HIGH PERFORMANCE, LOW LATENCY 3D SENSOR NETWORK FOR LIVE FULL OBJECT RECONSTRUCTION

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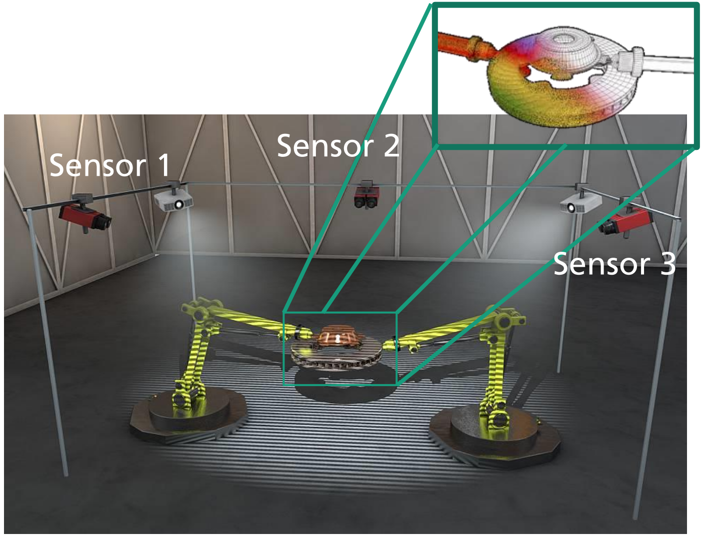
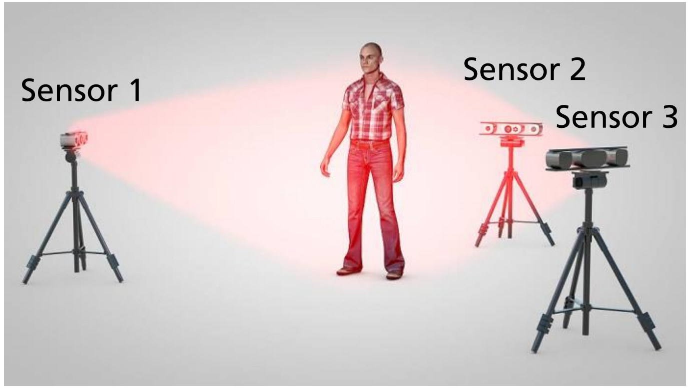
Motivation

- Continuous 3D capture for monitoring
  - Simultaneous 3D calculation and processing
- Combination of multiple sensors for full object reconstruction:
  - Occlusion-free monitoring (assembly, in-line quality control)
  - Human-Machine-Interaction (including medical application areas)





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- 3D sensor network system architecture
- Calibration approach
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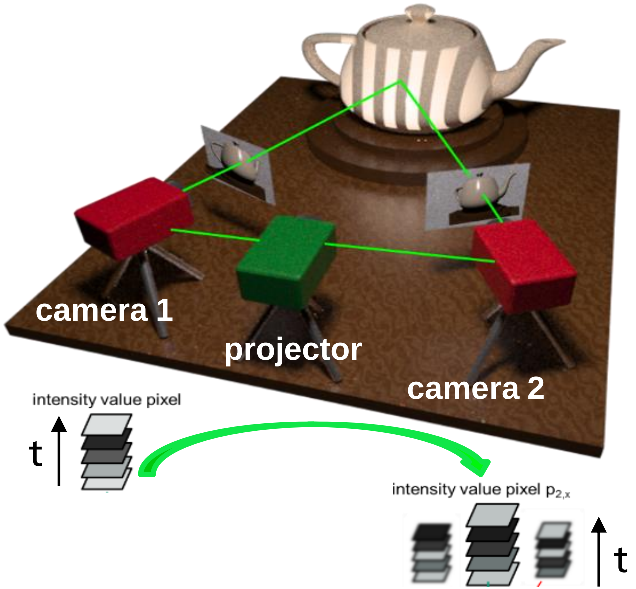
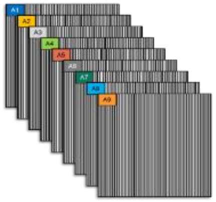
3D sensor network system architecture

