Recent development of micro-triangulation for magnet fiducialisation

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CERN CLIC European Commission PACMAN ETH zürich ETALON PRODUCTIVE METROLOGY

"In the Beginning was the…" PACMAN Project

a study on Particle Accelerator Components' Metrology and Alignment to the Nanometre scale

an Innovative Doctoral Program, hosted by CERN providing training to 10 Early Stage Researchers.

WP1: Metrology & Alignment

ETH zürich
Cranfield UNIVERSITY
HEXAGON METROLOGY
eTALON PRODUCTIVE METROLOGY

WP2: Magnetic Measurements

Università degli Studi del Sannio
SIGMAPHI
METROLAB
ELTOS

WP3: Precision mechanics & nano-positioning

TU Delft
DMP
SYMME
TNO innovation for life
lapp
Cranfield UNIVERSITY

WP4: Microwave Technology

UNIVERSITÀ DI PISA
IFIC
NATIONAL INSTRUMENTS

Outline

Objectives

Measuring system

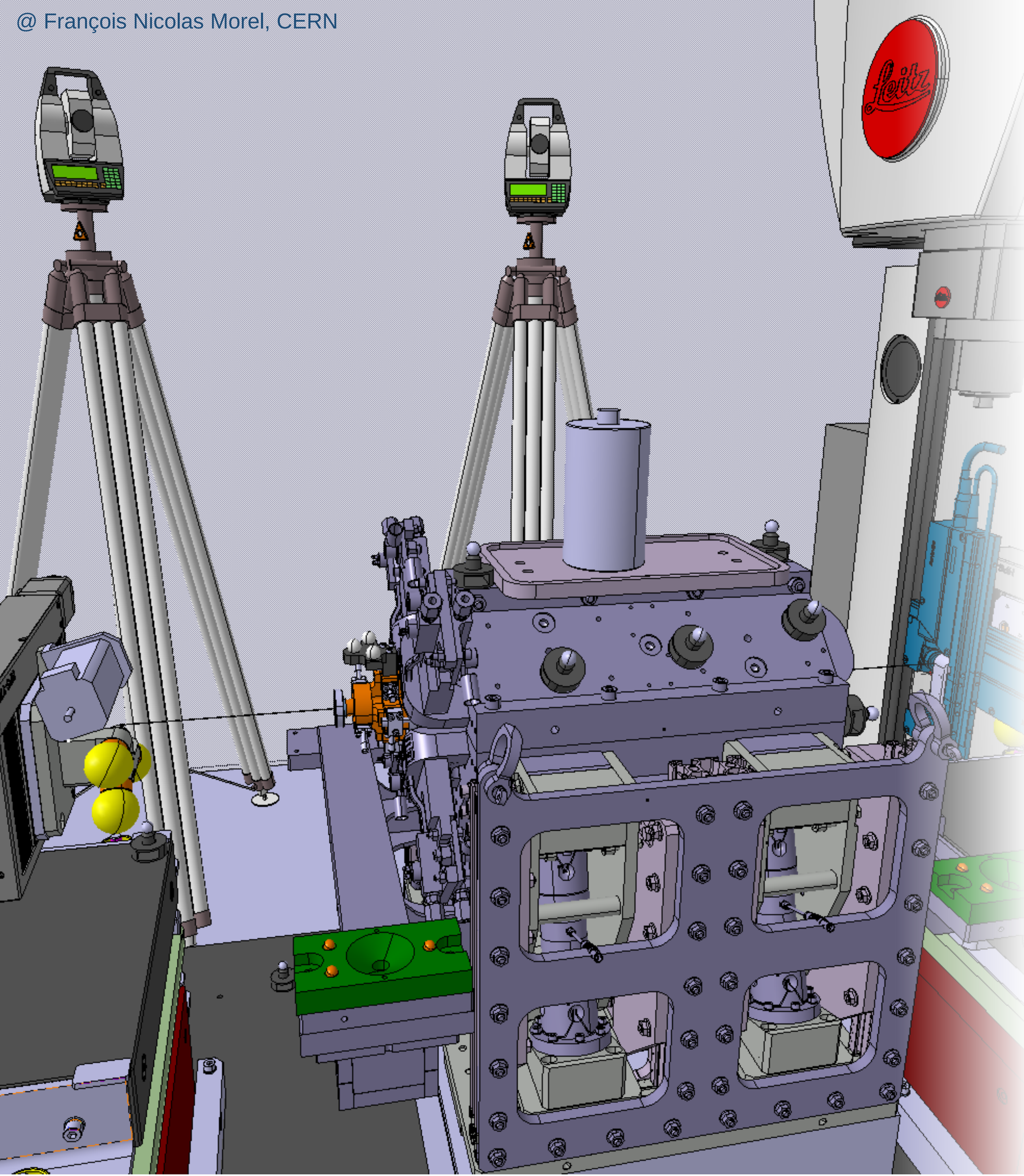
Developments

Measurement bench

Preliminary results

Conclusion & Outlook

Objective



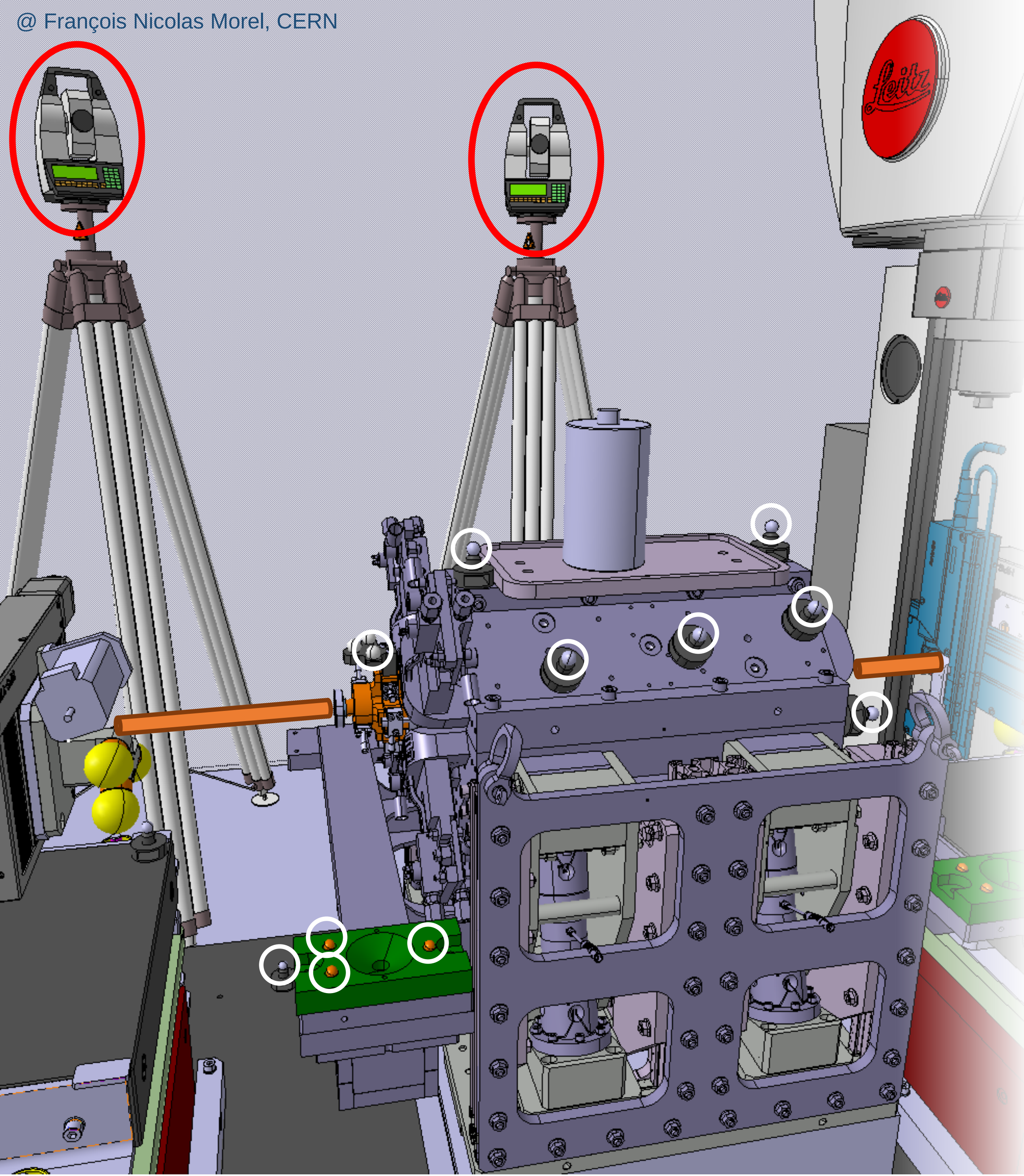
To link the fiducials with the wire, in geometric sense.

