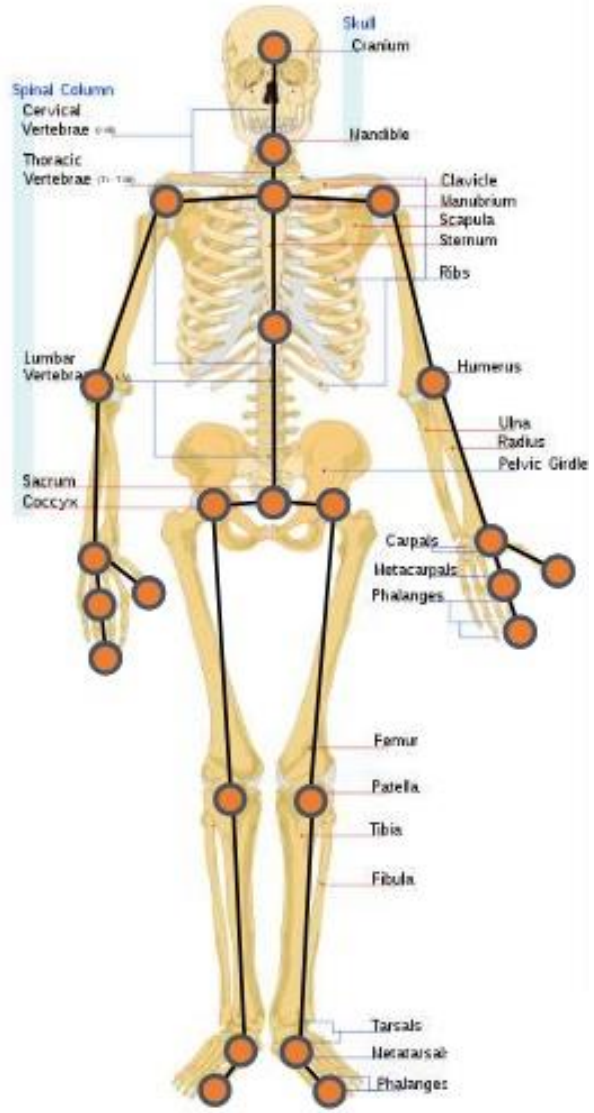
Vision systems for Motion Capture

TOF Systems

- **Markerless human-motion tracking**
  - Fully tracks up to six bodies simultaneously
  - Tracks up to 25 joints
    - Position in 3D space (in meters)
    - Absolute orientation (in quaternion)
  - (Hand state tracking)
  - (Face recognition)
  - Low cost (200 €)







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Villa Beretta - Experimental Setup

Gait and Movement Analysis Laboratory

1. BTS Smart-DX 7000 (8 cameras – 250 fps)
2. Footboard platform
3. Vision system for video recording

Our Setup

4. Kinect V2
   Single 3D camera
   30 fps

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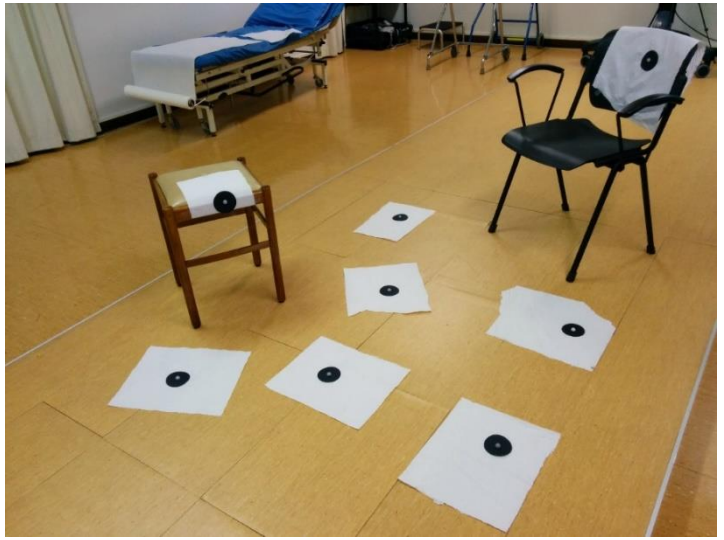
Villa Beretta - Experimental Setup

Registration of the 2 systems

- Set of point dispatched on the scene
  - Black circle detected by the Kinect V2 system
  - Reflective semi spheres detected by the BTS system