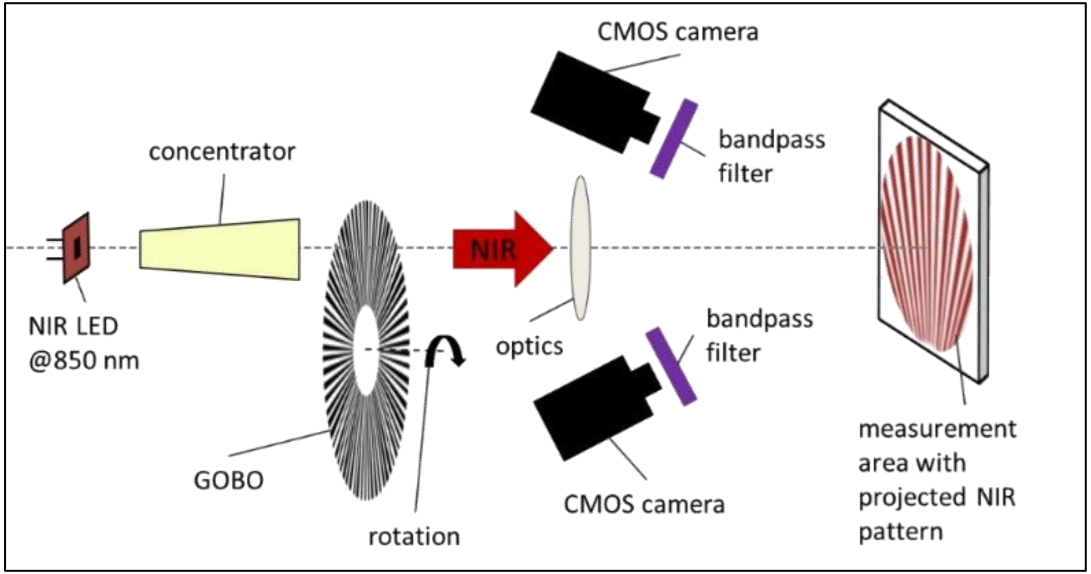


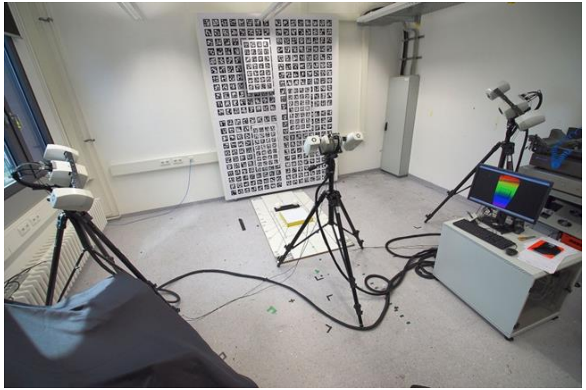


- Active pattern projection of aperiodic sinusoidal fringes in stereo setup[1]:
  - Detection of corresponding points by **normalized temporal cross-correlation**

[1] S. Heist, A. Mann, P. Kühmstedt, P. Schreiber, G. Notni: Array projection of aperiodic sinusoidal fringes for high-speed three-dimensional shape measurement, Opt. Eng. 53(11), 112208 (2014)

3D sensor network system architecture





- GoBo-based near infrared (NIR) pattern projection[1]:
  - Irritation-free: fringes are invisible (@ 850nm)

[1] Heist, Stefan; Lutzke, Peter; Schmidt, Ingo; Dietrich, Patrick; Kühmstedt, Peter; Tünnermann, Andreas; Notni, Gunther: High-speed three-dimensional shape measurement using GOBO projection, Optics and Lasers in Engineering 87, 2016

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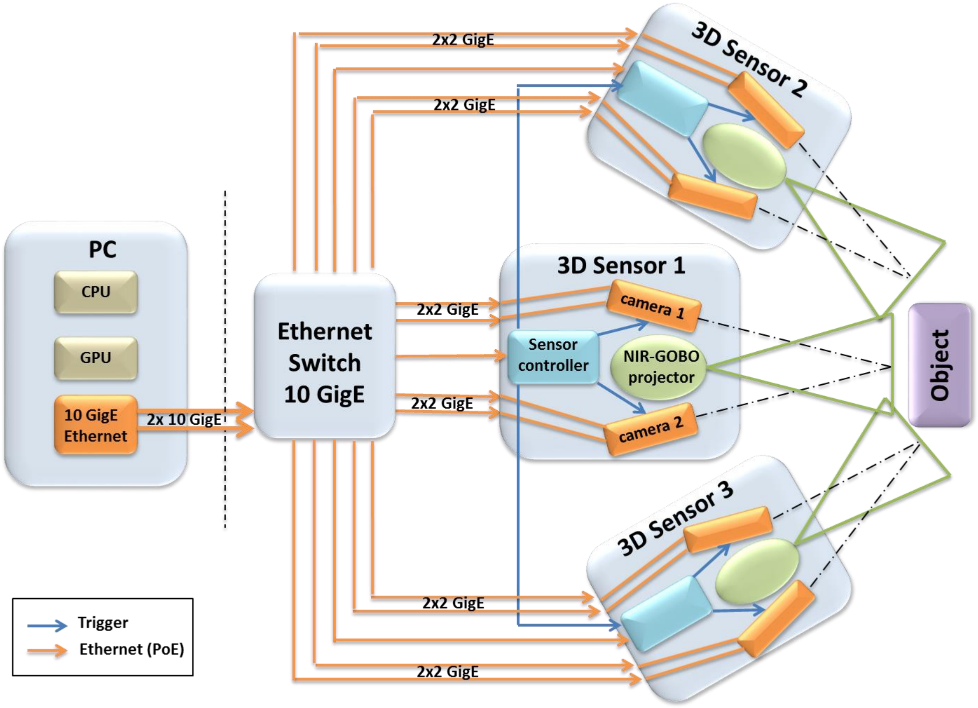
3D sensor network system architecture (three sensors)