- Mechanical axis → fiducials
- Magnetic axis } stretched wire
- Electric axis }

To measure the fiducials and the wire using theodolites.

- Observations → angles (horizontal, vertical)

- Leica TDA5005 theodolite.
- QDaedalus measuring system.
- Computer vision techniques.
- Least-squares analysis.



Leica TDA5005:

- Robotic theodolite.
- High accuracy:

$$0.5 \text{ arcsec} \,/\, 2.4 \, \frac{\mu\text{m}}{\text{m}}$$

Ceramic spheres:

- Ø 12.7 mm / Ø 8 mm
- Grade 40 (sphericity 1 µm)

Copper-Beryllium (CuBe) wire:

- Ø 100 µm / Ø 125 µm

Main features of micro-triangulation

☺ Advantages:

- Accurate – a few micrometers

- Automatic – no need for observers

- Contactless – ideal for stretched wires

- Remote-controlled – ≈ 7 m meters in cable, ∞ on-line

- Fast – a series (network) in < 10 min

- Portable – a few boxes…

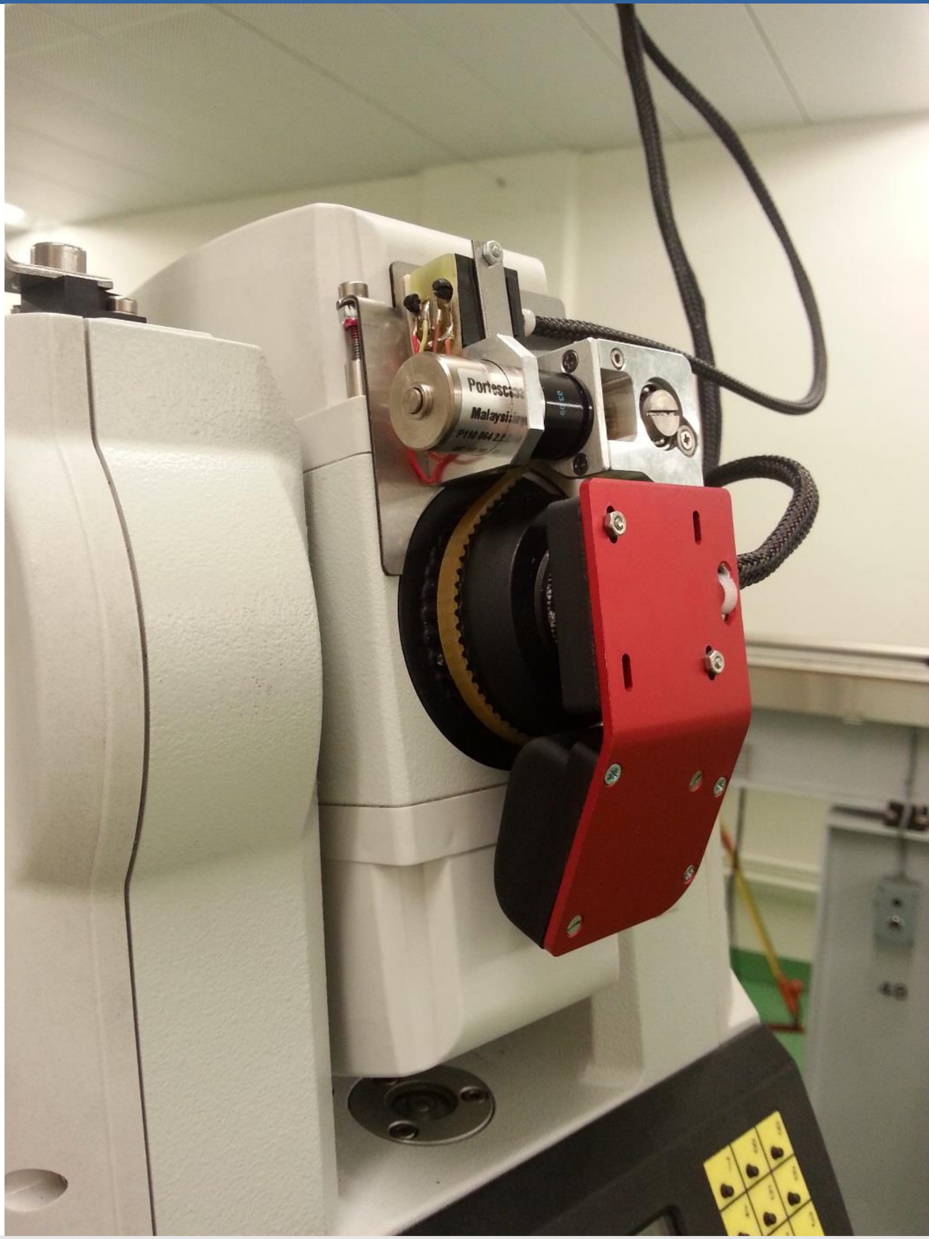
☹ Disadvantage:

- The scale: should be introduced as constraint

Measuring system

QDaedalus – hardware

- The system is developed at ETH zürich.
- Based on industrial robotic theodolites.
- **Principle**: reversible replacement



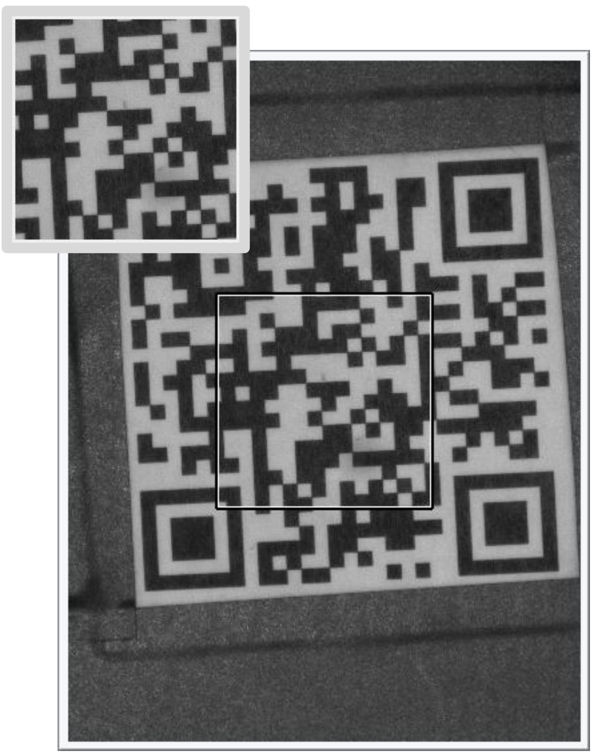
More info: B. Bürki et al., “DAEDALUS: A versatile usable digital clip-on measuring system for Total Stations”, in IPIN2010, Zurich, Switzerland, 2010.

