DIRECT GEOREFERENCING OF STATIC TERRESTRIAL LASER SCANS

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TS 1H – Developments in Scanner and Sensor Technologies, Monday 16 June 2008

FIG Working Week – Integrating the Generations

Stockholm, Sweden 14-19 June 2008

For what purpose do we require 3D data?

- 3D city models for planning issues or documentation tasks, e.g., in architecture or forensics
- Typical tasks of geodetic engineering: deformation measurements or high-precise as-built documentation

What is an efficient and effective way of acquiring data?

- Rapid mapping using kinematic terrestrial laser scanning (k-TLS)
  - Mobile mapping: scanning of static objects from a moving platform
  - **Fast scanning** of static/kinematic objects **from a static platform**
- 3D data acquisition in an absolute or global coordinate system; required for several scenarios

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Characteristics of k-TLS

- Fast high frequency and immediate 3D data acquisition
- High spatial resolution for short up to mid-ranges (<80m, phase-based laser scanner)
- Data acquisition in a relative or sensor-defined coordinate system

To-Do for using (k)-TLS data for above-named scenarios

- Observation of the laser scanner position and orientation
- Transform 3D data from local/sensor-defined to absolute/global coordinate system

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Outline

- **State-of-the-art in georeferencing of static terrestrial laser scans**
- **Adapted sensor-driven method for direct georeferencing**
  - Data acquisition and preprocessing
  - Robust estimation of the space curve
    - Projection of the 3D positions onto a best-fitting plane
    - Estimation of a best-fitting circle through the projected positions
  - Azimuth determination and result validation
  - Error budget
- **Conclusions and future work**

Terminology and brief overview of georeferencing

Registration → Process of linking laser scans from different stations to one similar (local) coordinate system

Georeferencing → Transformation of laser scans from a relative/local sensor system to an absolute/global coordinate sys.

- Indirect method: Georeferenced control points
- **Direct method:** **Use of additional sensors**
  Observation of the laser scanner position and orientation
- *Data-driven method: Georeferenced data base*

State-of-the-art in georeferencing of static TLS

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Adapted sensor-driven method for direct georeferencing

System concept and aim of the presented method

- Use a minimized number of additional sensors
- Direct estimation of the laser scanner position and orientation
- Work without georeferenced control points
- Do not disturb the operation of the laser scanner
- Use to constant rotation of the laser scanner about the vertical axis as time and orientation reference
- High frequency data acquisition of a phase-based laser scanner demands a data-rate of at least 10 Hz for additional sensors

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⇨ Aim can be achieved by kinematic GNSS with a maximum number of 2 antennas to get the position and orientation