- Dual Gigabit Ethernet links for up to 230 Megapixel / s 2D image rate
- 10 Gigabit Ethernet Switch as uplink concentrator for up to 10 cameras per off-the-shelve PC dual port Ethernet card
- Online 3D calculation using GPU-based vendor-neutral OpenCL code



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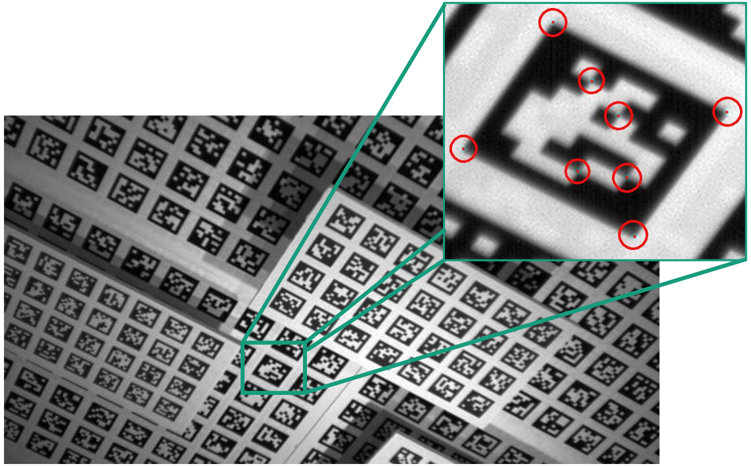
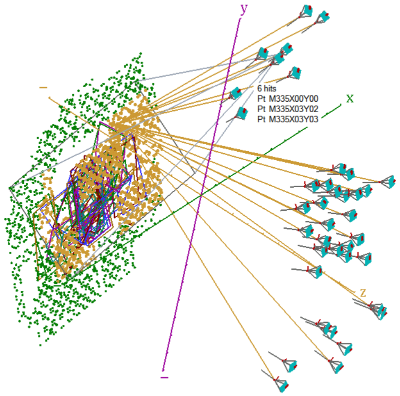
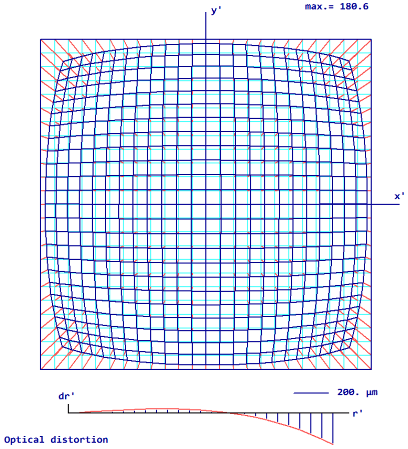
Calibration approach – intrinsic

- Intrinsic calibration via photogrammetry / bundle block adjustment
  - 2000+ markers using ArUco[1)] marker encoding
  - Multiple calibration images with uniform NIR-lighting
  - Bundle block adjustment for precise camera parameter determination







[1)] S. Garrido-Jurado, R. Munoz-Salinas, F.J Madrid-Cuevas, M.J. Marín-Jiménez: Automatic generation and detection of highly reliable fiducial markers under occlusion; ArUco; https://www.uco.es/investiga/grupos/ava/node/26; Pattern Recognition (2014)

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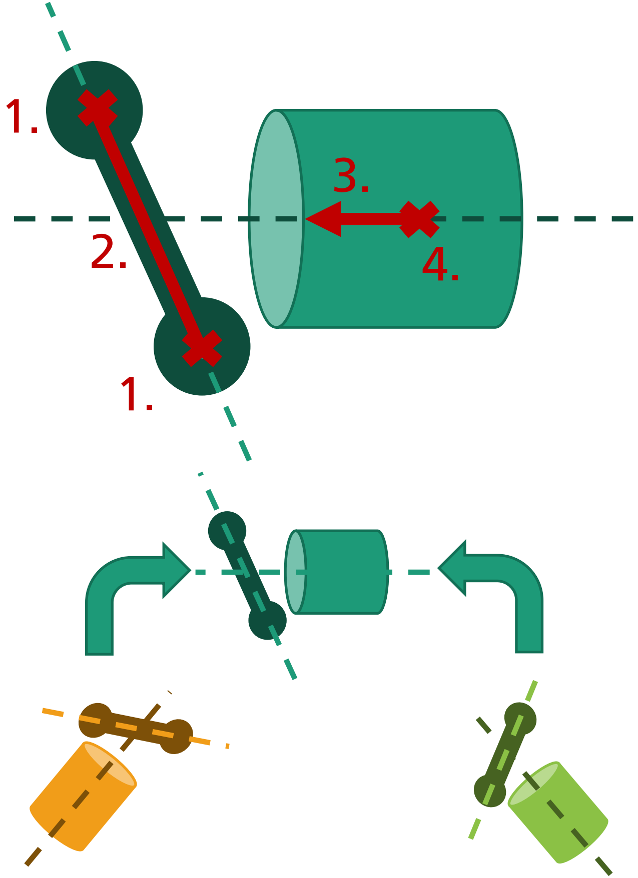
Calibration approach – extrinsic