- 2 sparse point clouds measured and aligned through the solving of the Procrustes problem with an SVD-based algorithm
  - Dorst, Leo. **"First order error propagation of the procrustes method for 3D attitude estimation."** *Pattern Analysis and Machine Intelligence, IEEE Transactions* on 27.2 (2005)
  - Calculate the rotation matrix and the translation vector of one reference system respect to the other one
  - Computationally efficient and immediate (closed form solution)
  - Minimize the root mean square error

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Villa Beretta - Experimental Setup

- Single Marker Placement:
  - Wrist
  - Elbow
  - Shoulder
  - Cervical C7 vertebra
  - Thoracic T5 vertebra

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Villa Beretta - Standardized Exercises

Human Motion Capture

- Standardized exercises
  - Abduction
  - Hand-to-mouth
  - Reaching
  - Flex Elbow
  - Squat





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Villa Beretta – Standardized Exercises

Focus on Inverse Kinematics

- Position reaching (Wrist)
  - Position measurements in 3D space
  - Abduction exercise
  - Hand-to-mouth exercise
  - Reaching exercise

- Angle motion ranges
  - Range of angular motion, min and max extension
  - Flex Elbow exercise
  - Squat exercise

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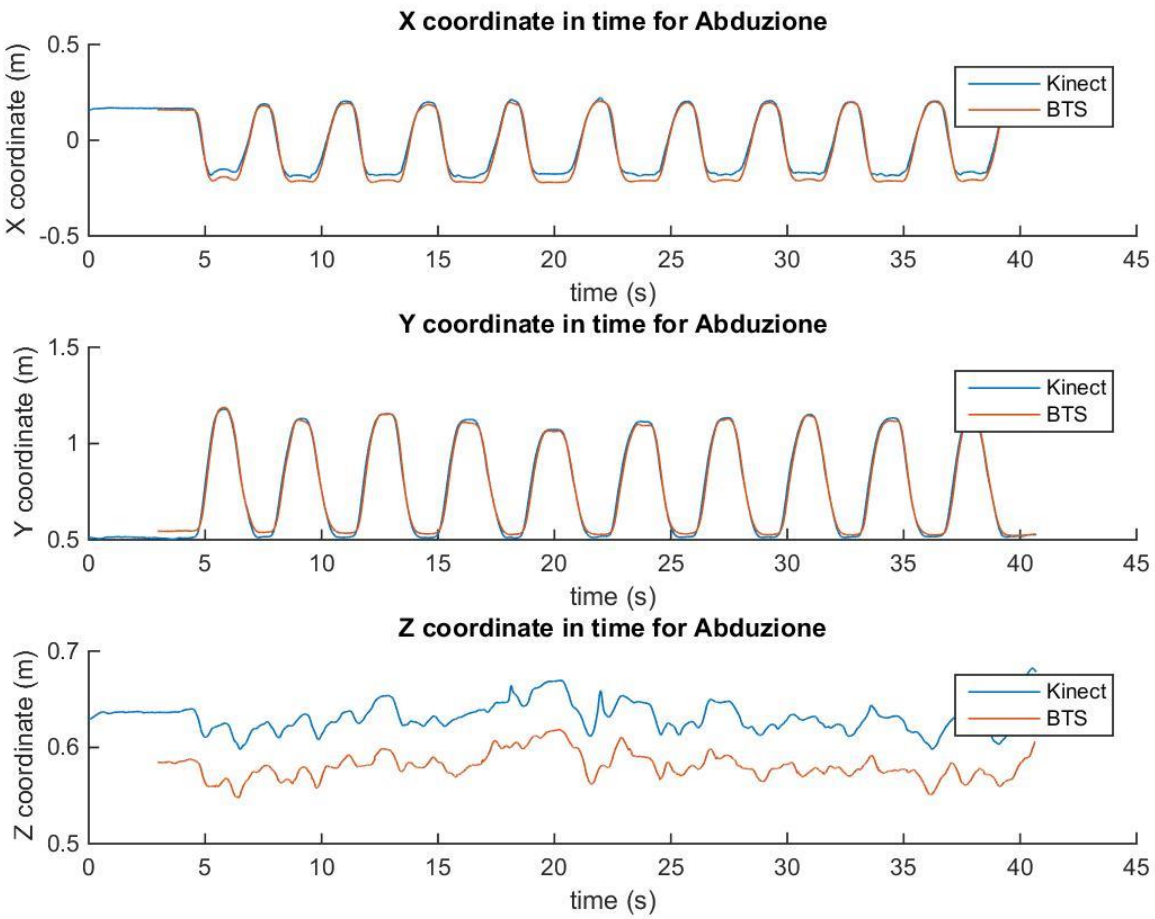
Villa Beretta – Position Measurement