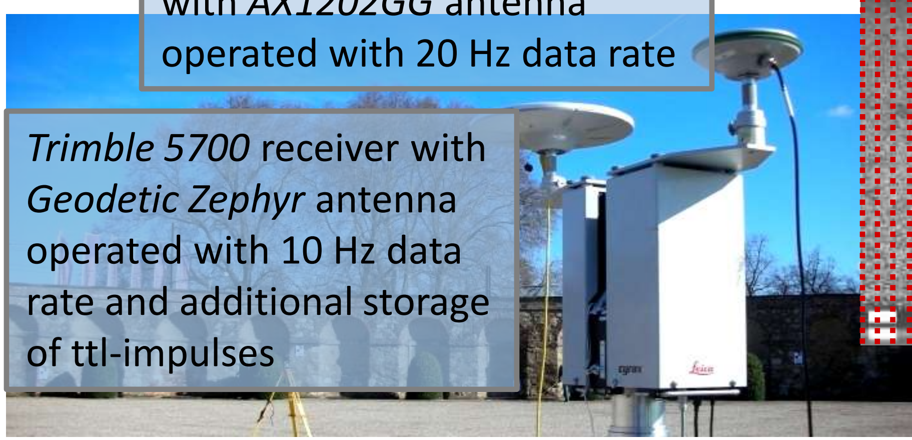
Data acquisition and preprocessing

System setup for the measurements on 5th March 2008

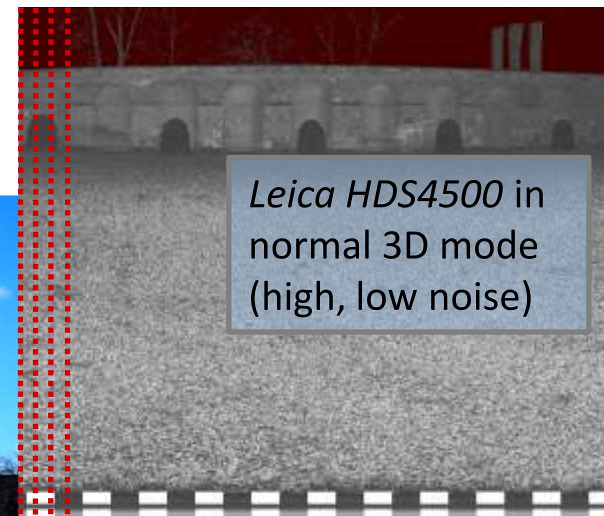
- Place of measurements: “Ehrenhof” in the “Große Garten” of the “Herrenhäuser Gärten” in Hannover
- Data acquisition time approx. 15 minutes

Local reference station

Leica GRX1200GG Pro receiver with *AX1202GG* antenna operated with 20 Hz data rate



Trimble 5700 receiver with *Geodetic Zephyr* antenna operated with 10 Hz data rate and additional storage of ttl-impulses



Leica HDS4500 in normal 3D mode (high, low noise)

Preprocessing: time synchronization

- 3D laser scan consists of several scan lines characterized by one turn of the vertical step motor
- Per scan line one ttl-impulse is available which is used for time synchronization task
- With the event marker input of the GNSS-receiver for every ttl-impulse a GPS timestamp is obtained and stored in the RINEX observation file
- Optional interpolation of missing ttl-impulses

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⇨ Unique time synchronization between scan lines and ttl-impulses is now given

Preprocessing: GNSS analysis

- Trajectory of the antenna reference point (ARP) described by the orbital motion of the laser scanner is a space curve
- 2 different approaches were performed to estimate the trajectory

  (1) Calculation of a baseline between the local reference station and each antenna installed on top of the laser scanner

  (2) Calculation of a relative baseline between the two antennas installed on top of the laser scanner

  Software used for GNSS analysis: (1) *Trimble Total Control* by *Trimble*, (1) *Geonap* by *Geo++* and (1) + (2) *Wa1* by *Lambert Wanninger*

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⇨ Calculation of an azimuth for each scan line in the 3D laser scan from the GPS trajectory

Two step model of the robust parameter estimation

(1) Projection of the 3D positions onto a best-fitting plane

- Take in account the full 3D information of the points
- Consideration of rotations due to the coordinate transformations

(2) Estimation of a best-fitting circle through the projected positions

- Improvement of the azimuth determination by using adjusted/smoothed instead of original/noisy positions

- Robustness means here to perform Baarda's data-snooping for outlier detection and elimination
- Estimation is independent of the coordinate system
  - Here: transformation to the Gauss-Krüger System for comparison with terrestrial measurements by a tachymeter

