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Noise Analysis of High Sensitivity GNSS-Receivers for Direct Geo-Referencing of Multi-Sensor Systems

- **IAG • C4 Symposium • Wrocław** -

SC 4.1 Session 1

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Motivation • Direct Geo-Referencing of Multi-Sensor Systems

Objective

- Increase efficiency of stationary Terrestrial Laserscans (TLS) - provide geodetic datum for 3D point clouds
- Estimate transformation paramters from topocentric to global coordinates
- Direct geo-referencing by Multi-Sensor-System (MSS) - combine GNSS (GPS+GLO) and TLS

MSS, courtesy of Paffenholz, © GIH 2016

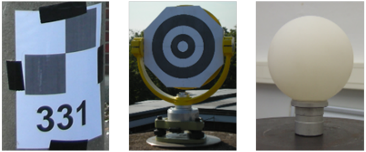
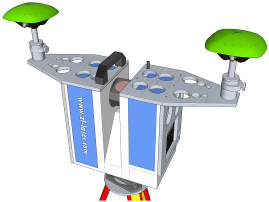


Figure: Different kinds of marker types for pass point transformation of 3D point clouds.

Motivation • From Geodetic GNSS to Single Frequency GNSS (high sensitivity)

Current approach according to [Paffenholz, 2012]

- Estimation of transformation parameters by means of 3 D coordinates
- **Geodetic GNSS (L1&L2)** equipment, high rate data acquisition rate ($\geq$10 [Hz])
- Extended Kalman filter (EKF) with simplified stochastic to obtain transformation parameters from GNSS (GPS+GLO) processing



Enhanced Approach by simplifications (justified? • similar quality?)

- **Low-cost GNSS (GPS/GLONASS L1)** equipment, data acquisition rate $\geq$1 [Hz], capable to record raw data
- TLS duration: **13 Minutes** (equals GNSS observation-window)
- Analysis of stochastic model of EKF with focus on system noise / Filter performance
- Noise analysis of single frequency receiver, benchmark test w.r.t. geodetic GNSS receiver

High Sensitivity Receiver Benchmark Test and Noise Analysis

Benchmark Test

- Zero- and very short baseline (8 m) at Laboratory network of IfE (**precisely known reference coordinates**).
- Geodetic GNSS receiver (reference) vs. single frequency GNSS receiver (test sample)
- Data acquisition
  - Five days (01.-06.07.2016, DOY 183-188), static mode, GPS + GLONASS, **5 sec** sampling
  - **Code Phase: C/A (C1C)**, **Carrier Phase: L1 (L1C)**, **Signalstrength: S1 (S1C)**

Open questions and desired information

- **We like to know:** What is the performance of carrier/code phase observations (long-time stability > 13 minutes)
- **We want:** Statistics of benchmark test as important elements for simplified Kalman Filter to improve / justify the MSS approach.

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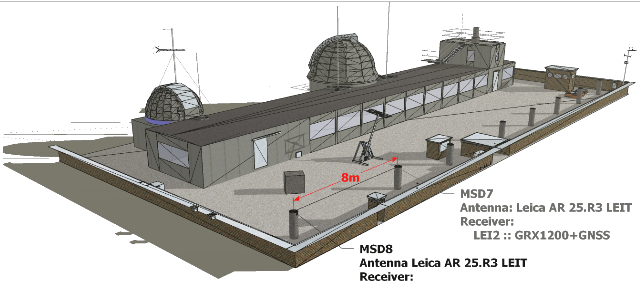
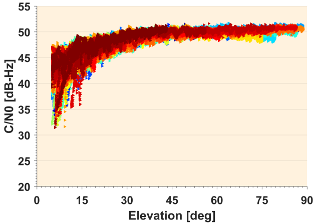
Setup of Receiver Benchmark Test

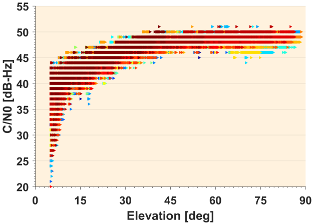


Receiver	ID	Serial	Firmware	Steering	Baseline	Point
Leica GRX1200+ GNSS	**LEI1**	5035	9.20	yes	zero	MSD8
EVK-M8T	**UBX1**	0681	3.01	yes	zero	MSD8
EVK-M8T	**UBX2**	0808	3.01	no	zero	MSD8
EVK-M8T	**UBX3**	0867	3.01	no	zero	MSD8
A07-N-11	**NVSX**	0003	A07-M	no	zero	MSD8
Leica GRX1200+ GNSS	**LEI2**	5791	9.20	yes	short	MSD7