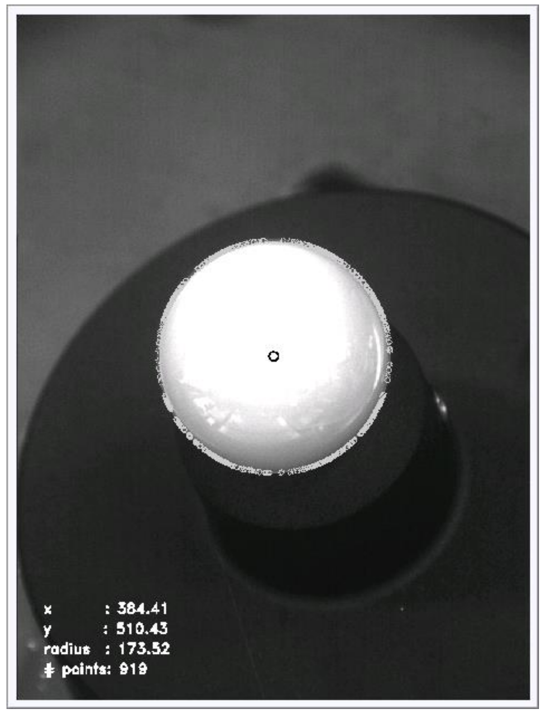
QDaedalus – software

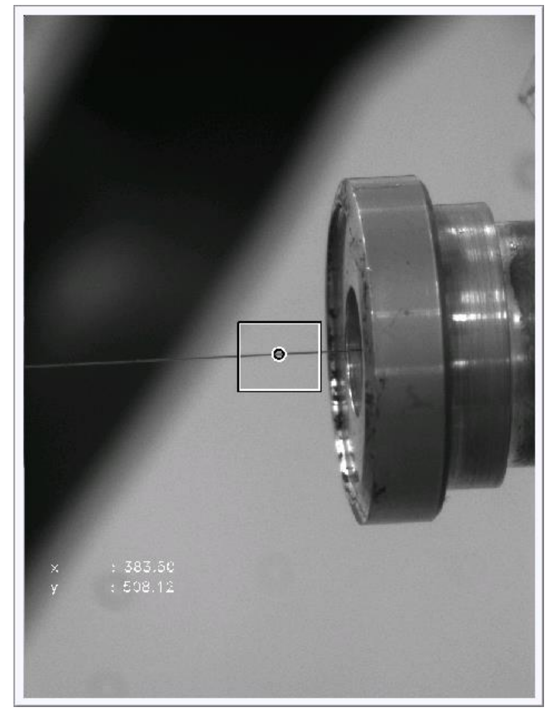
Based on Open Source Software:

Optical Target Recognition algorithms:

- Template least-squares matching
- Circle matching
- Line matching (developed in PACMAN)







More info: S. Guillaume et al., “QDaedalus: Augmentation of Total Stations by CCD Sensor for Automated Contactless High-Precision Metrology”, in FIG Working Week 2012, Rome, Italy, 2012.

Developments

Developments within PACMAN Project

Aim: To measure the targets (**fiducials**) and the **stretched wire** in a one coordinate system.

- ✓ **Development** and **validation** of an **algorithm** to **detect** and **measure** the stretched wire.
- ✓ **Development** and **validation** of a **method** to **integrate** the stretched wire into a geodetic network.
- ✓ **Development** and **validation** of a **software** to **solve** and **simulate** the integrated geodetic network.

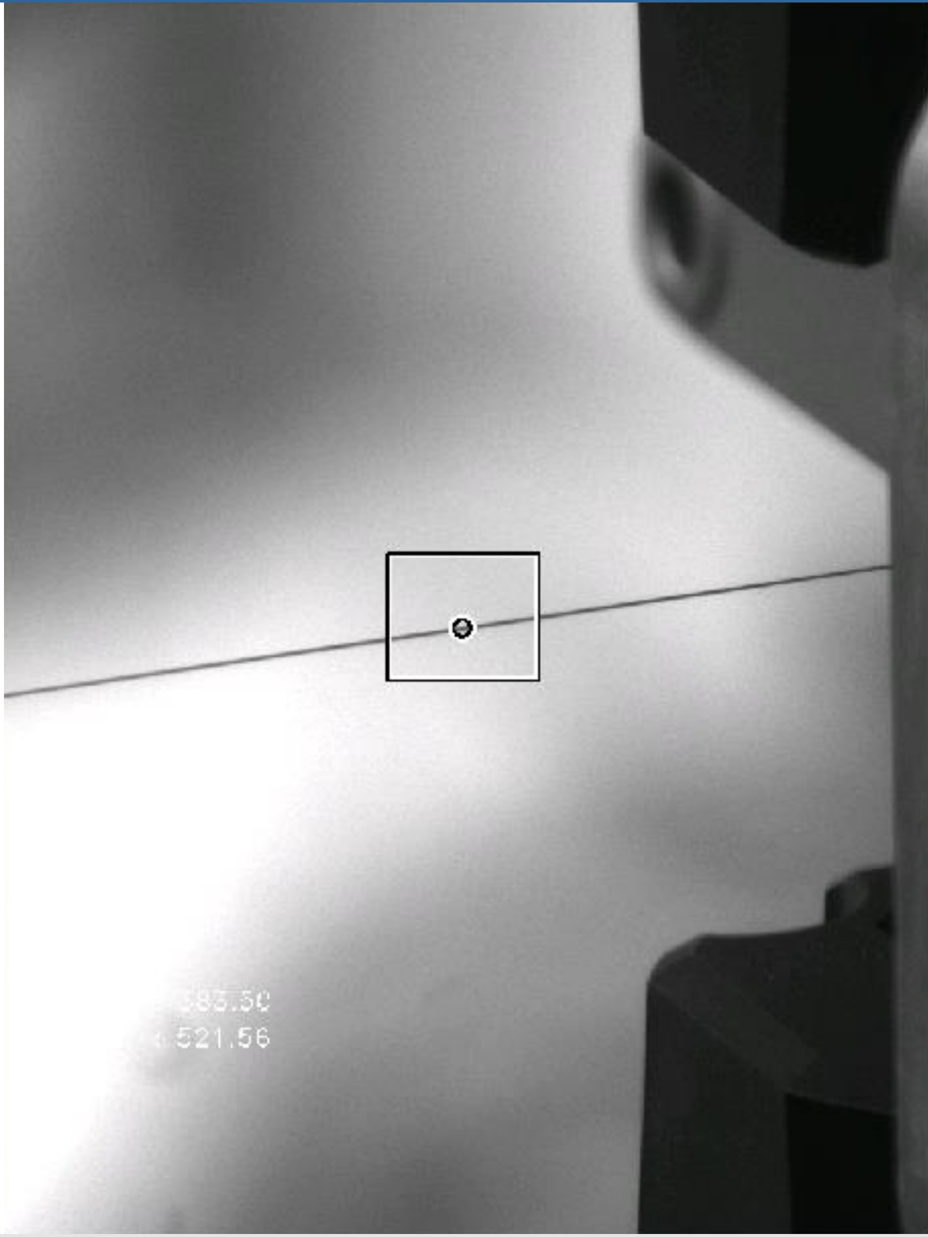
Wire detection and measurement

- The algorithm is developed in:

- Based on edge detection.