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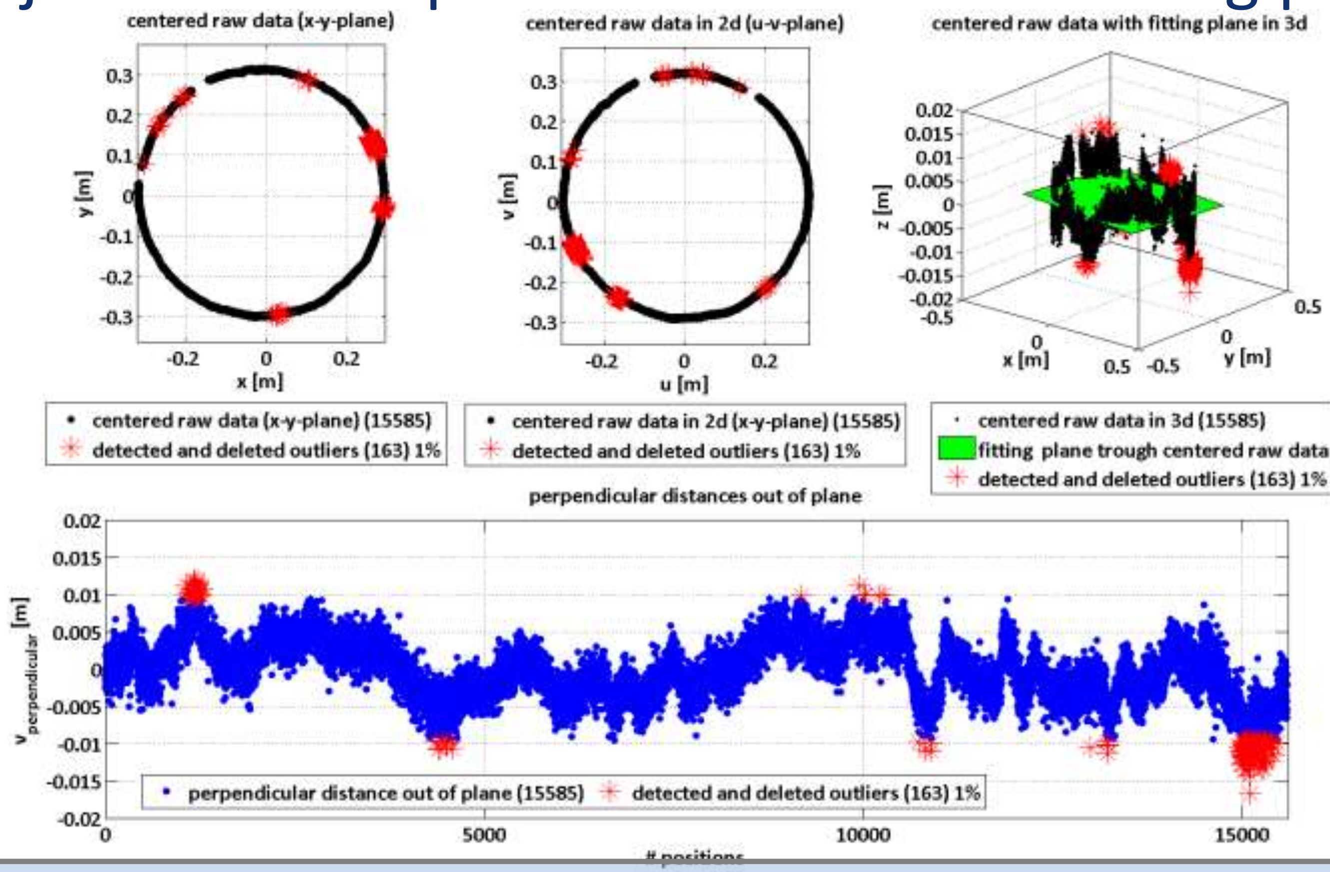
(1) Projection of 3D positions onto a best-fitting plane

- Orthogonal projection of 3D positions onto a best-fitting plane with a principal axis transformation (acc. to DRIXLER (1993))
  - Introducing centered point coordinates
  - Analysis of the perpendicular distances for all points
  - Comparison of all perpendicular distances in an iterative process according to the (1-α) quantile value of the normal distribution (α=1%)
  - Corresponding points to a rejected null hypothesis are eliminated
  - Perform normal projection of the centered points onto the plane
  - Perform principal axis transformation