- **Abduction exercise:**



Comments:

- X / Y follow the same pattern
- Offset in Z (depth)
- Different positions are tracked for the wrist, translated in Z, due to marker placement

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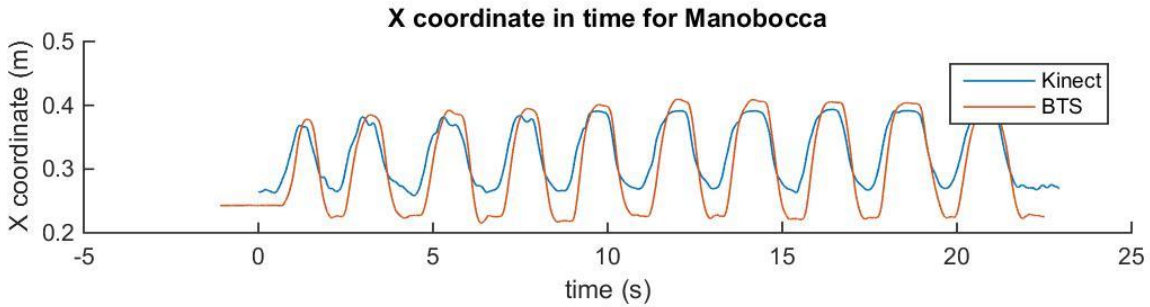
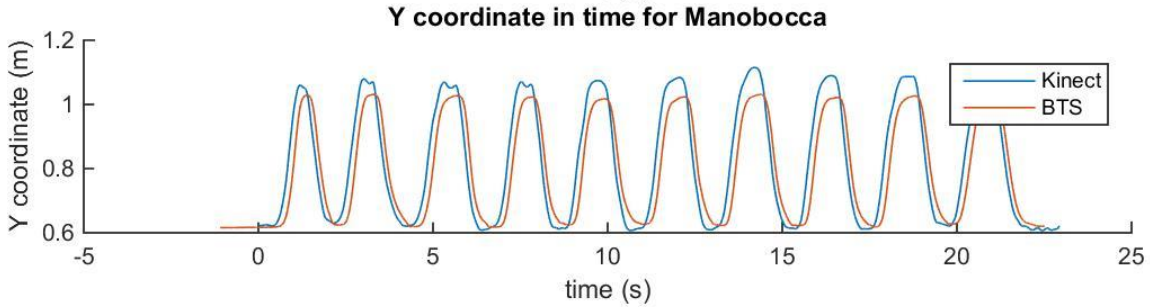
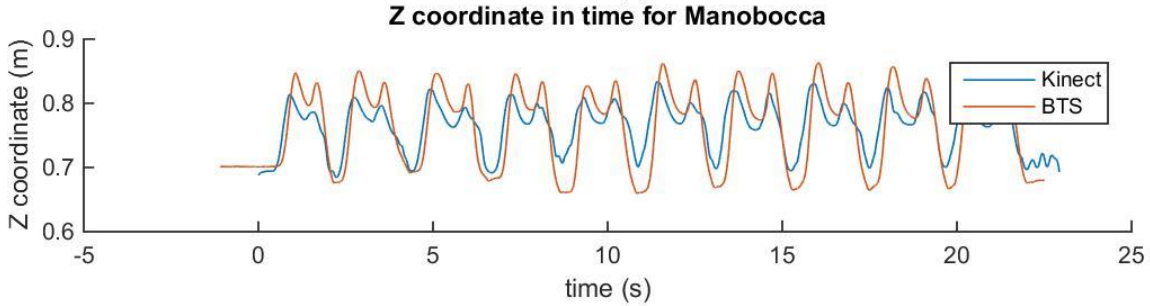
Villa Beretta – Position Measurement

- **Hand-to-mouth exercise:**







Comments:

- Follow the same pattern
- Offset in X, Y & Z

- Different positions are tracked for the wrist, translated in all directions, due to marker placement