- User defined parameters:

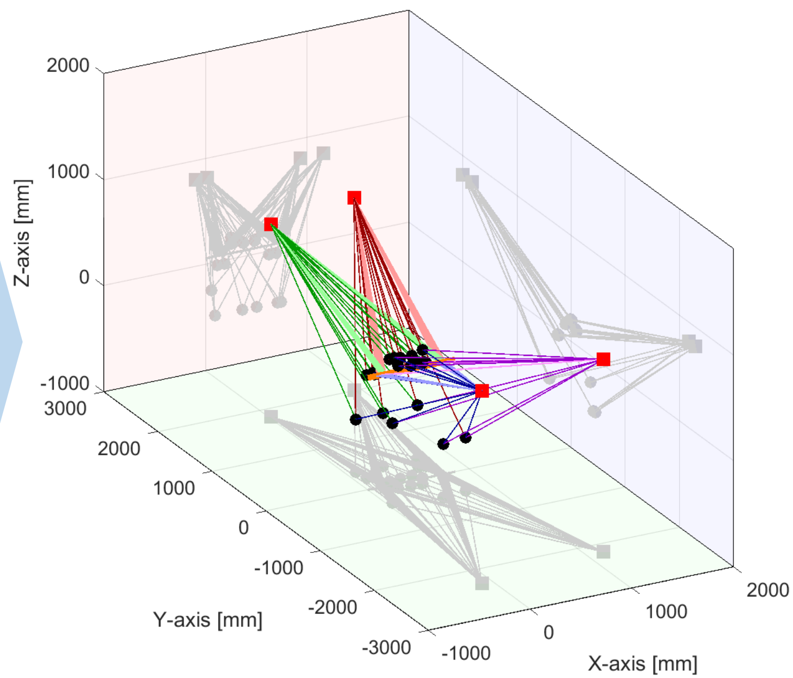
  1. **Minimum number of edge points**
  2. **Region Of Interest (ROI) width**
  3. **Region Of Interest (ROI) height**
  4. **Maximum residual**
  5. **Canny threshold**



Least-squares analysis software

Input:

- horizontal and vertical angles to targets and wires (with uncertainties).
- Approximate coordinates of the network (with uncertainties).
- datum constraints.
- user parameters.