(1) Projection of 3D positions onto a best-fitting plane

“Absolute” baseline

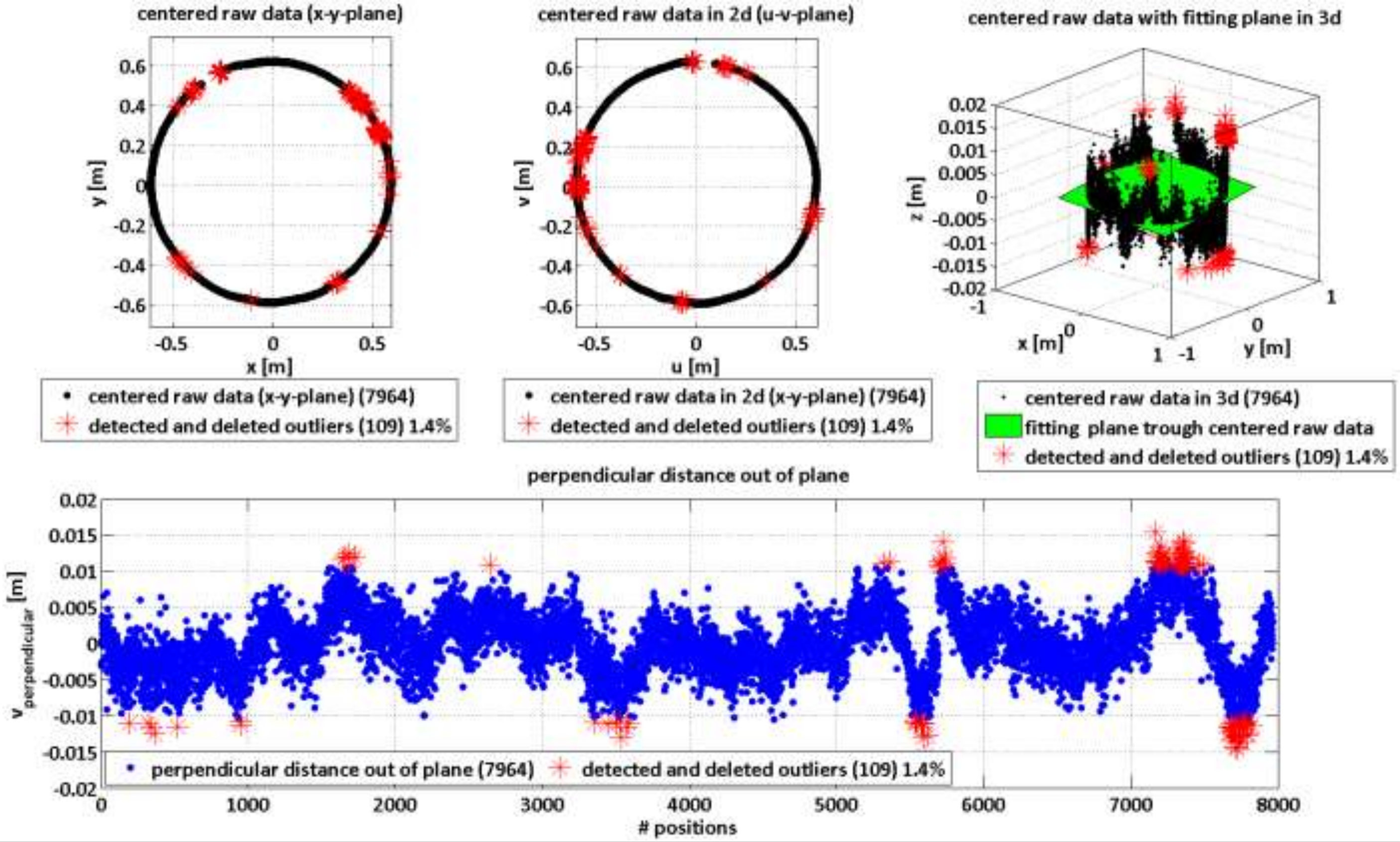
local reference station – *Leica* antenna



data set /7001hg4lgn.bgk with GNSS analysis by wa1 and coordinate transformation by gn

(1) Projection of 3D positions onto a best-fitting plane

"Relative" baseline
***Leica* antenna – *Trimble* antenna**



data set /hg4thg4lgnCA.bgk with GPS analysis by wa1 and coordinate transformation by gn