- Calibration target: ball bar connected with cylinder
- Three sensors → Three 3D-views
- Step by step using knowledge:
  1. Sphere center points
  2. Ball bar length
  3. Cylindrical axis
  4. Any inner cylindrical point on axis



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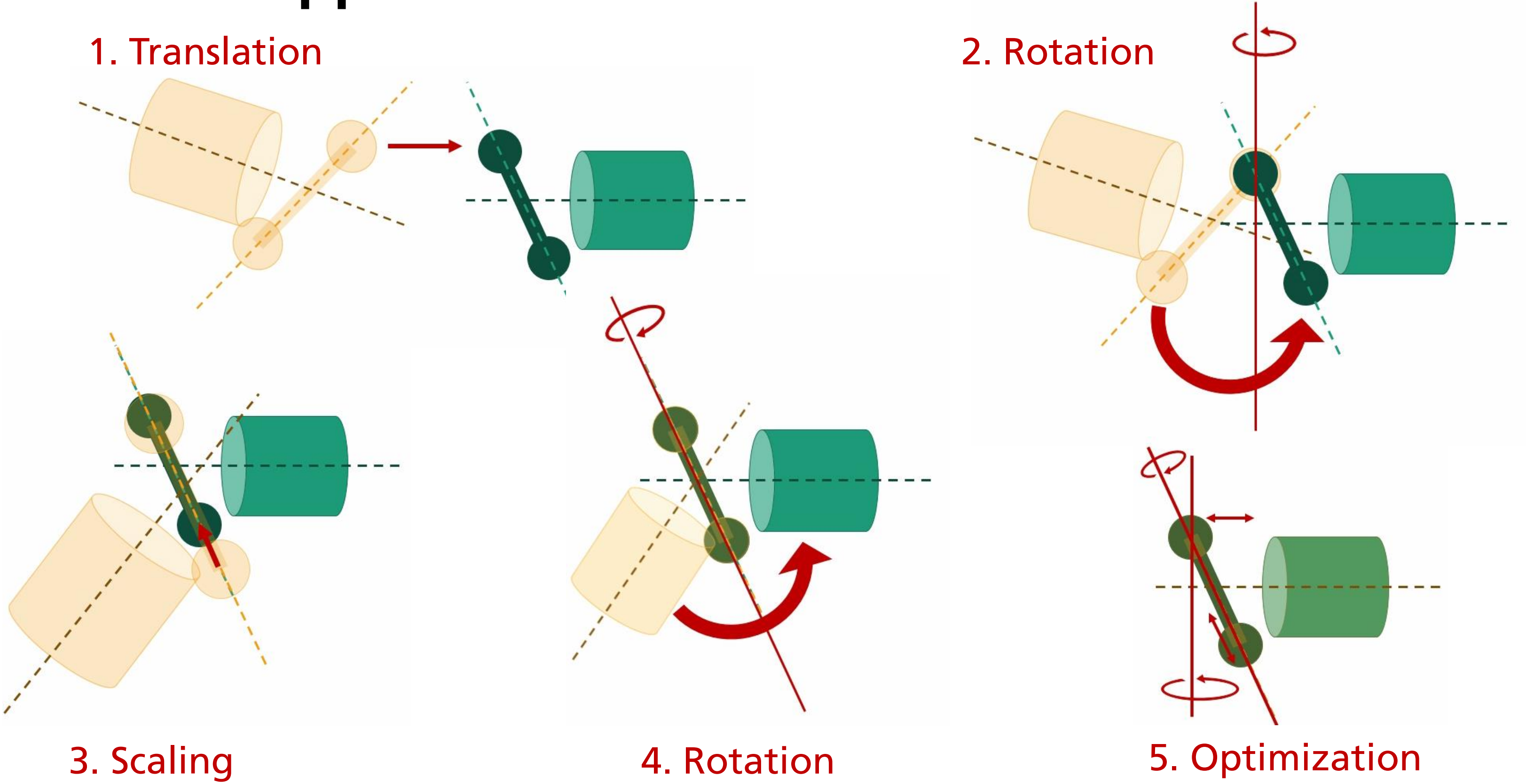
Calibration approach – extrinsic