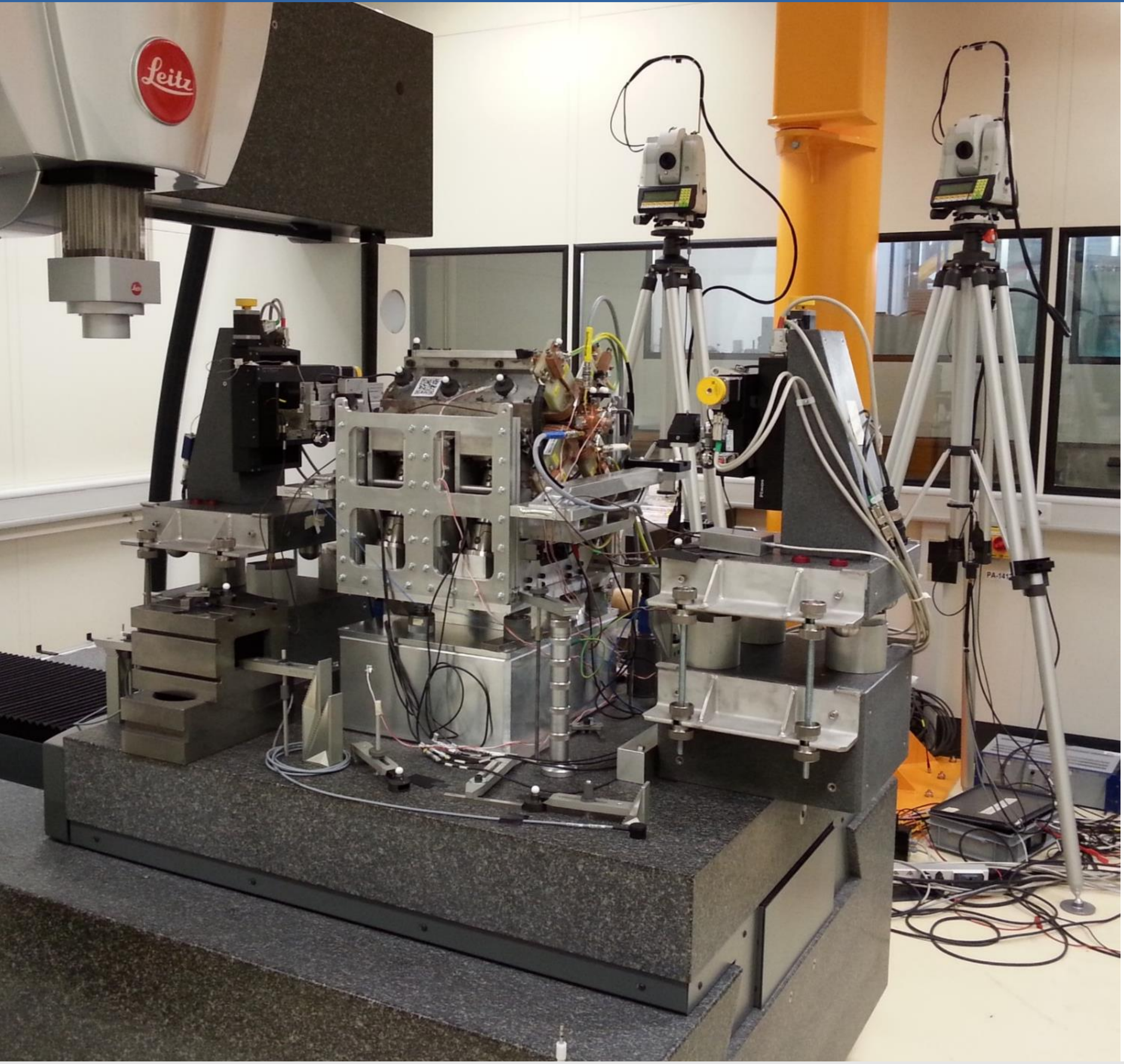


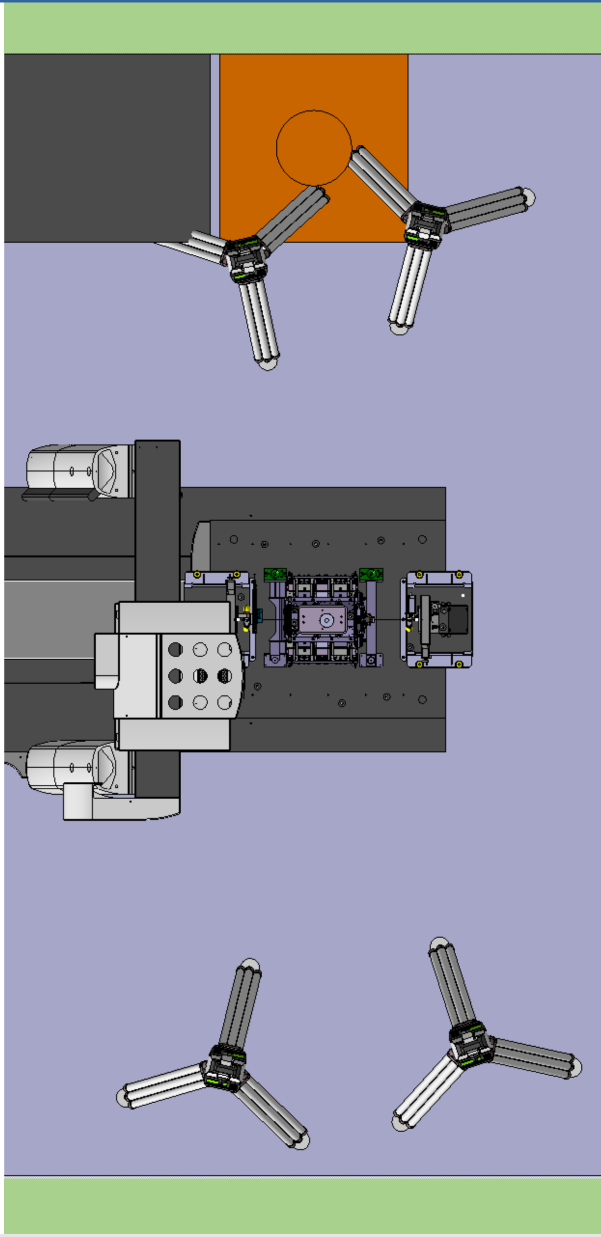
Output:

- stations: coordinates, orientations, and 3 systematic errors per instrument.
- targets: coordinates.
- wires: position, orientation and coordinates of the observed points.
- uncertainties.

