FIG WORKING WEEK 2023

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Protecting Our World, Conquering New Frontiers

Direct Geo-Referencing of 3D Point Clouds in a Multi-Sensor System Approach

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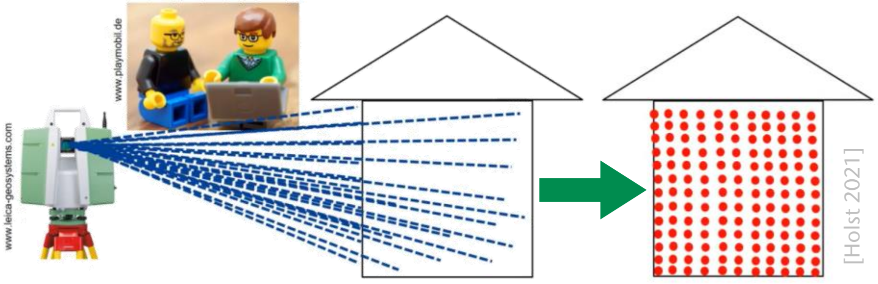
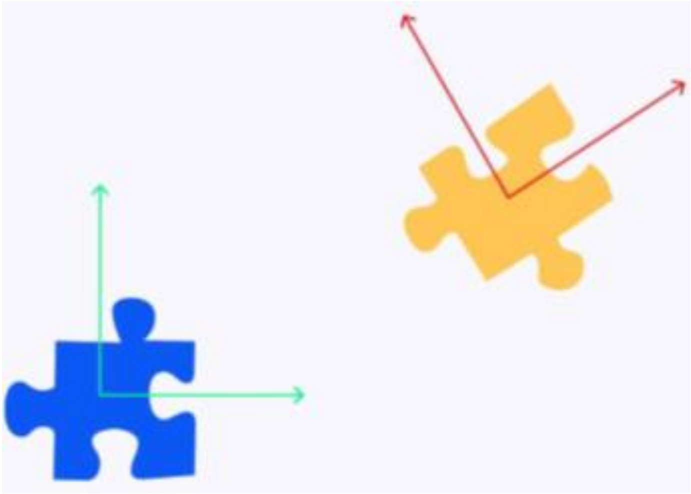
Motivation

- Terrestrial laser scanner for areal capturing
- Local sensor-defined coordinate system
- Aim: 3D point cloud in a global coordinate system

$$\begin{bmatrix} x_1 \\ y_2 \\ z_2 \end{bmatrix} = \mathbf{R} \cdot \begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix} + \mathbf{t}$$



[Holst 2021]



[Liebler, i3mainz, CC BY SA 4.0 nach Wujanz 2019b]

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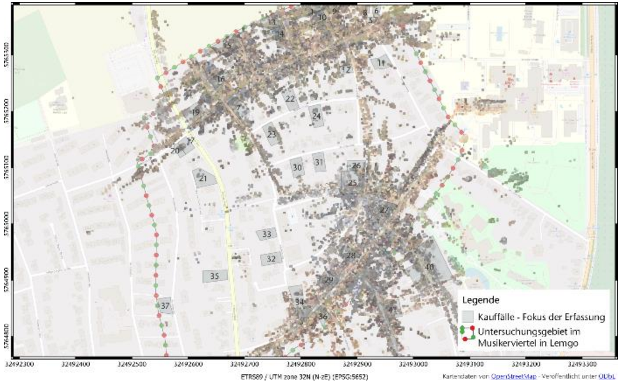
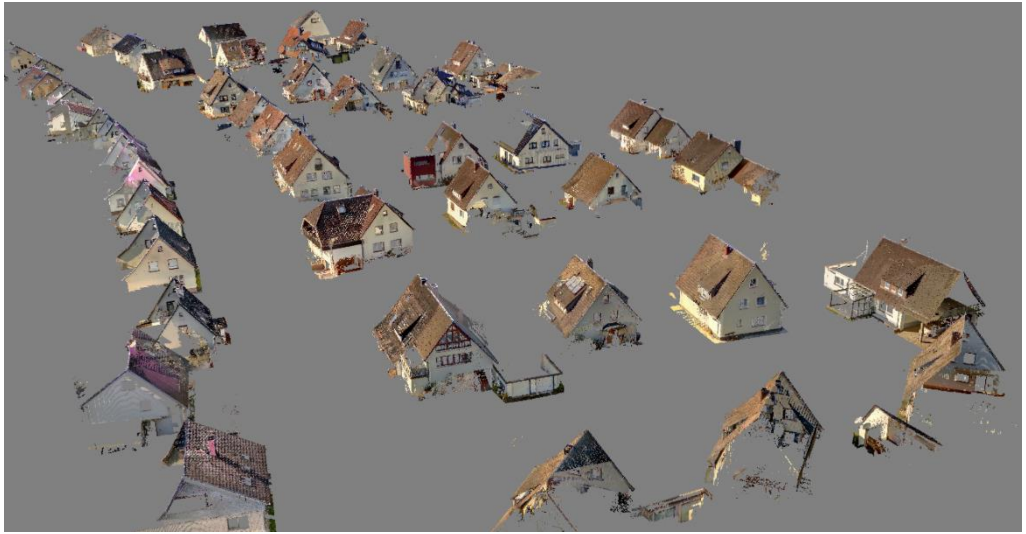
Urban areas