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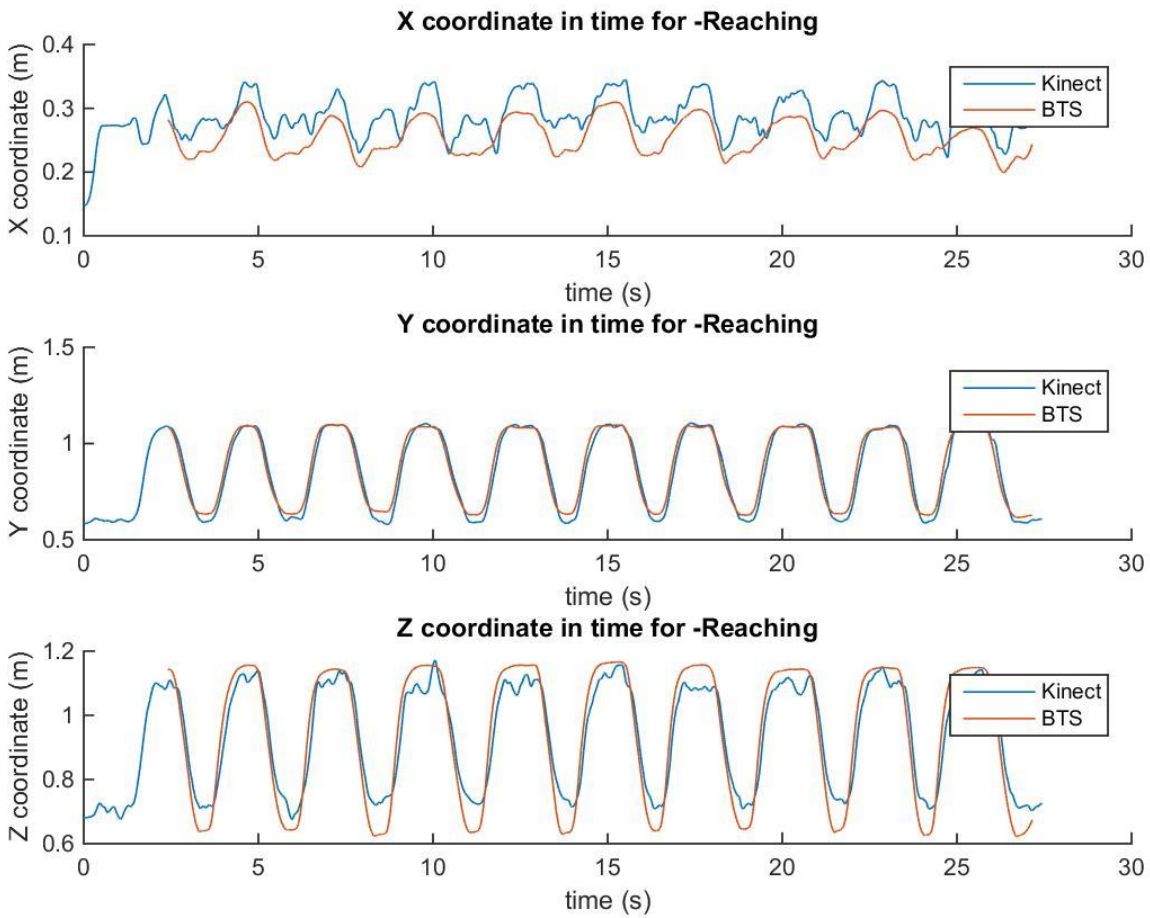
Villa Beretta – Position Measurement

