Adaptive Extended Kalman Filter for Geo-Referencing of a TLS-based Multi-Sensor-System

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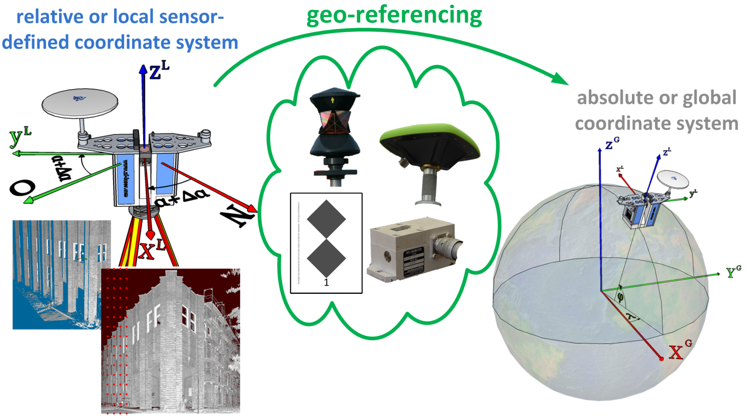
Motivation



Why is a direct geo-referencing useful?

- No demand for control points (estimating control point coordinates is a generally time /computational consuming task)
- Efficient and effective work flow for acquiring geo-referenced 3D data

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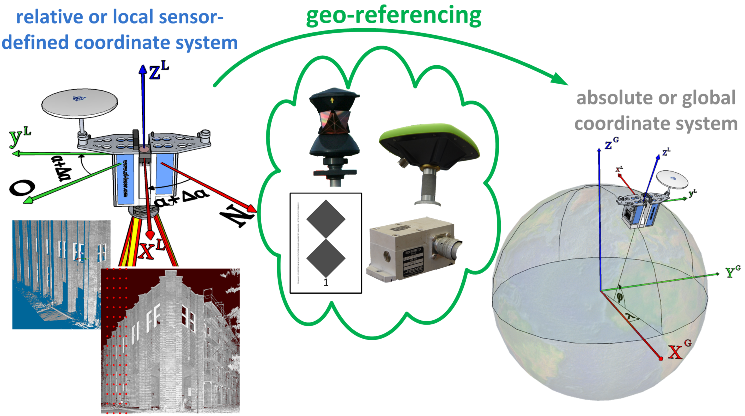

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Outline

1. Concept and strategy for the direct geo-referencing of static 3D laser scans
   - Observation concept for the transformation elements
   - TLS-based MSS @GIH
   - Present strategy for the direct geo-referencing procedure
2. Adaptive extended Kalman filter approach for direct geo-referencing purposes
   - Present filter setup: state vector and equation of motion
   - GNSS tracking results
   - Comparison of tracking approaches
3. Summary and future work

Methodology for direct geo-referencing of static 3D laser scans

Jens-André Paffenholz, Hamza Alkhatib, Hansjörg Kutterer

Transformation rule

$$\mathbf{X}_E = \mathbf{R}_S^E \cdot \mathbf{X}_S + \Delta\mathbf{X}_S^E$$

- Position vector of scan points in the local coordinate system
- Position vector of TLS center point in the global coordinate system
- Rotation of the local to the global coordinate system

Required elements to observe

- Spatial rotation about the $Z-$axis (orientation/azimuth)
- Position vector $\Delta\mathbf{X}_S^E$ constant per station

Optional elements to observe

- Spatial rotation about the $X-$ and $Y-$axis (leveling, optional residual divergence observable by inclinometer)

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AKEF for Direct Geo-Referencing of a TLS-based MSS

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Observation concept for the transformation elements

Terrestrial laser scanner (TLS) with integrated geo-referencing

- Using only a minimum number of additional sensors with an adequate data rate
- Estimating the laser scanner position and orientation directly
- Undisturbed operation of the laser scanner
- Using the vertical axis rotation of the laser scanner as time reference
- Working without geo-referenced control points

Commercial products

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TLS-based MSS @GIH

Multi-Sensor-System (MSS) configuration

- Phase-based TLS *Z+F Imager 5006* (data rate: ≈ 10100 Profiles@364°, TTL-puls)
- *Javad* GNSS receiver Delta (data rate: 100 *Hz*, GPS&Glonass, PPS, GPS event)
- *Schaevitz LSOC-1°* inclinometer
- Optional tracking sensor: *Trimble* 5700 (data rate: 10 *Hz*, GPS) or tacheometry with 360°-prism (2 *Hz*)