- Integration in geo-referenced data provided by
  - 3D city models
  - Building Information Modelling (BIM)
- At least a few tie points have to be pre-determined
  - RTK GNSS





Monitoring – epoch-wise deformation monitoring

- Man-made structures
  - Dams
- Natural structures
  - Soil erosion

→ Quality of geo-referencing defines the validity of the monitoring and obtained deformations and object changes, resp.

Short sum up of challenges in monitoring applications

- Straightforward in controlled environments with
  - Pillar-based tie points
  - Laboratory
- Comparatively static environments
  - Minor changes over time
- Man-made objects & scenes

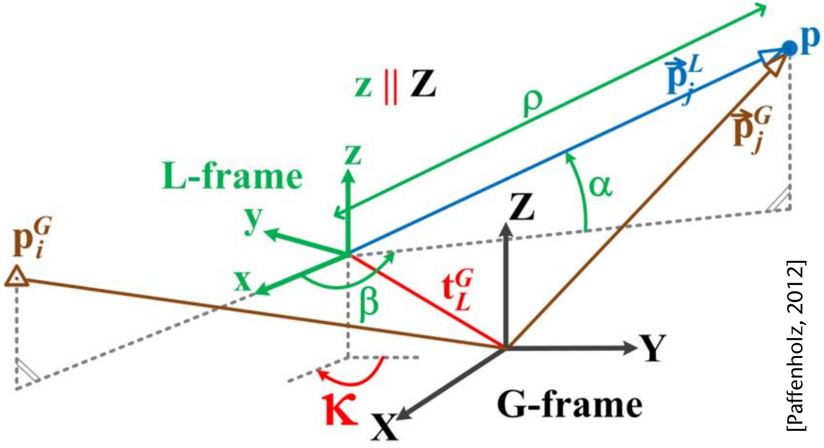
- Significantly changing environments
  - Construction sides
  - Poor distribution of (vertical) features
- Natural objects and scenes

Agenda

- Geo-referencing approaches
- The multi-sensor system
- Evaluation data set
- Conclusions and outlook

Geo-referencing approaches

- Indirect geo-referencing
- Direct geo-referencing
- Pure data driven approaches

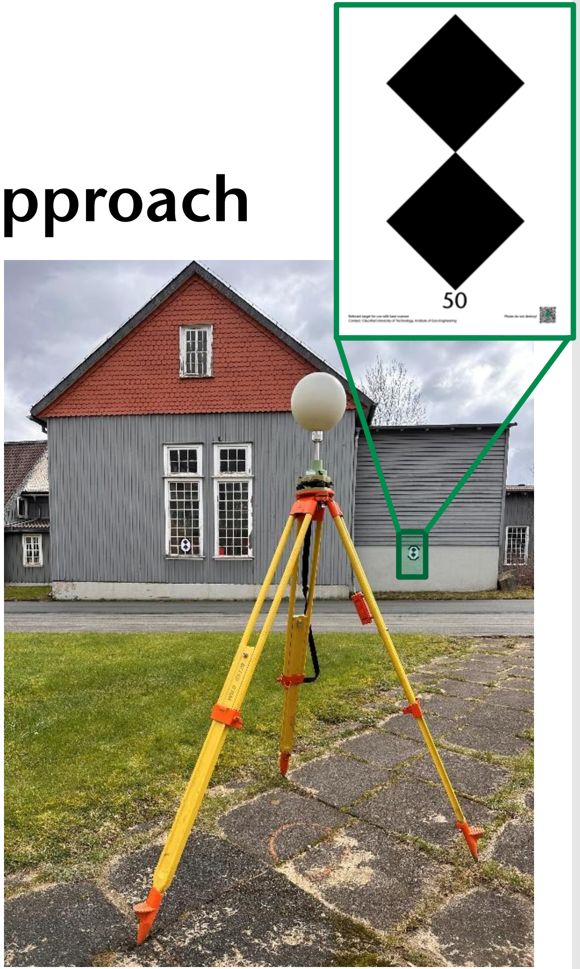


[Paffenholz, 2012]