- **Reaching exercise:**



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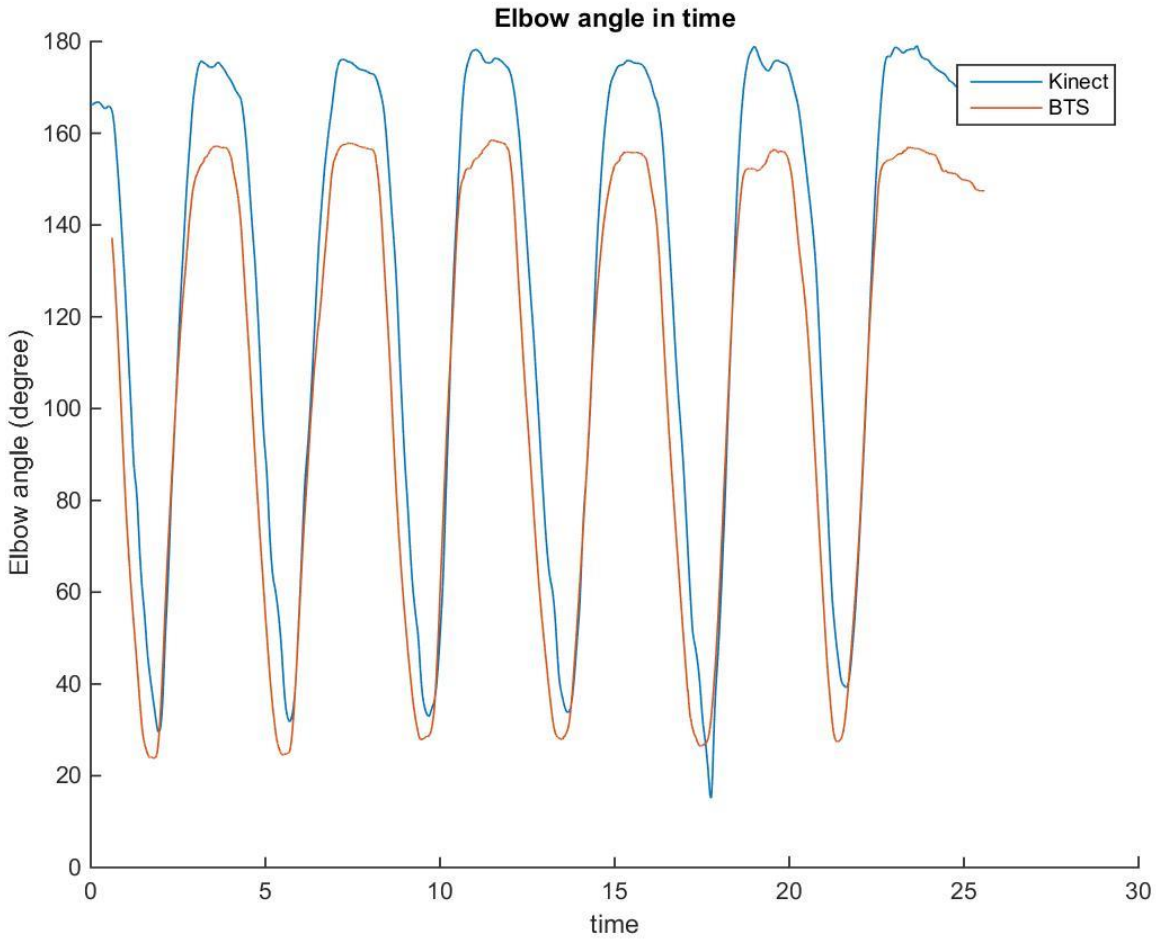
Villa Beretta – Angle Measurement

- **Flex elbow exercise:**



Comments:

- Follow the same pattern
- Extrema are differents

- Different positions are tracked for shoulder, elbow and wrist

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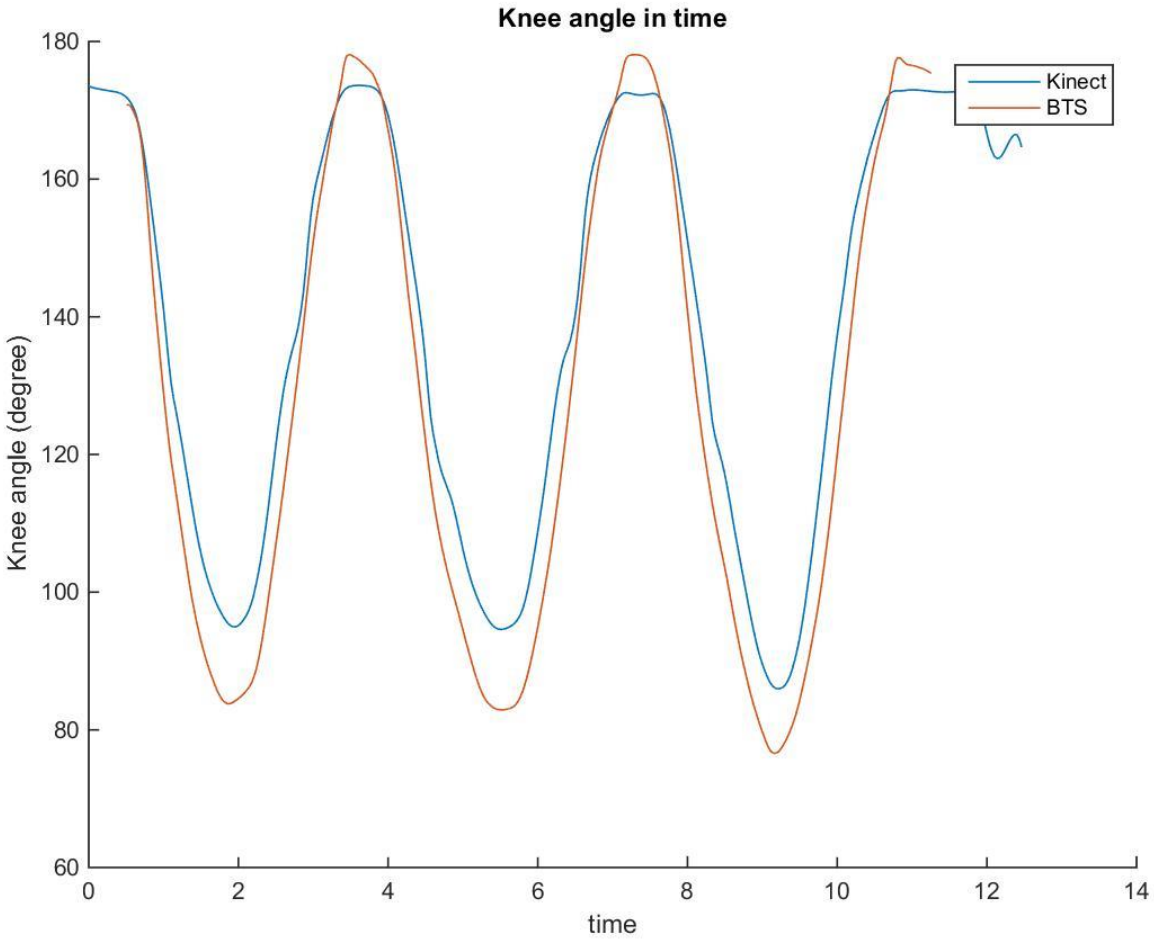
Villa Beretta – Angle Measurement