Robust estimation of the space curve

(2) Estimation of a best-fitting circle through projected pos

- Use of known data-snooping method in circle adjustment by transferring the Gauss-Helmert model (GHM) into an equivalent Gauss-Markov model (GMM) (acc. to JÄGER ET AL. (2005))
- Instead of the plane adjustment (1) here in step (2) the stochastic information for the positions are considered
  - By a variance-covariance matrix given by the GNSS analysis the results for the circle adjustment could be improved
- In the end the adjusted positions as well as the center point are transformed to the original coordinate system (x-y-z) by the inverse principal component transformation

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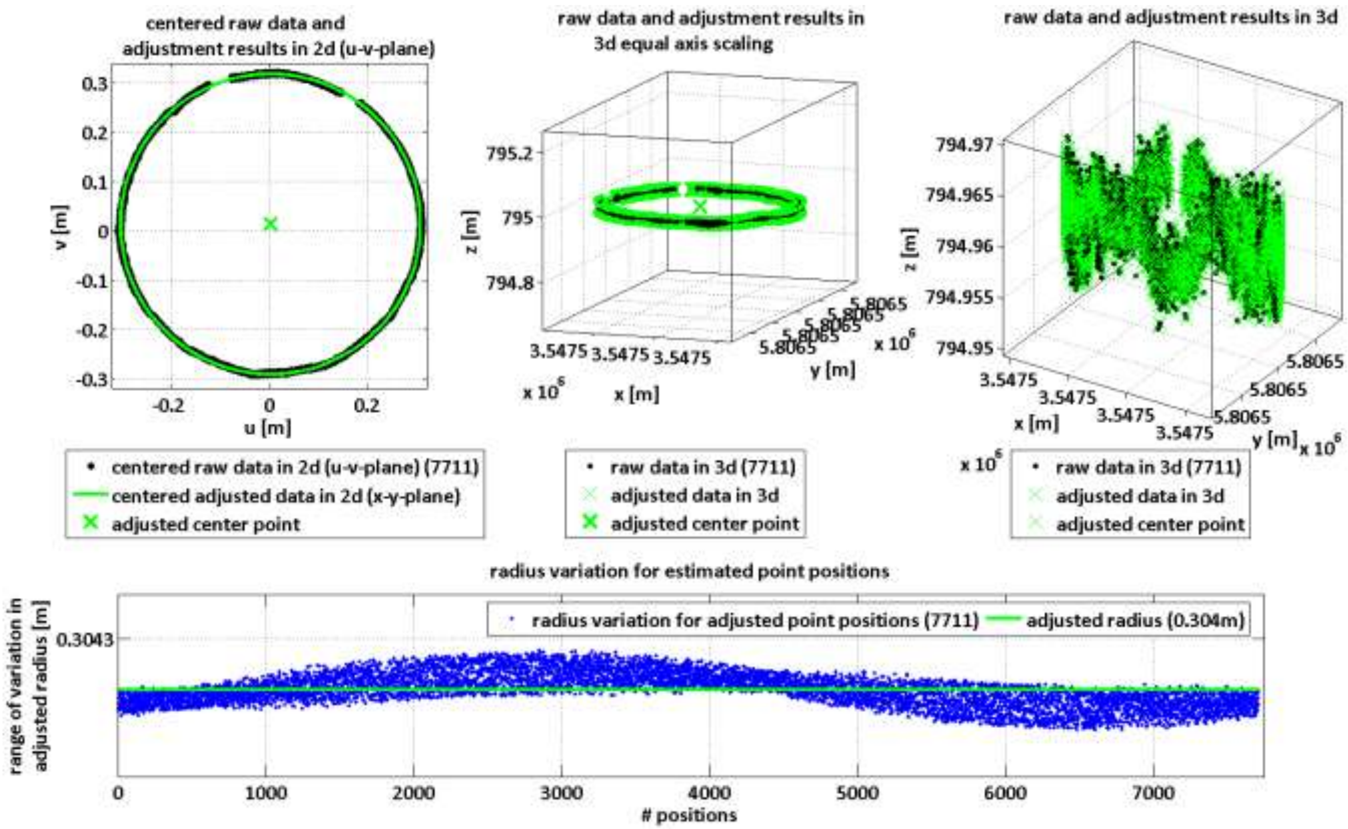