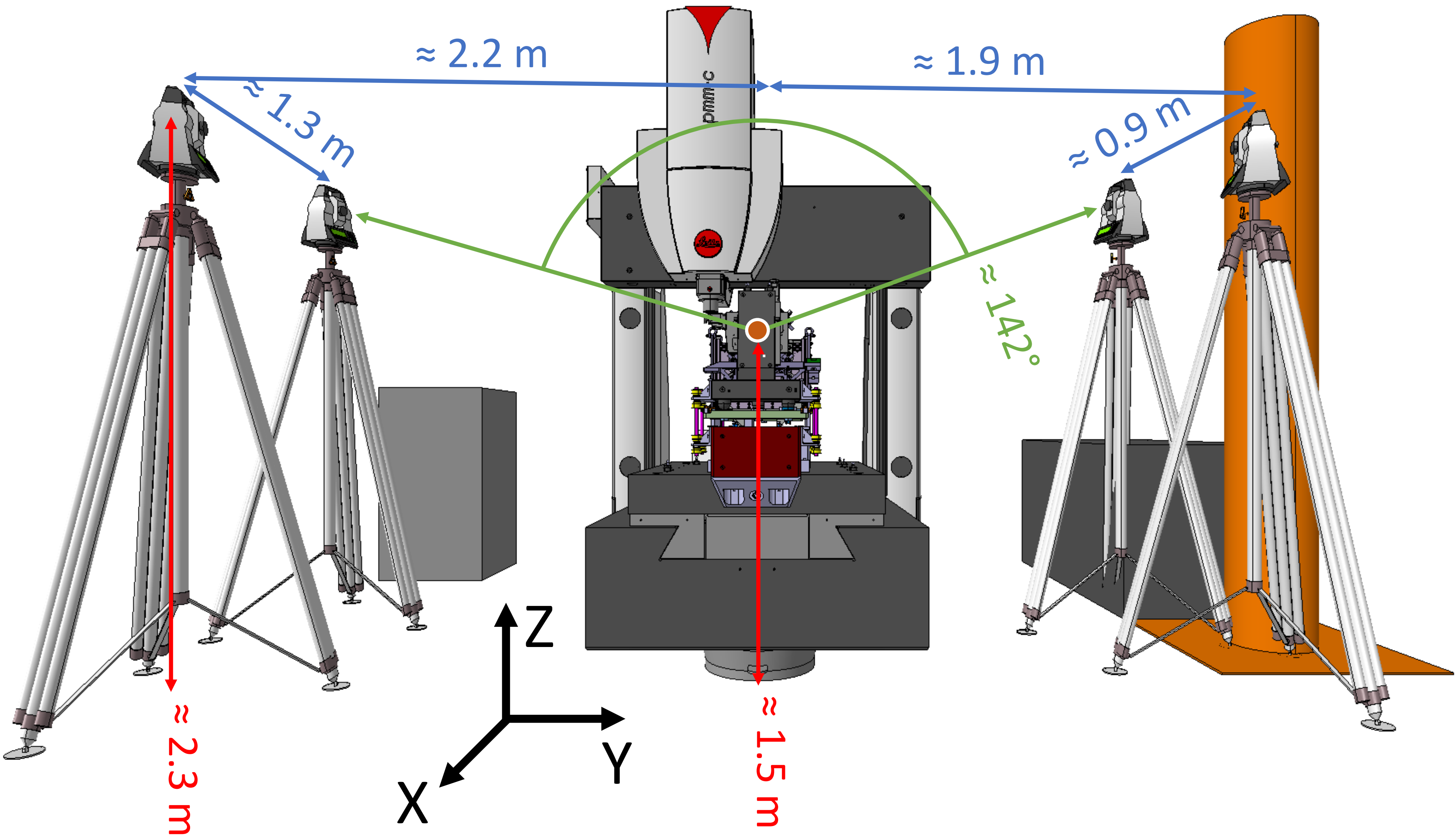
Measurement bench

PACMAN test bench in the Metrology room

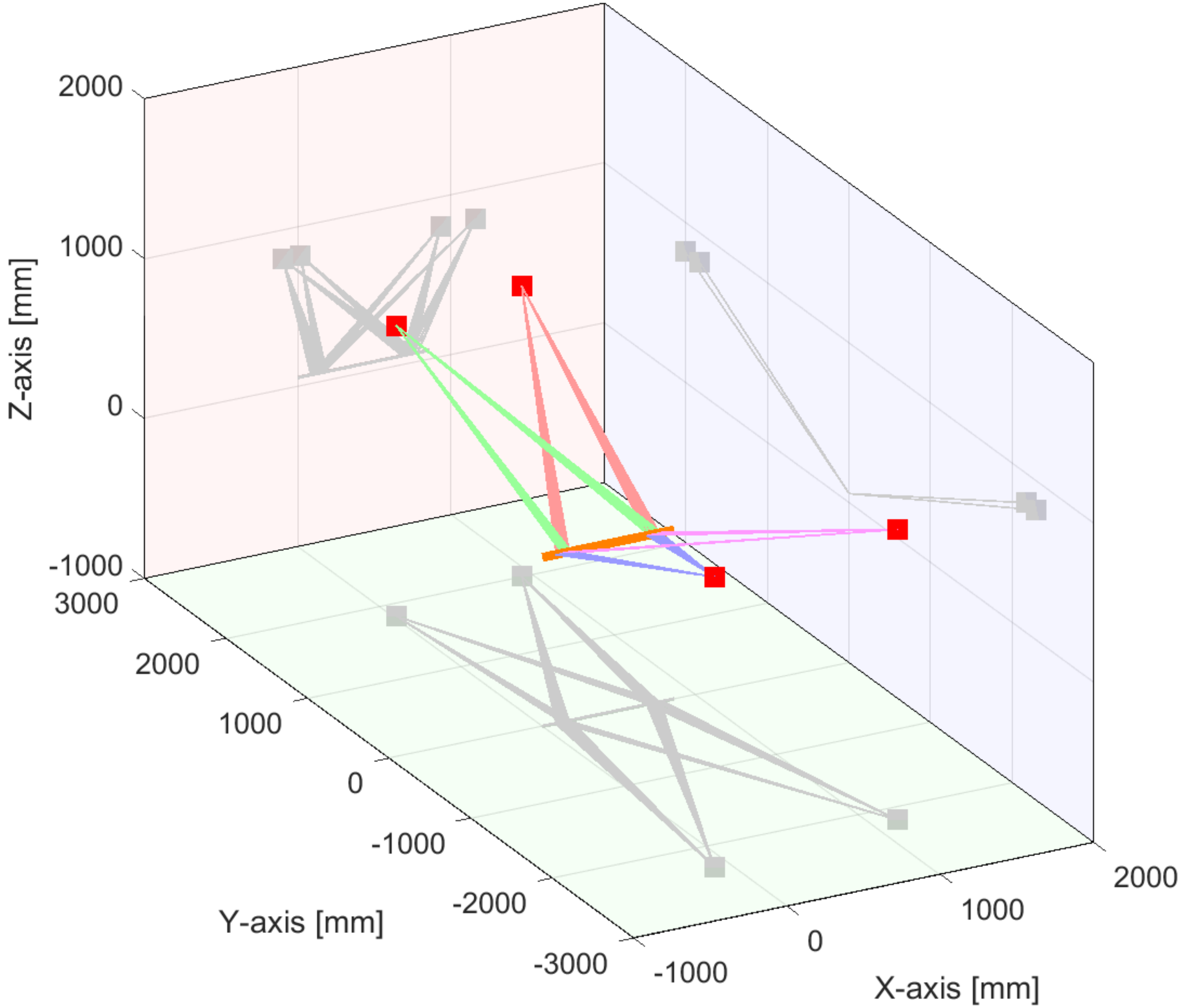




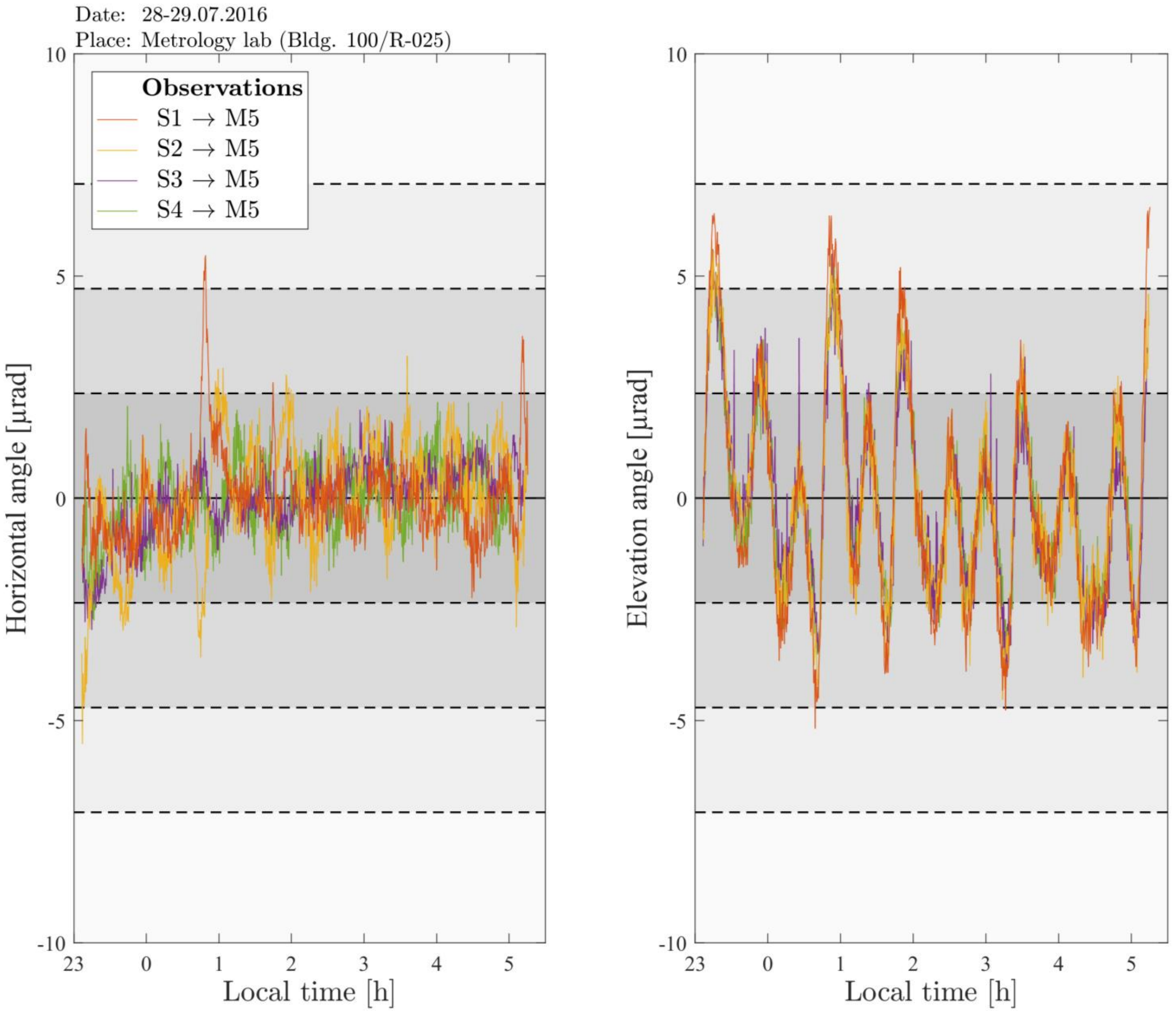
Poor network geometry



Poor network geometry