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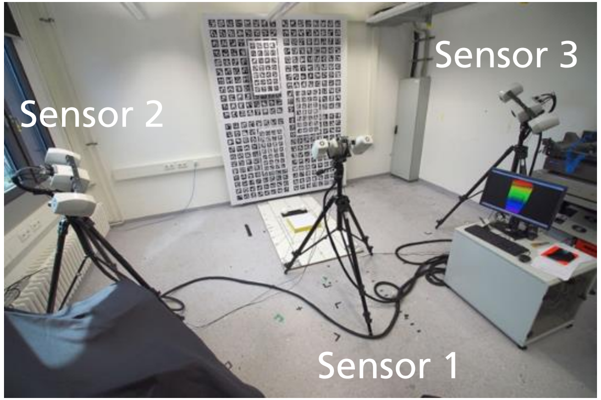
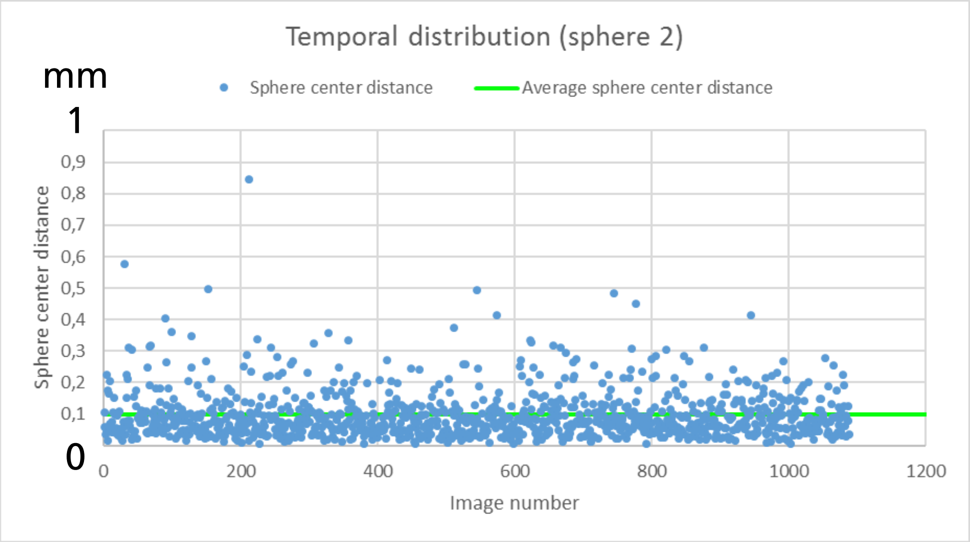
Three sensor system characterization



Three sensors, continuous data stream:

- 10 fps (@ 2 megapixel)
- End to end latency: ~90 ms … ~150 ms
- Sphere: Average distance to average sphere center σ:
  - Three sensors: σ= 0.10 mm



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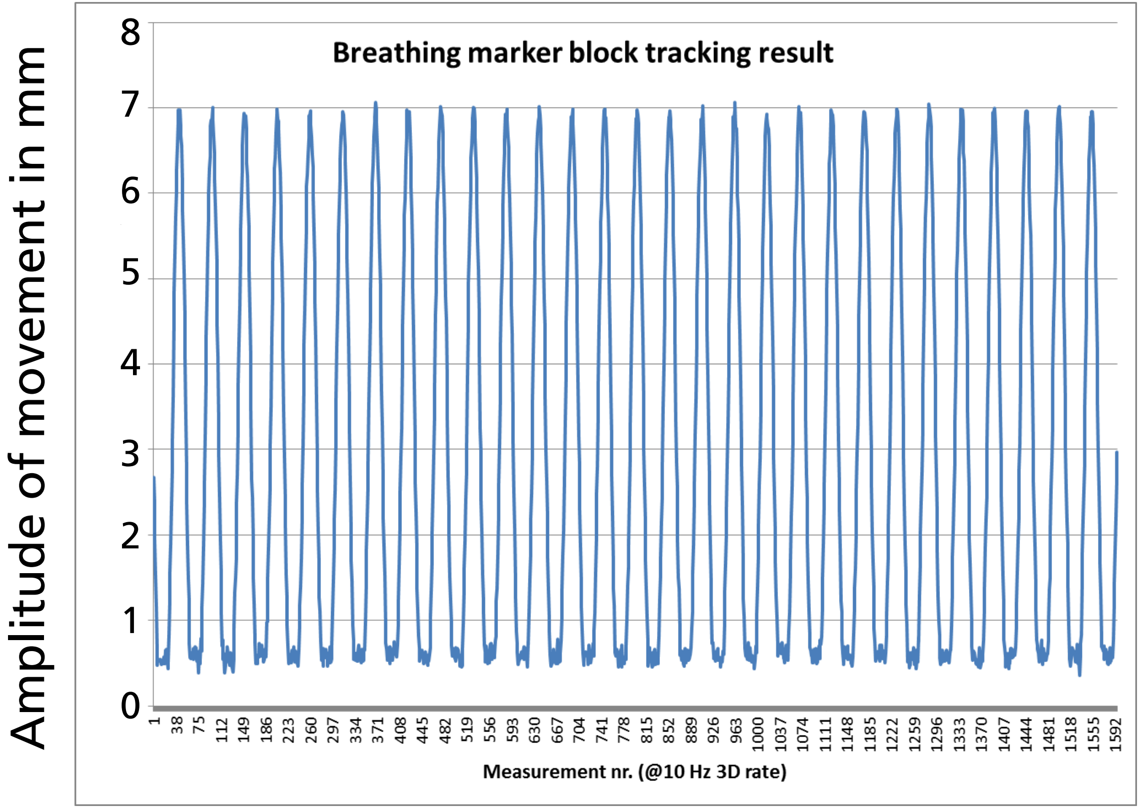
Measurement examples (1)