- **Squat exercise:**



Comments:

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- Different positions are tracked for hip, knee and ankle

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Villa Beretta – Standard Exercises

Global Results / Comments

- The **global movement** is measured by both system: the Kinect is able to track the position of the joints in a similar way than the single marker placement with BTS

- 2.5 / 3 dimensions systems
  - Kinect: 2.5D system acquire from a **single point of view**
    - Suffer from **occlusion**
  - BTS: full 3D system acquire from **different point of view**
    - Allow a **full 3D tracking**

- Different positions are tracked by the 2 systems:
  - Kinect: more "**true**" position of the joint
  - BTS: a **marker** representative for the joint

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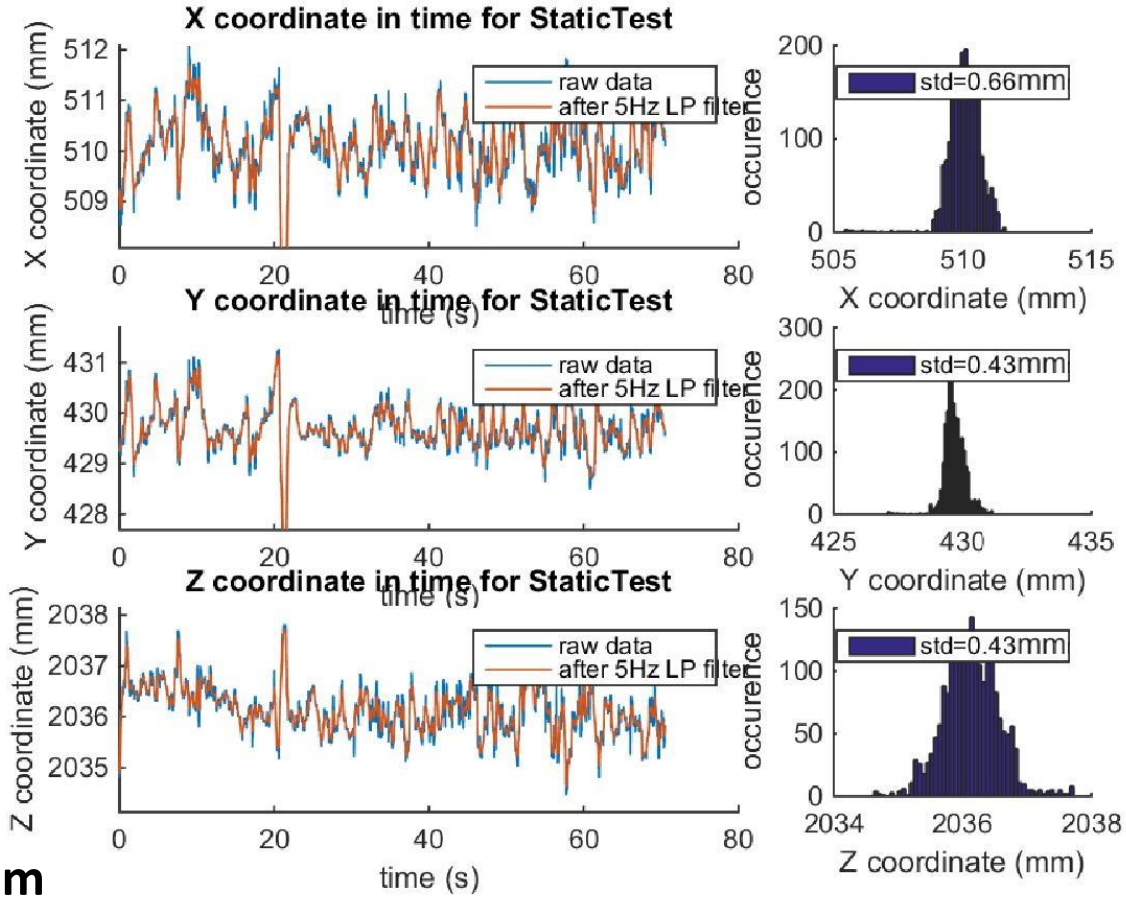
Villa Beretta – Accuracy Estimation