$$\mathbf{p}_j^G = \mathbf{R}_L^G\left(\omega, \varphi, \kappa\right) \cdot \mathbf{p}_j^L + \mathbf{t}_L^G$$

Indirect geo-referencing – classical approach

- Artificial, signalized reference points (targets)
  - Pre-determined coordinates (global tie points)
  - Local tie points
- Natural common points → data driven approach
- Pro: Highest accuracy and reliability
- Cons: Efforts for target placement, etc.



Direct geo-referencing – Multi-Sensor System (MSS) approach

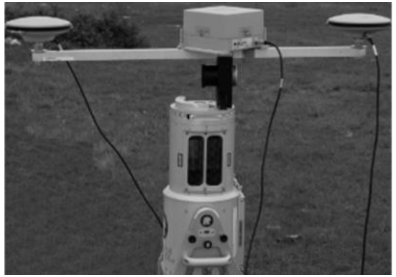
- Object capturing
  - Laser scanner
- Referencing sensors
  - 3D Positioning sensors: total station, GNSS equipment
  - Navigation sensors: IMU

- Pro: Immediately transformed 3D point cloud
- Cons: Additional sensors required

Direct geo-referencing

- Laser scanner can be centered and leveled on a fix point
- Scale known from calibration
- Minimizing targets up to full abstinence

[Reshetyuk ,2010]



[Wilkinson et al., 2010]

[IGE, 2022 after Paffenholz, 2012]

Direct geo-referencing – Commercial approaches (1)

[Datenblatt des Herstellers Leica, 2019]

Leica RTC360	
Range	0,5 m - 130 m
Field of view	360° x 300°
Scan rate	2 million points / second; <2 min for 360° object capturing
Range noise	0,4 mm @10 m und 0,5 mm @20 m
Weight	6 kg
Object resolution	▪ 3 / 6 / 12 mm @10 m

Accuracies	▪ Angle accuracy 18“
	▪ Range accuracy 1 mm + 10 ppm
	▪ 3D accuracy
	  ▪ 1,9 mm @10 m
	  ▪ 2,9 mm @20 m
	  ▪ 5,3 mm @40 m

Navigation sensors	Visual inertial system, altimeter, compass, GNSS

Direct geo-referencing – Commercial approaches (2)

[Datenblatt des Herstellers Z+F, 2019]

Zoller und Fröhlich (Z+F) IMAGER 5016	
Range	0,3 m – 365 m
Field of view	360° x 320°
Scan rate	▪ 1.1 million pixel / second ▪ max. 55 rps
Range noise	▪ 0,2 mm (10 m and 80% reflectivity) ▪ 0,4 mm (25 m and 14% reflectivity)
Beam diameter	~3,5mm @1 m | 0,3 mrad
Weight	7,5 kg
Particular feature	▪ Dynamic compensator ▪ Integrated HDR camera and LED Spots ▪ GPS(L1), barometer, accelerometer, gyroscope

Agenda

- Geo-referencing approaches
- The multi-sensor system
  - Development of a suitable adaptation to accommodate the sensors
  - Development of a calibration strategy for the MSS
  - Appropriate evaluation strategy for deriving the geo-referencing parameters
- Evaluation data set
- Conclusions and outlook