Underlying 2D image


Single 3D reconstruction

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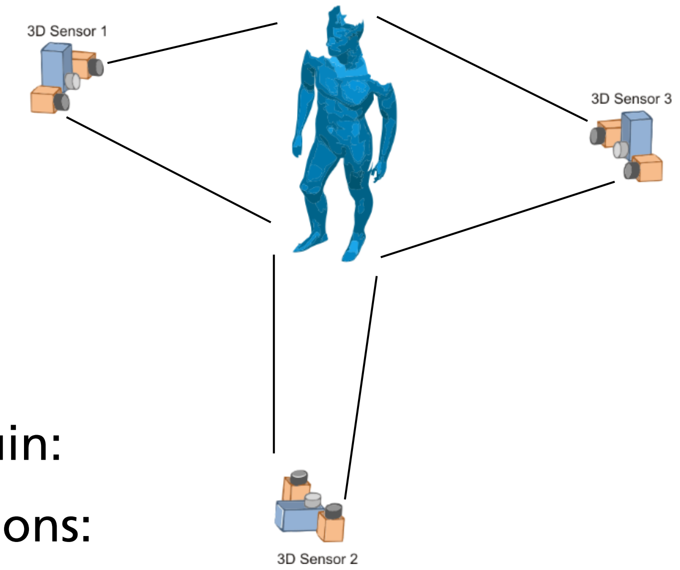
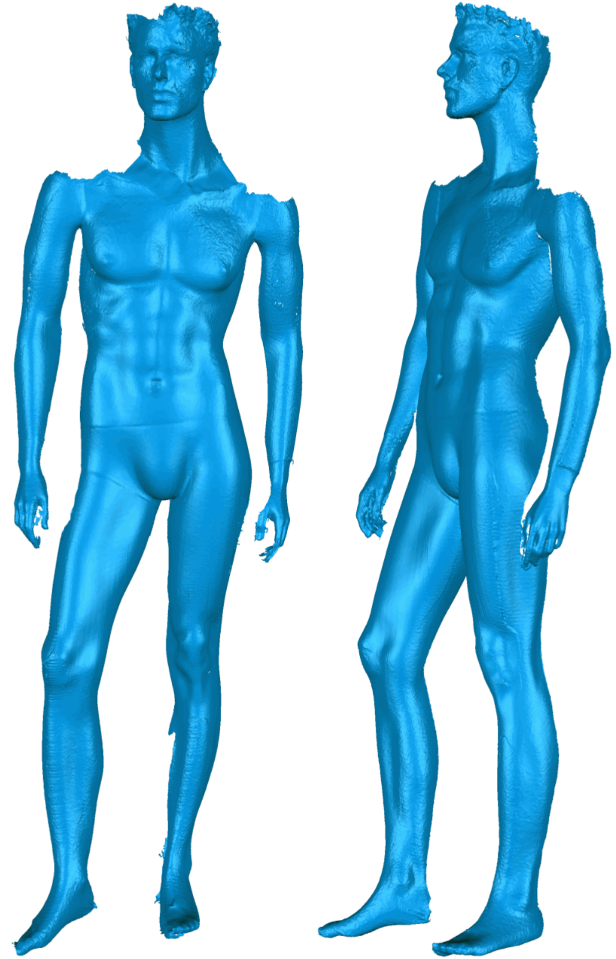
Measurement examples (2)





Object – Mannequin:

- Object dimensions:

  570 x 1850 x 320 mm³

- Measuring field:

  600 x 2000 x 400 mm³

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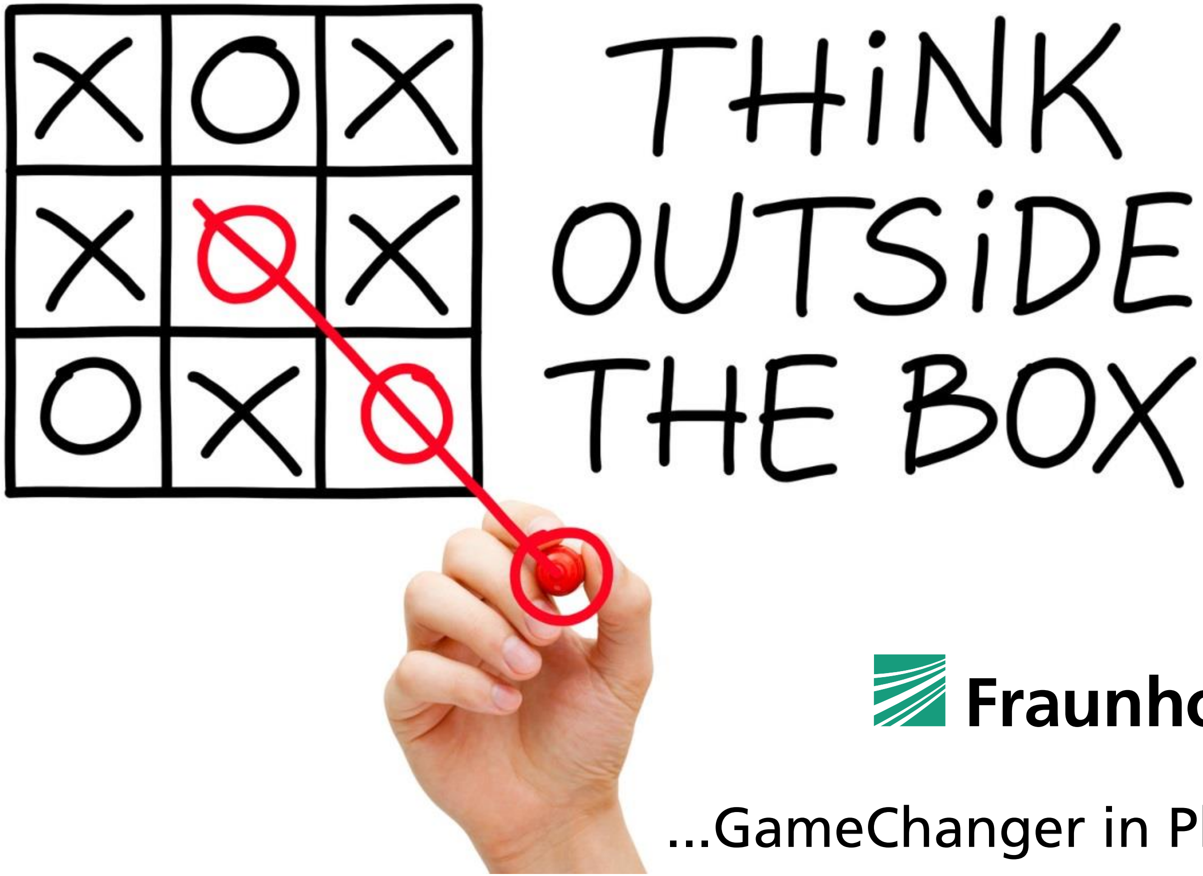
Summary

- We have shown a 3D scanning system with:
  - Continuous data stream with three sensors with 10 fps @ 2 megapixel
  - Several synchronized 3D sensors in a smart system architecture
  - Simultaneous calculation and processing of 3D data
  - Low latency measurements with high measurement accuracy
  - Measurement of a complete human body with irritation free fringes