MSS v09t: Present realization @ GIH

Time synchronization aspects

Unique time scale for the different measurement types

(a) Use of the internal laser clock of a suitable device such as a TLS as temporary time reference

(b) Use of an external clock such as a GNSS receiver as absolute time reference

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Present strategy for the direct geo-referencing procedure

1. Data acquisition
   Individual data pre-processing for each sensor type of the MSS
   - 3D laser scan
   - Inclinometer measurements
   - GNSS data processing
2. Data synchronization
   Introduction of GPS time as unique time reference in the MSS
3. Data fusion
   Interpolation of measured data for each scan profile
4. Adaptive extended Kalman filtering
   Estimation of transformation parameters for the MSS
5. *Result visualization and applying the transformation parameters to the scan data*
   Next step in the ongoing work:
   $\Longrightarrow$ Transformation of at least two different laser scanner stations from the same scene

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Overview Kalman filter

Main aim of a Kalman filter (KF)

- Optimal combination of a given physical information for a system and external observations of its state
- State estimation only optimal in case of linear state space systems

Modeling of trajectories of moving vehicle

Enhancement of the EKF with additional parameters

Overview Kalman filter

Main aim of a Kalman filter (KF)

Modeling of trajectories of moving vehicle

- Often leads to nonlinearities in the system equations of the KF
- Here: Functional relationship between the MSS coordinates and the other state parameters is nonlinear
- Solution: Extended Kalman filter (EKF) which is based on an approximation of the nonlinear functions by a Taylor series expansion (1^{st} order)

Enhancement of the EKF with additional parameters

Overview Kalman filter

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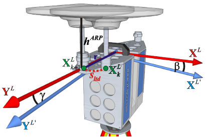
Enhancement of the EKF with additional parameters

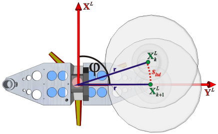
- Additional parameters are time invariant, system specific parameters with well known initial values
- Why?
  - Improvement of the filtering by adaption of the dynamic model
  - Brings the model closer to reality

$\Longrightarrow$ EKF with adaptive parameters (AEKF); also well known as dual estimation

State vector and equation of motion

State vector: $\mathbf{X}_k = \begin{bmatrix} \mathbf{X}_k^G & \alpha^L_{Scan,k} & \beta^L_{Scan,k} & \gamma^L_{Scan,k} & r_k & \varphi_k & s_{ltd,k} \end{bmatrix}^T$





Equation of motion:

$$\mathbf{X}^G_{k+1} = \mathbf{X}^G_k + \mathbf{R}^G_{\alpha G}(\lambda,\varphi) \cdot \mathbf{R}^{\alpha G}_L\left(\alpha^G\right) \cdot \mathbf{R}^L_{ScanN}\left(\alpha^L_{Scan,k}\right) \cdot \left[\mathbf{X}^L_{k+1} - \mathbf{X}^{GNSS}_{ScanN,k}\right]$$

- Disoriented local step between two epochs
- Local orientation by angle/motor increments of the TLS
- Global orientation of the MSS (a priori initial value computed by means of global positions)
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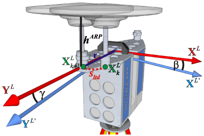

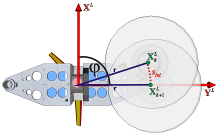

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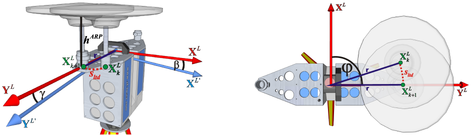

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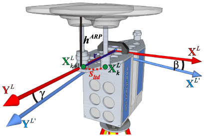

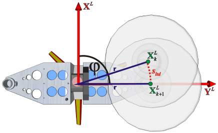

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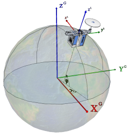