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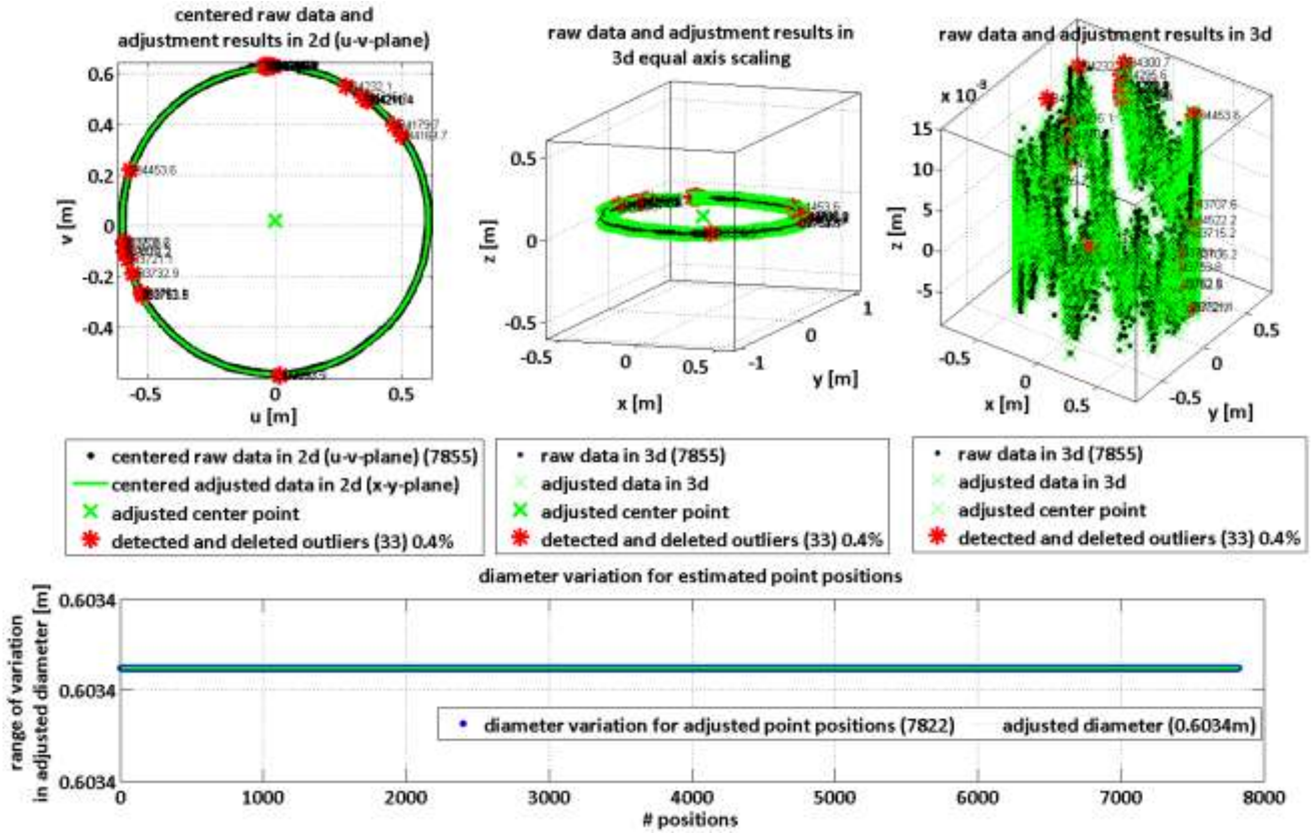