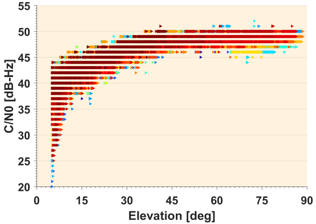
Signal to Noise (C/N0) comparisons • Individual Stations



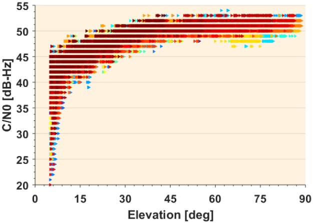
(a) LEICA GNSS+ (LEI2)



(b) UBX1



(c) UBX2/UBX3



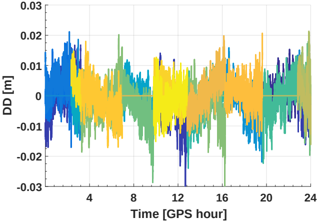
(d) NVSX

Signal to Noise • C/N0 comparisons

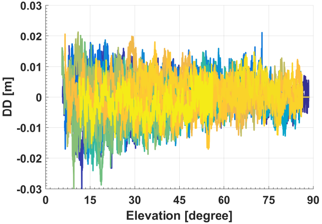
Receiver / Elevation	**@10°** [*dB-Hz*]	**@15°** [*dB-Hz*]	**@45°** [*dB-Hz*]	**@75°** [*dB-Hz*]	**@90°** [dB-Hz]
LEI1	4	5	2	3	1
LEI2	4	5	2	3	1
UBX1	5	6	4	6	1
UBX2	5	6	4	6	3
UBX3	5	6	4	6	3
NVSX	5	6	4	6	3

Table: C/N0 deviations in [*dB-Hz*] over elevation bins of 5° for a 24 hour data set (DOY 188, 2016), benchmark: LEI1/LEI2.

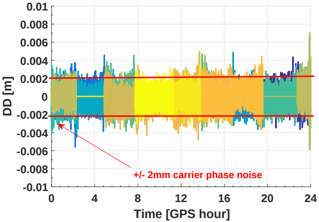
Double Differences • GPS L1 - Zero and Short Baseline - 24 hour



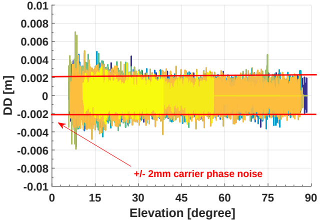
(a) short baseline (LEI1-LEI2)



(b) short baseline (LEI1-LEI2)

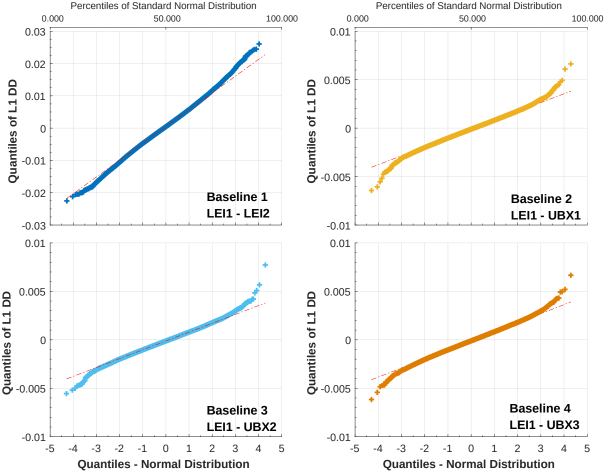


(c) zero baseline (LEI1-UBX1/UBX2/UBX3/NVSX)



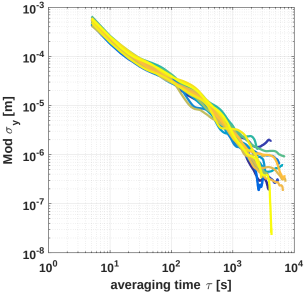
(d) zero baseline (LEI1-UBX1/UBX2/UBX3/NVSX)

Double Differences • GPS L1 - Statistics

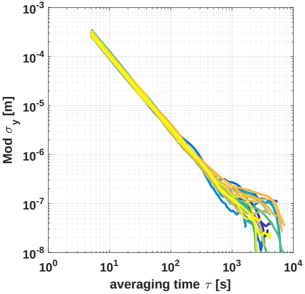


(a) Quantile-Quantile plot, DOY 188, 2016 all satellites per baseline

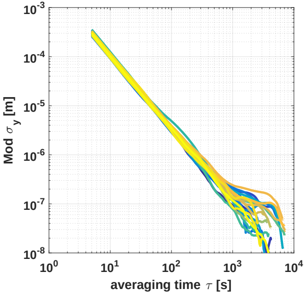
Double Difference • Noise Analysis - Allan Deviation ($\tau_0 = 5\,sec$)