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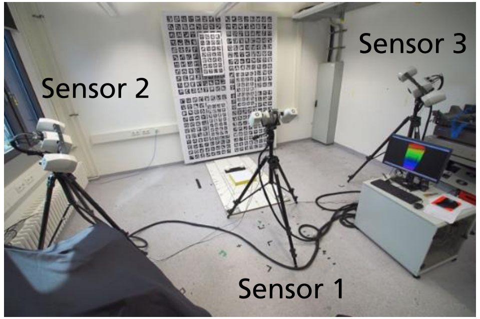
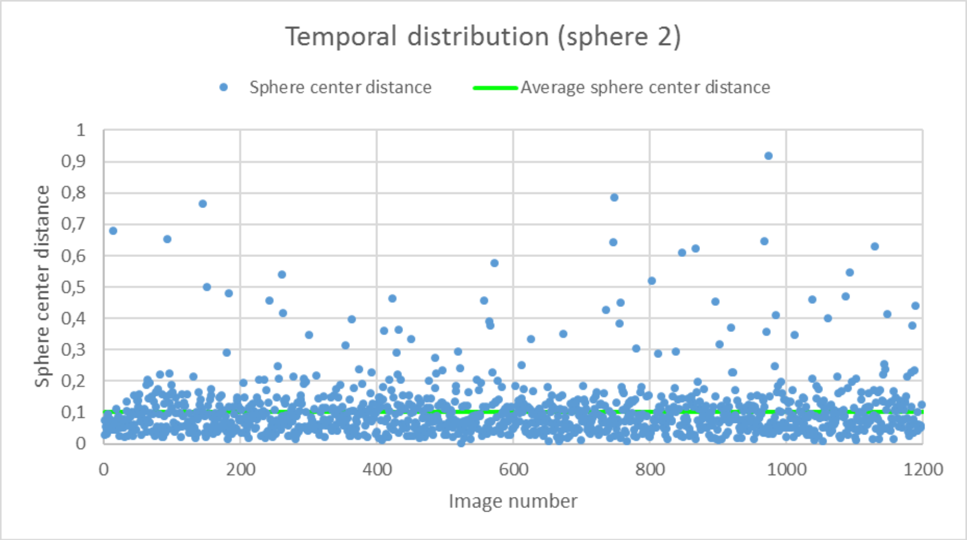
Three sensor system characterization



Single sensor, continuous data stream:

- 10 fps (with 2 megapixel)
- End to end latency:
  ~90 ms … ~150 ms
- Sphere: Average distance
  to average sphere center σ:
  - Sensor 1: σ= 0.07 mm
  - Sensor 2: σ= 0.09 mm
  - Sensor 3: σ= 0.10 mm



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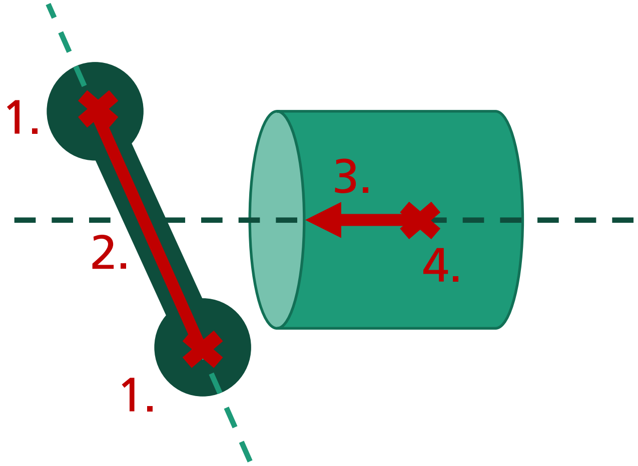
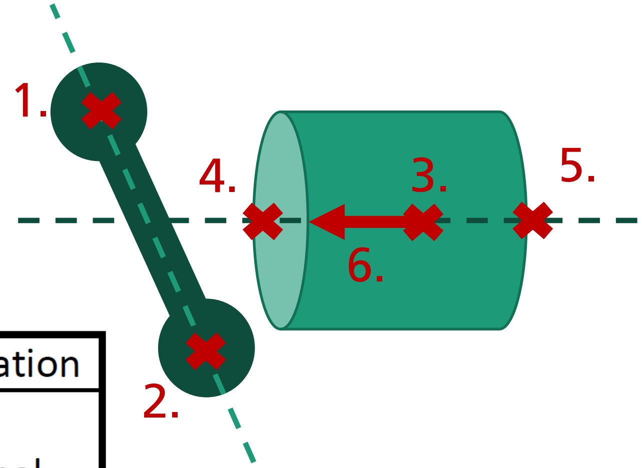
Calibration approach - extrinsic



- **Simulation** based on standard deviation of fitted/measured data:
  1. Sphere center points: standard deviation $\sigma = \mathbf{200}\mu\mathbf{m}$
  2. Ball bar length: depending on 1.
  3. Cylindrical axis: $\sigma = \mathbf{0.001}°$ (equal to 300 µm deviation within cylinder)
  4. Any inner cylindrical point on axis: $\sigma = \mathbf{300}\mu\mathbf{m}$
- **10,000 runs** each (i.e. with and without optimization)

Calibration approach – extrinsic



			with optimization		without optimization		
			deviation		deviation		
			standard	maximal	standard	maximal	
	sphere 1	1.	0.034	0.166	0	0	mm
	sphere 2	2.	0.033	0.162	< 1e-12	< 1e-12	mm
Cylinder	inner point	3.	0.073	0.450	0.0780	0.501	mm
	frontal point	4.	0.074	0.388	0.099	0.512	mm
	rear point	5.	0.073	0.358	0.121	0.670	mm
	axis	6.	0.013	0.070	0.011	0.046	°

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