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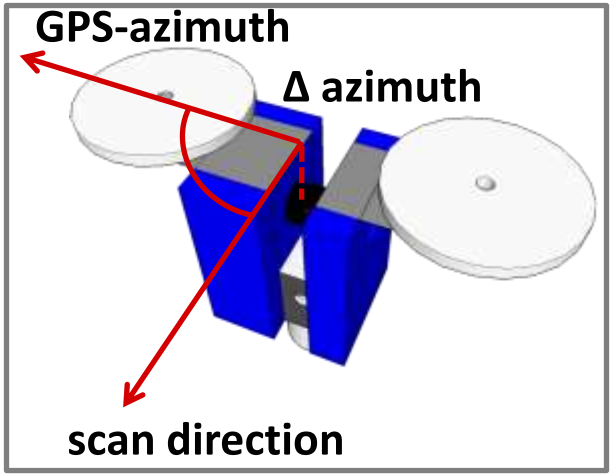
Azimuth Calculation for each scan line from GPS trajectory

- Δ azimuth between each scan line and the corresponding part of the GNSS trajectory
- Δ azimuth can be derived by the constant rotation of the laser scanner about its vertical axis



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- Consideration of Δ azimuth at each vertical motor position of the laser scanner

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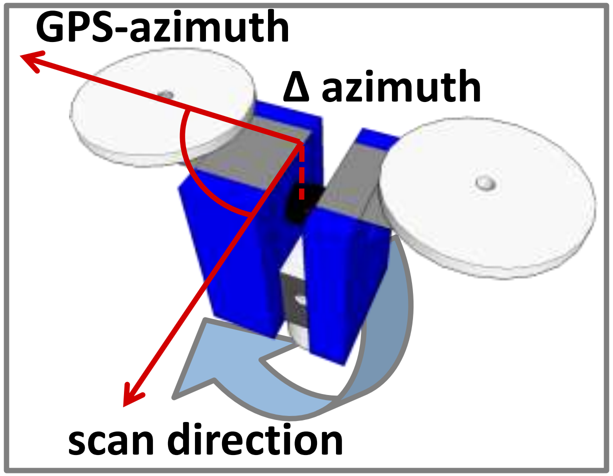

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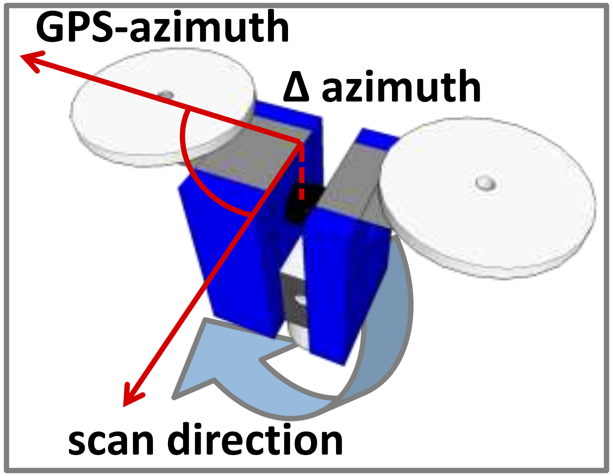