Wrist position uncertainty measurement estimation:

- Static position for more than a minute (30Hz)
  - **> 1800 samples**
- **HP filter at 0.01Hz**
  - Removes drift
- **LP filter at 5Hz**
  - Reduces noise
- Statistical characterisation
  - uncertainty = f(std)
- **Position uncertainty < 1 mm**



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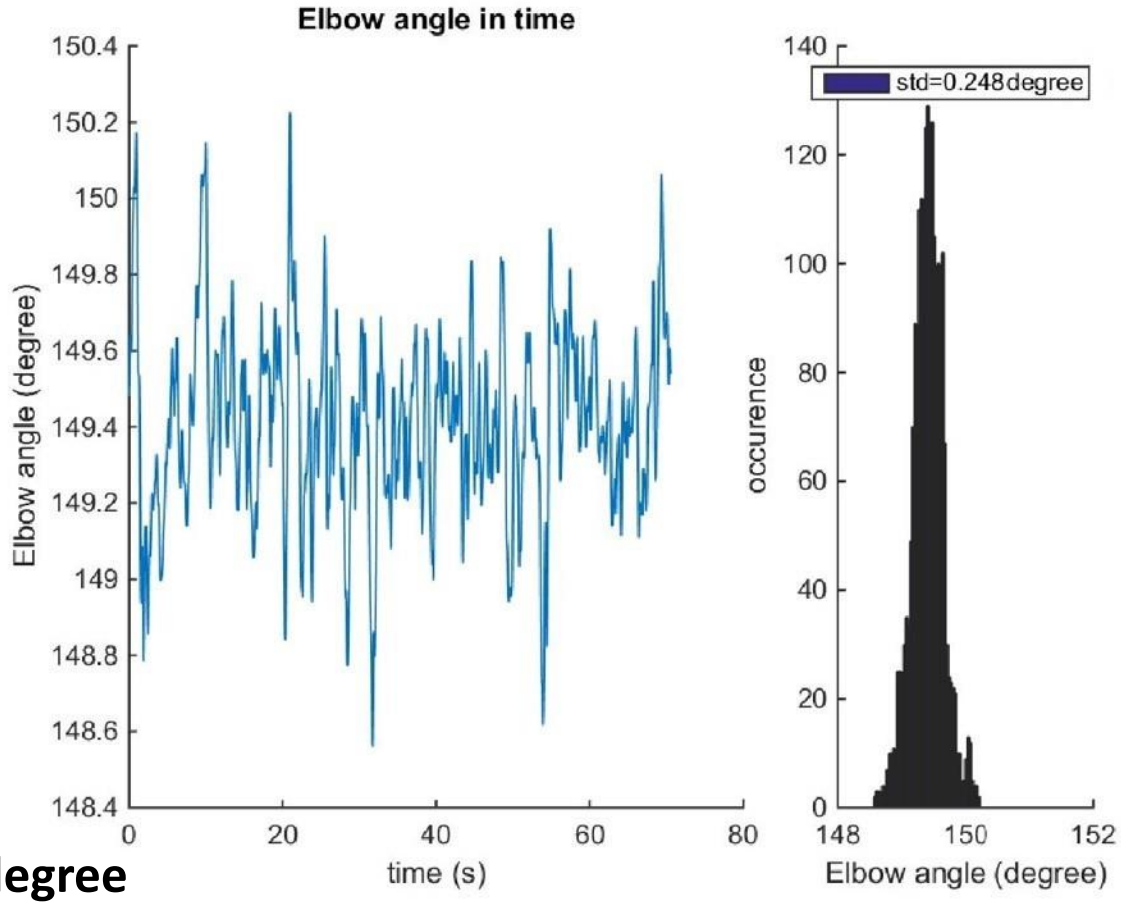
Villa Beretta – Accuracy Estimation