Thermal effect on the tripods



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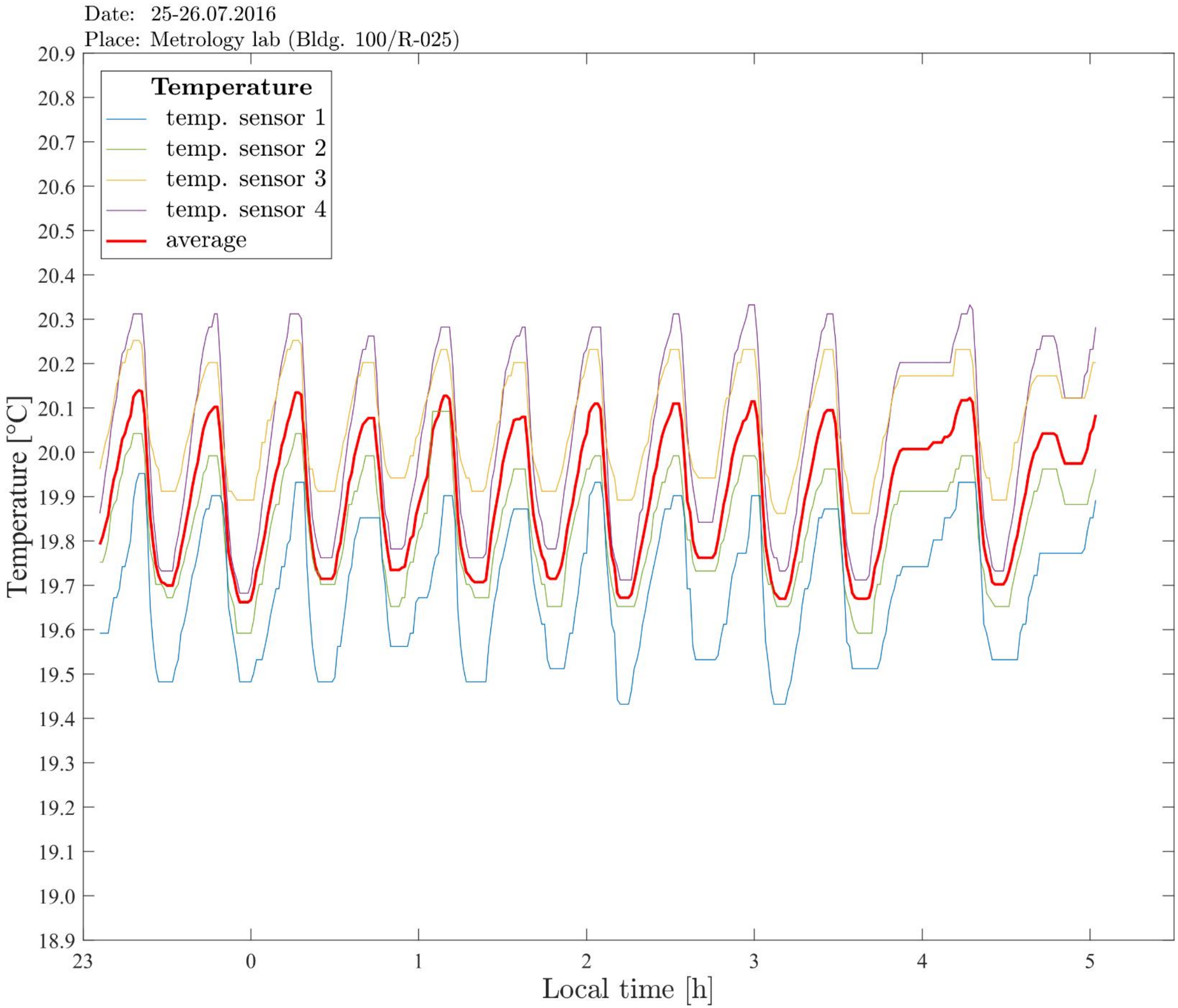

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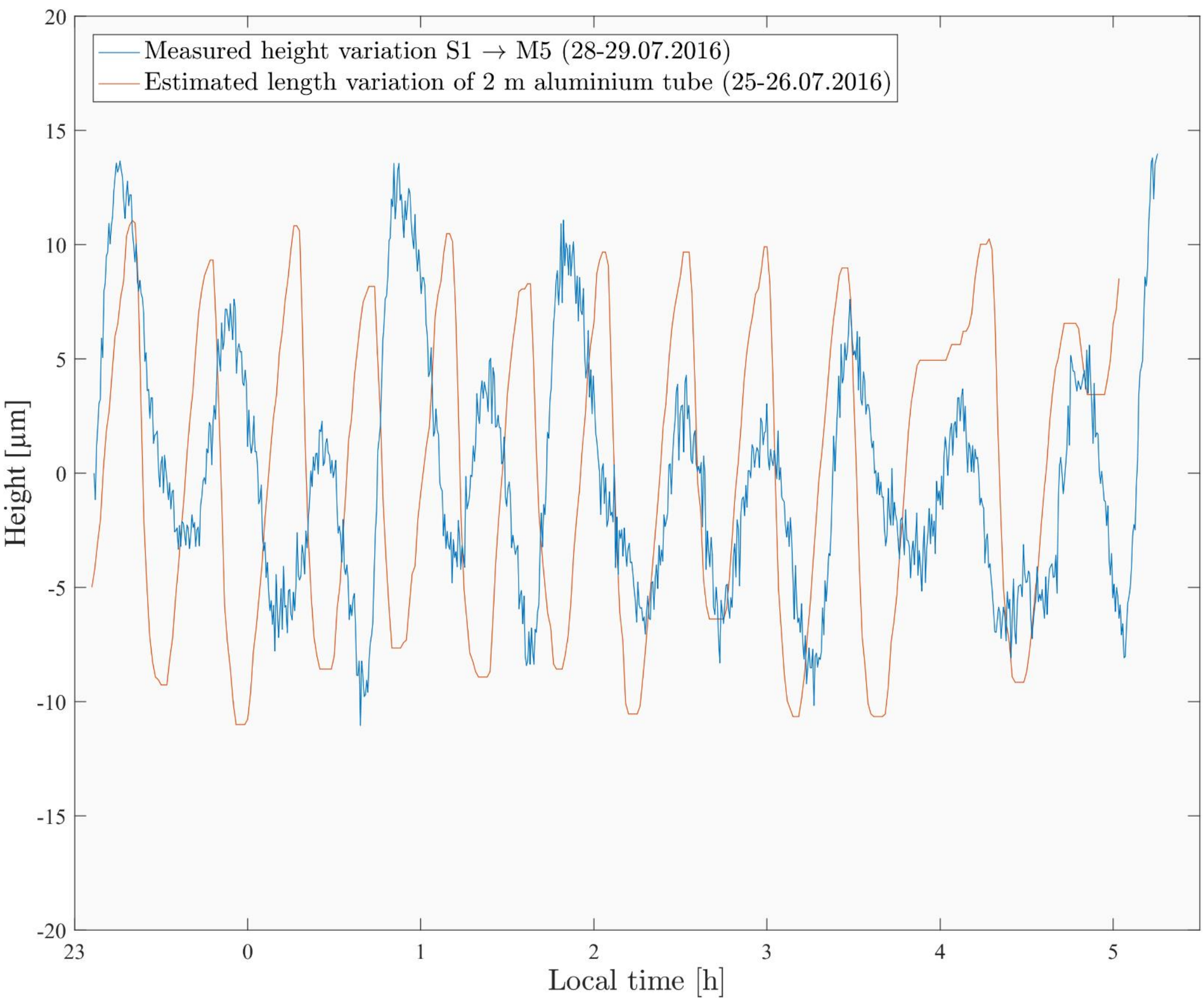
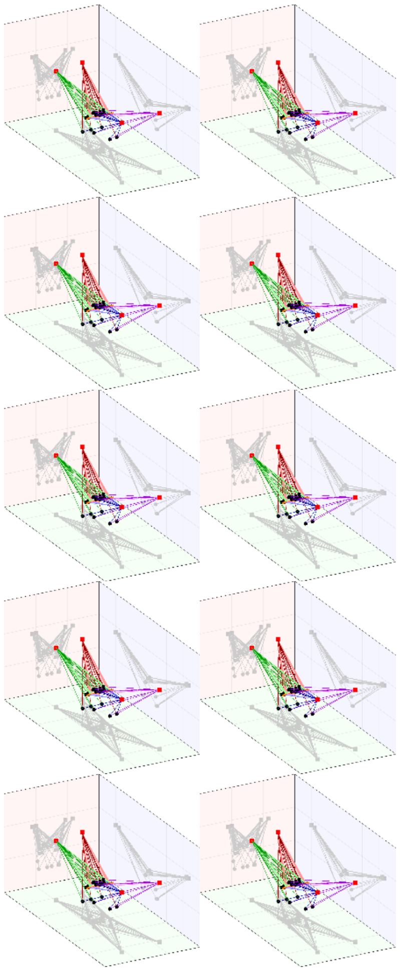