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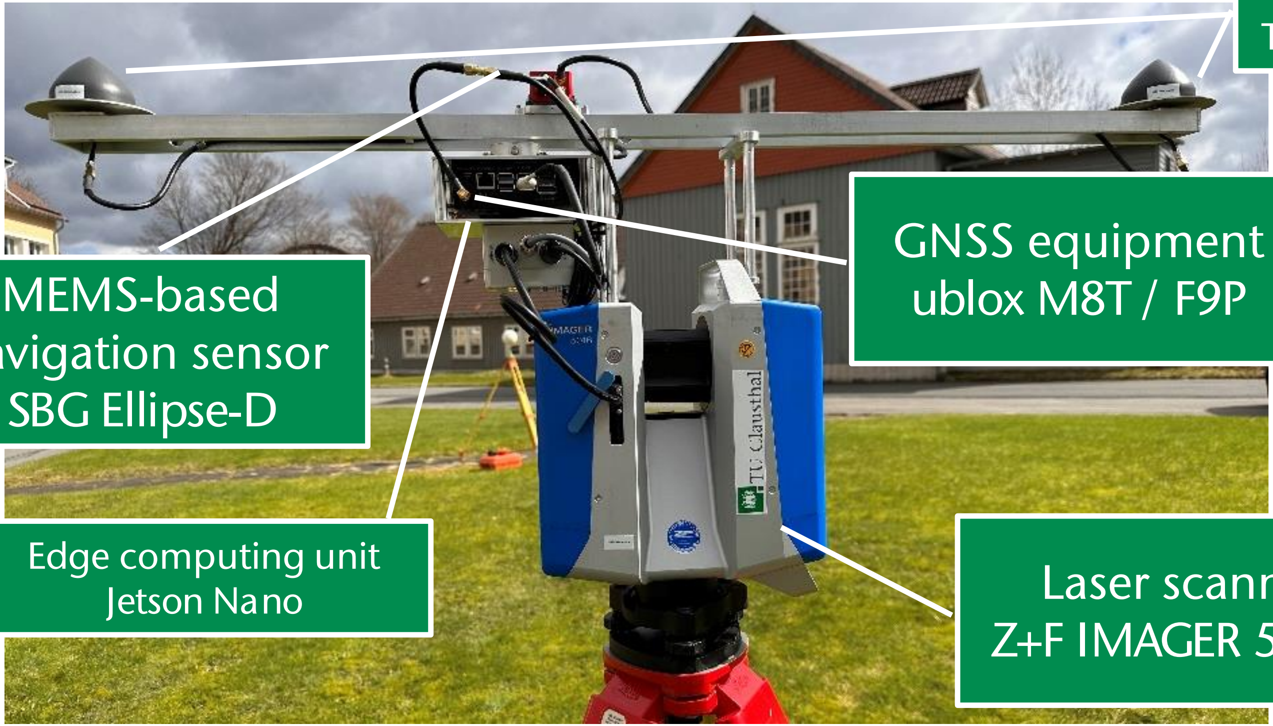
The multi-sensor system and its components



Development of a suitable adaptation aka grefbar to accommodate the sensors

- Light weight and balanced to minimize impact of sensor's rotational axis while having an easy mount and demount
- Up to two eccentrically mounted 3D positioning sensors
- Near centrically mounted external IMU

Development of a calibration strategy for the MSS

- Lab based vs. in-field or in-situ
- Less additional infrastructure
- Adequate reference sensor (e.g., total station, laser tracker) fitting the used MSS components specs

- Make use of the circular movement
  - Point describes a circle in 3D (x, y, z) → Translation
    - Assumption of a levelled MSS → 2D (x, y) → Translation
- Starting direction of the laser scanners data acq → Orientation

Development of a calibration strategy for the MSS

- Common points in the environment
  - Tie points coordinates determined with
    - GNSS (only for plausibility checking)
    - Total station (calibration situation)
  - Equipped with spheres during scanning
- Determine points on the grefbar structure

→ Determine the lever arm in
  - x-y-z and
  - Azimuth: angle from center to eccentrically points @grefbar

Appropriate evaluation strategy for deriving the geo-referencing parameters – Observation pattern

- 100% parallel to object capturing work flow
- 360° rotation with desired scanning solution
- Time consuming
- Redundant 3d point cloud
  - 2nd face might be interesting for laser scanner calibrations

- Extra task
- 2 * 360° rotation with lowest scanning resolution
- Less time and data consuming
- Redundant trajectory
  - Beneficial to increase reliability due to low-cost GNSS of short trajectory

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The evaluation data set: Industrial area