Elbow angle uncertainty measurement estimation

- Static position for more than a minute (30Hz)
  - **> 1800 samples**
- **HP filter at 0.01Hz**
  - Removes drift
- **LP filter at 5Hz**
  - Reduces noise
- Statistical characterisation
  - uncertainty = f(std)
- **Angle uncertainty < 0.25 degree**



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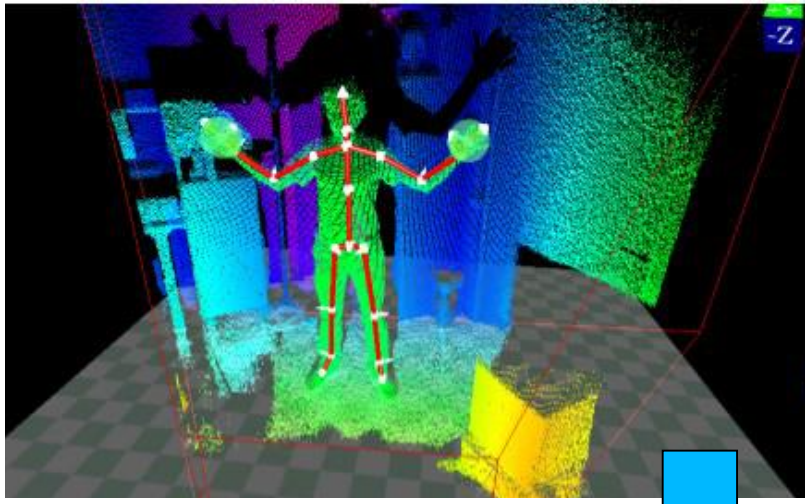
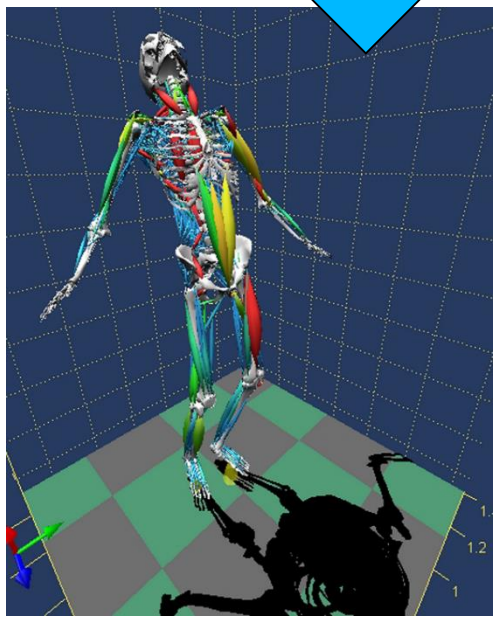


Kinect V2 sensor for gait analysis:

- Markerless vision system
  - ➢ reduces preparation time
- Track position inside a body
  - ➢ real joints, not markers
- Precision < 1 mm; < 0.3 degree
  - ➢ aggravation from one order of magnitude respect to BTS solution

Next Steps:

- Extend study on all the joints measured by the Kinect
- Extend to more than 1 Kinect
  - ➢ Multi-view RGB-D measurement
- Extend to Dynamics study:
  - ➢ Pass trajectories to Villa Beretta Multi Body model in order to get muscle activity measurements
  - ➢ Coupling with BoB (Biomechanics of Bodies) Human Multi Body Kinematics and Dynamics model



Summary

- Introduction
- Vision systems for Motion Capture
  - BTS Smart-DX 7000
  - Microsoft Kinect V2
- Kinematics analysis
  - Experimental Setup
  - Wrist position measurement
  - Elbow angle measurement
- Uncertainty Estimation
  - Wrist position
  - Elbow angle
- Conclusion
- **References**

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