Measurement campaign

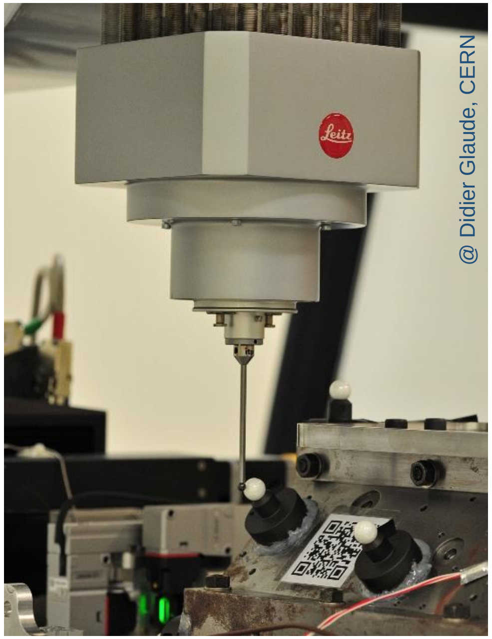
1st period of QDaedalus:

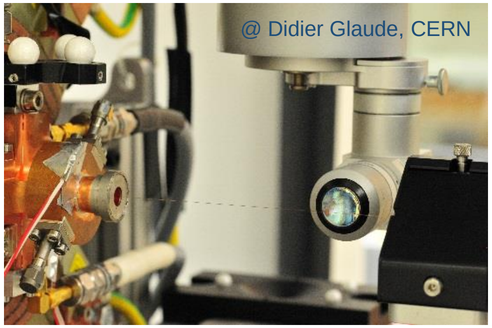
- 10 network measurements
- ≈ 5:30 – 7:20 (≈ 10 min each)



Leitz Infinity measurement:

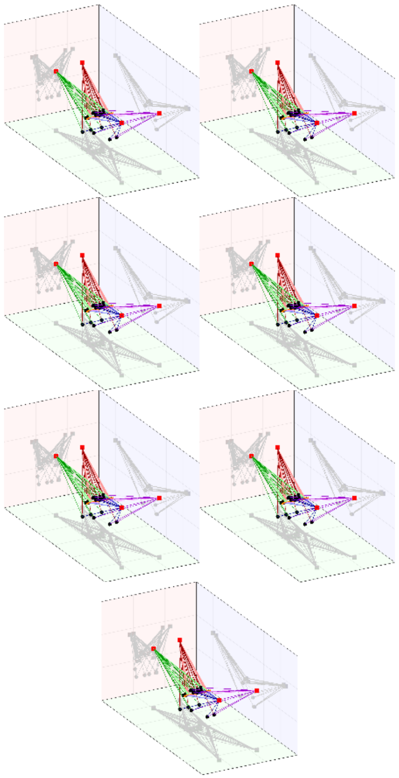
- Tactile & Contactless
- ≈ 7:30 – 14:00





2nd period of QDaedalus:

- 7 network measurements
- ≈ 14:50 – 16:30 (≈ 10 min each)



Preliminary results

Evaluation of precision

	X[1] [µm]	Y[1] [µm]	Z[1] [µm]	X[2] [µm]	Y[2] [µm]	Z[2] [µm]
Points on the magnet						
M1	2	6	2	2	4	3
M2	1	5	3	3	3	3
M3	1	5	2	3	5	3
M4	–*	–*	–*	–*	–*	–*
M5	–*	–*	2	–*	–*	3
M6	1	6	2	2	7	2
M7	1	5	2	2	9	2
M8	1	5	3	2	6	2
Points on the WPS support plates						
P1	3	6	2	5	9	2
P2	4	6	2	6	9	2
P3	3	5	2	5	7	2
P4	2	6	2	4	9	2
P5	2	4	1	5	5	1
P6	2	2	2	5	5	3
Points on the CMM granite table						
T1	3	7	3	10	8	3
T2	5	5	3	12	6	3
T3	6	6	3	9	9	4
T4	4	4	2	9	5	5
T5	4	5	2	6	3	6
T6	5	6	3	9	8	5

	X[1] [µm]	Y[1] [µm]	Z[1] [µm]	X[2] [µm]	Y[2] [µm]	Z[2] [µm]
Point on the wire						
WP	–*	3	2	–*	3	1
	[µm/m]	[µm/m]	[µm/m]	[µm/m]	[µm/m]	[µm/m]
Direction vector of the wire						
WV	–*	12	2	–*	27	1

* Constraint

1 Standard deviation of 10 QDaedalus measurements, 1st period: 5:30-7:20

2 Standard deviation of 7 QDaedalus measurements, 2nd period: 14:50-16:30

1st period	2nd period
100% < 8 µm	80% < 8 µm
76% < 5 µm	58% < 5 µm

Evaluation of accuracy

	$X^0 - X^1$ [µm]	$Y^0 - Y^1$ [µm]	$Z^0 - Z^1$ [µm]	$X^0 - X^2$ [µm]	$Y^0 - Y^2$ [µm]	$Z^0 - Z^2$ [µm]
Points on the magnet						
M1	7	-20	-9	7	-13	-7
M2	5	-16	-11	4	-15	-9
M3	3	-9	-10	0	-5	-7
M4	2	-6	-19	4	-4	-16
M5	-4	10	-19	-4	4	-17
M6	1	3	-11	3	-2	-14
M7	0	27	-2	0	25	0
M8	0	10	-6	1	11	-7
Points on the WPS support plates						
P1	1	6	8	2	6	7
P2	5	-5	-1	5	-6	-1
P3	1	8	-2	2	7	-3
P4	2	0	5	2	-1	7
P5	1	15	9	2	15	11
P6	0	7	15	1	9	18
Points on the CMM granite table						
T1	-3	-26	16	-8	-17	11
T2	-10	-2	1	-10	2	-4
T3	-7	-17	11	-4	-20	12
T4	2	9	15	1	7	11
T5	0	10	12	-4	7	11
T6	-5	-5	-3	-5	-10	-3

	$X^0 - X^1$	$Y^0 - Y^1$	$Z^0 - Z^1$	$X^0 - X^2$	$Y^0 - Y^2$	$Z^0 - Z^2$
	[µm]	[µm]	[µm]	[µm]	[µm]	[µm]
Points on the wire						
WP	–*	-17	-15	–*	-17	-14
	[µm/m]	[µm/m]	[µm/m]	[µm/m]	[µm/m]	[µm/m]
Direction vector of the wire						
WV	–*	-54	-44	–*	-30	-46

* Constraint

0 CMM measurement: 7:30 - 14:00

1 Average of 10 QDaedalus measurements 1st period: 5:30-7:20

2 Average of 7 QDaedalus measurements 2nd period: 14:50-16:30

<u>1st period</u>	<u>2nd period</u>
85% < 15 µm	90% < 15 µm
70% < 10 µm	73% < 10 µm
40% < 5 µm	45% < 5 µm

Conclusion & Outlook

Conclusion & Outlook

- Micro-triangulation can be used for magnet fiducialisation.
  - Advantages: accurate, automatic, contactless, remote-controlled, fast, portable.
  - Disadvantage: Lack of scale.

- 1st validation test (realistic scenario, no optimisation) preliminary results:
  - Precision (1σ) – fiducials: < 10 µm, wire orientation ≈ 20 µm/m.
  - Accuracy – fiducials: ≈ 15 µm, wire orientation ≈ 50 µm/m.

- New measurements are scheduled for the near future.
  - Geometry optimisation, lower setup for the theodolites.