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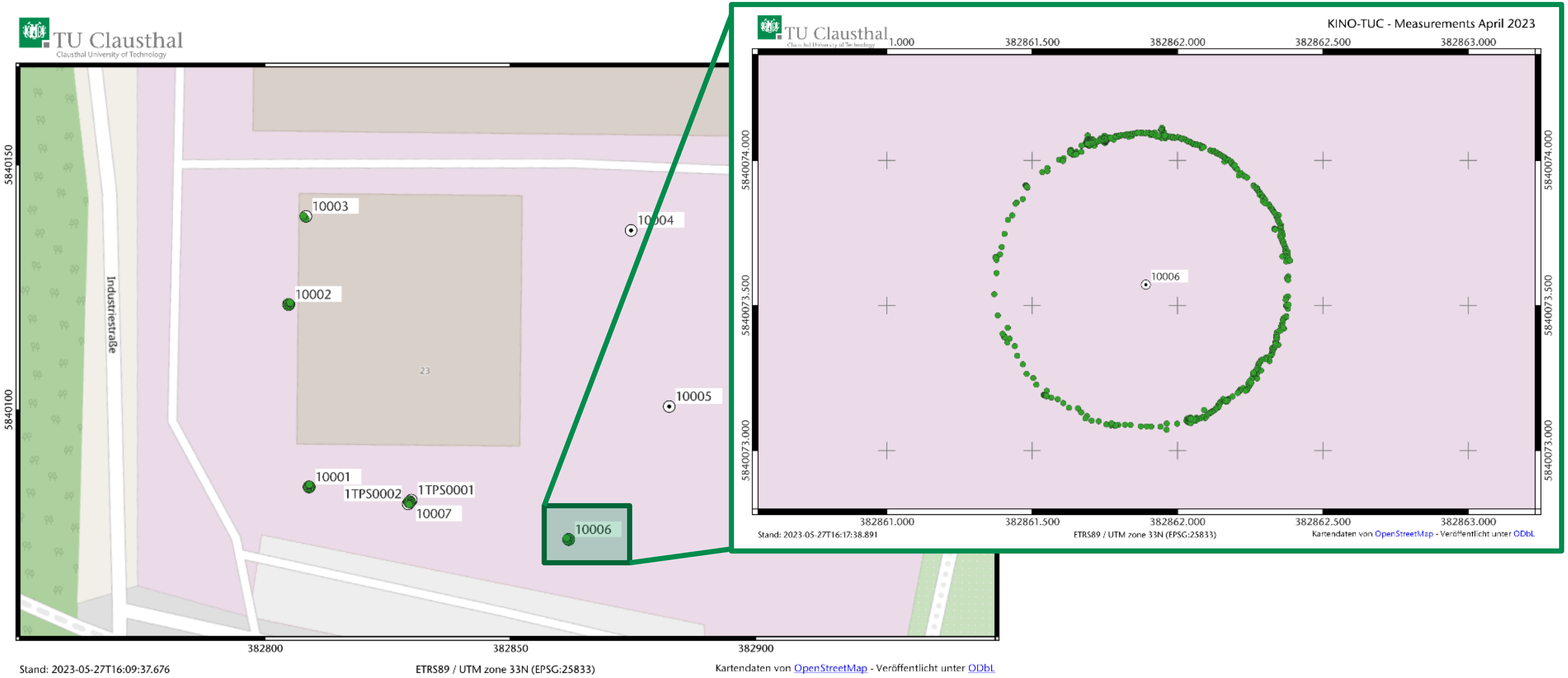

Exemplarily transformation parameters of 6 stations

- Two times 2 * 360° of the laser scanner
- Standard deviations of the x-y-z component from local sensor to UTM coordinate system of each station

Station	σ_x [mm]	σ_y [mm]	σ_z [mm]	σ_x [mm]	σ_y [mm]	σ_z [mm]
10007	6,6	5,4	22,2	7,5	4,5	24,9
10006	5,9	6,2	14,5	5,3	4,9	12,9
11006	7,6	6,3	25,1	7,8	6,2	30,5
10004	2,4	7,4	12,4	3	6	13
10003	38,5	116,9	305	19,4	75,4	160,7
10001	4,8	5,9	17,1	7,8	9	11,9

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The evaluation data set: Industrial area

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Conclusion

- Clear potential for less structured environments
- Starting values for subsequent data driven approaches
- Beneficial over built-in sensors since azimuthal orientation is more reliable → no demand for special handling during station change

Outlook

- Make use of second antenna
- Make (more) use of the IMU data
- Bundle block adjustment of single station network

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FIG Working Week 2023, Orlando, FL – Scientific Workshop on Uncertainty and Quality of Multi-Sensor Systems [10587] – 27.05.2023

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