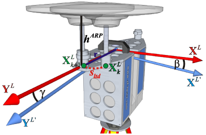

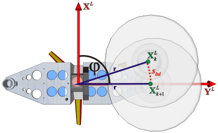

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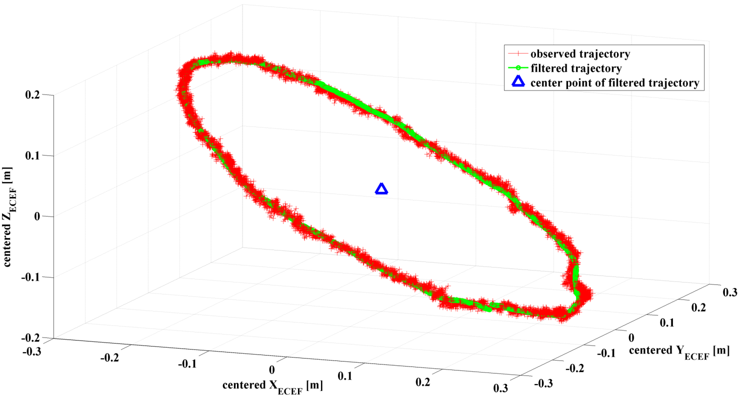
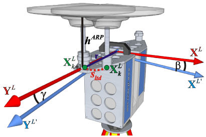
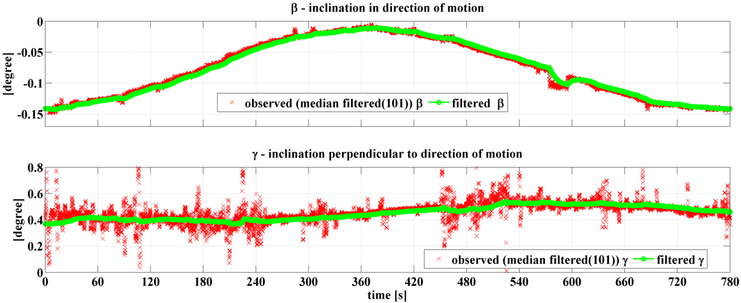
AEKF – results: trajectory

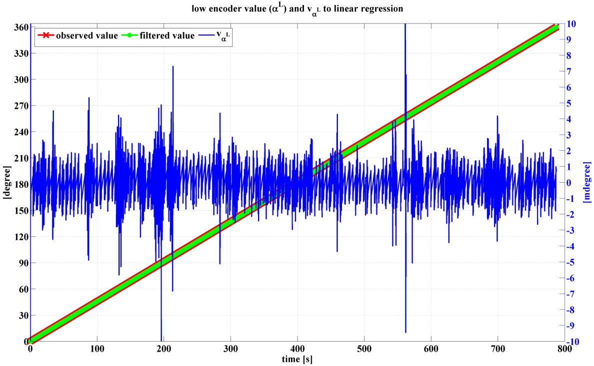


AEKF – GNSS tracking results: inclinations





AEKF – GNSS tracking results: azimuth



Determination of the final global azimuth

- Calculation of geodetic azimuth (α_k^G) for each epoch $k \in \{1 \dots n\}$ between filtered trajectory and calculated center point $\Longrightarrow \alpha^G = \frac{1}{n}\sum_{k=1}^{n}\left(\alpha_k^G\right)$
- Metric uncertainty of $\approx 1\,cm$ for the global azimuth calculation @35 m

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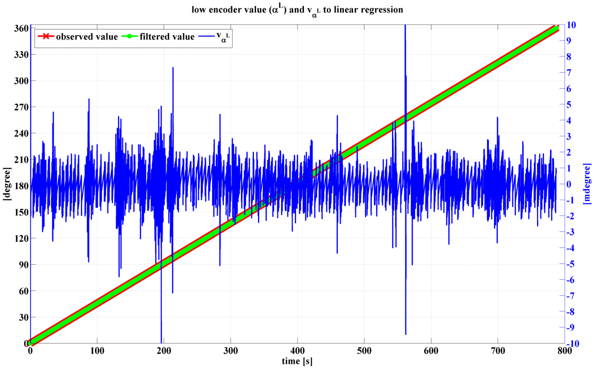

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Comparison of GNSS and tacheometer tracking

point no	dx [m]	dy [m]	dz [m]	ds [m]
328	-0.002	-0.034	-0.038	0.051
348	-0.001	-0.041	-0.038	0.056
318	-0.001	-0.042	-0.038	0.057
330	-0.003	-0.033	0.042	0.053

Table: Coordinate differences between GNSS and tacheometer tracking for several control points

Facts for the comparison of the tracking approaches

- Distance between the TLS station and the targets is $\approx 16\ m$
- Coordinate differences between GNSS and tacheometer tracking are less than one decimeter
- Comparisons to global reference control points shows significant larger differences (1.5 times)

3D scan of the *Lower Saxony Steed* (Lower Saxony's landmark) and MMS with tracking sensors

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- Transformation parameters estimation by an AEKF approach

Future work

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- Improvement of the prediction method for lower position data acquisition rates (collocation)
- Improvement of the stochastic model to gain better understanding of the process noise ($\Longrightarrow$ variance component estimation)

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Contact

Thank you for your attention!

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