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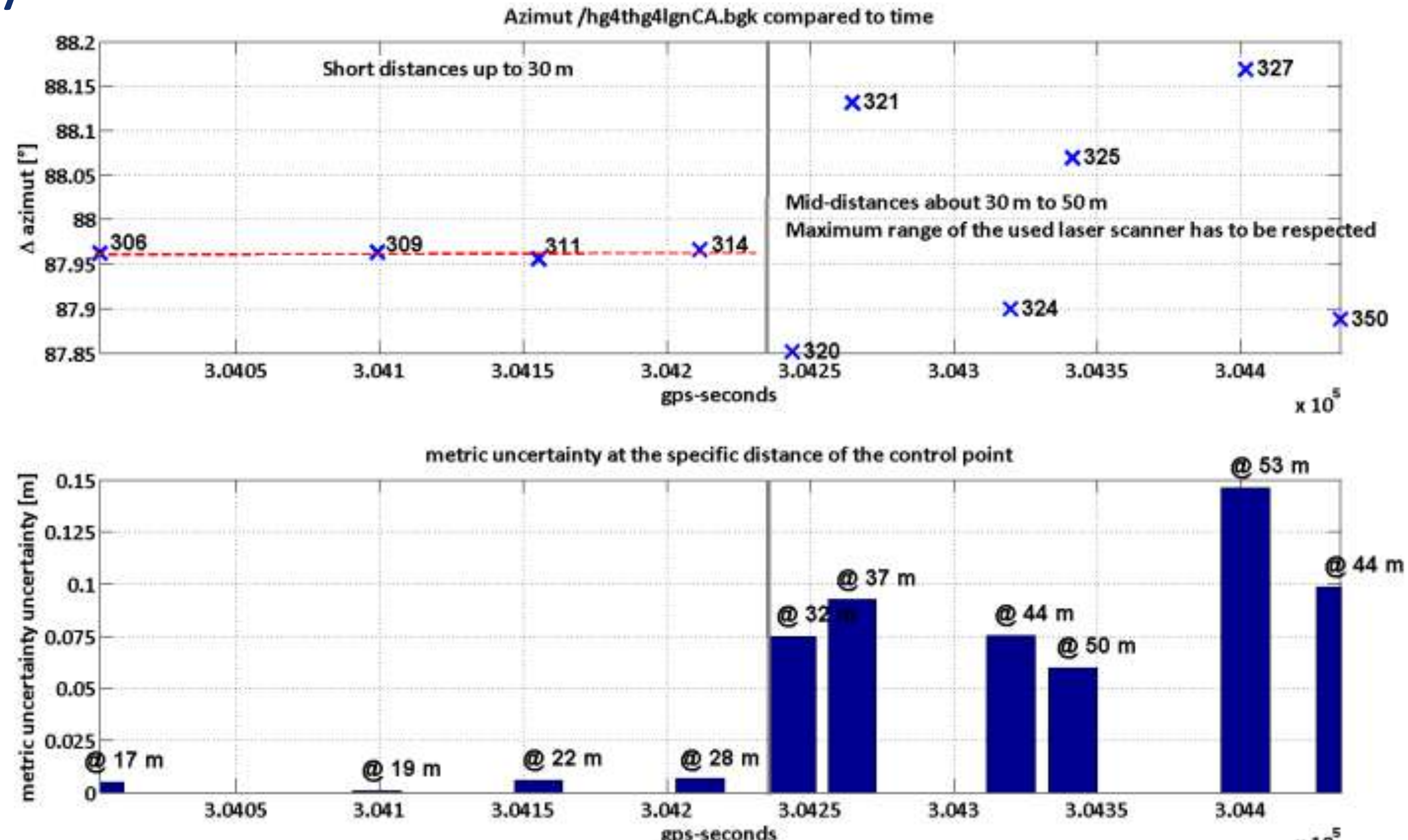
⇒ 3D laser scan referenced to a global coordinate system and/or start values for iterative algorithms for registration tasks

Result validation

Tachymeter versus TLS directions



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Separate inspection of hybrid sensor system components

Concentration only on that kind of errors which are directly concerning the presented approach

Laser scanner

- Trunnion axis error caused by the weight of the antennas
- Anomaly in the horizontal as well as vertical rotation speed

GNSS component as well as GNSS analysis

- Near-field effects caused by the antenna adaption made of aluminum on the laser scanner or possibly multipath
- Alternating antenna orientation

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Adapted sensor-driven method for direct georeferencing

- Use of the constant rotation of the laser scanner in combination with kinematic GNSS for a direct observation of the laser scanner position and orientation
- Improved azimuth determination by a two step model for robust estimation of the space curve of the ARP
- Metric uncertainty of about 1 cm for the azimuth calculation on a distance up to 30 m

- Modify the antenna installation for the use with the Z+F IMAGER 5006
- Detailed investigations on the presented error budget
- Consider stochastic information for the plane adjustment
- Implementation of a robust parameter estimation

Acknowledgements

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Future Work

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