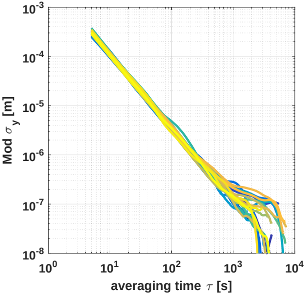
(a) short baseline (LEI1-LEI2)



(b) zero baseline (LEI1-UBX1)

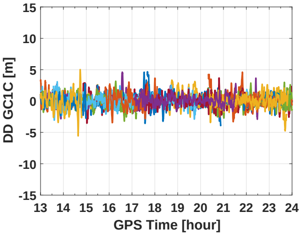


(c) zero baseline (LEI1-UBX2)

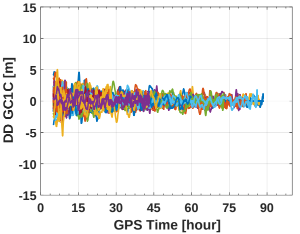


(d) zero baseline (LEI1-UBX3)

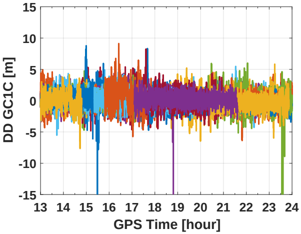
Double Differences • GPS C/A Code - Zero and Short Baseline - DOY 183, 2016



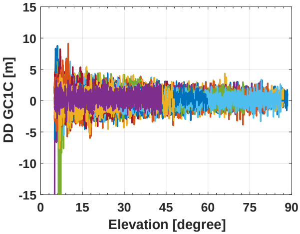
(a) short baseline (LEI1-LEI2)



(b) short baseline (LEI1-LEI2)

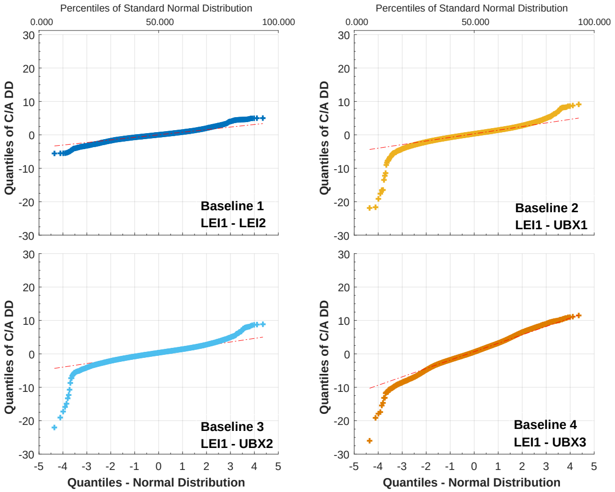


(c) zero baseline
(LEI1-UBX1/UBX2/UBX3/NVSX)



(d) zero baseline
(LEI1-UBX1/UBX2/UBX3/NVSX)

Double Differences • GPS C/A - Statistics



(a) Quantile-Quantile plot, DOY 188, 2016 all satellites per baseline

Positioning Benchmark • GPS L1 Static Baseline Solutions

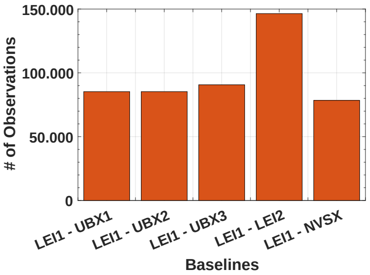
Setup for Positioning Benchmark Test

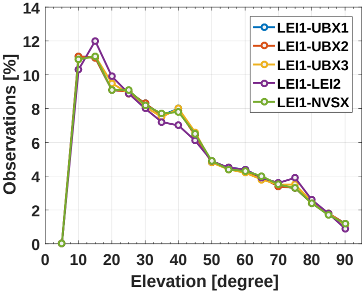
- Bernese 5.2 carrier phase based L1 only processing (baseline solutions)
- Coordinate solutions w.r.t. Laboratory network reference coordinates
- GPS/GLO combined processing with SIGMA Ambiguity search, $\cos(z)$-weighting

Processing scheme

1. 5 days zero baseline and short baseline solution (GPS/GNSS) with 24 hour data
2. 5 days short baseline GPS+GLO solution with 20 minutes (characteristic TLS duration)

Positioning Benchmark • GPS L1 Static Baseline Solutions

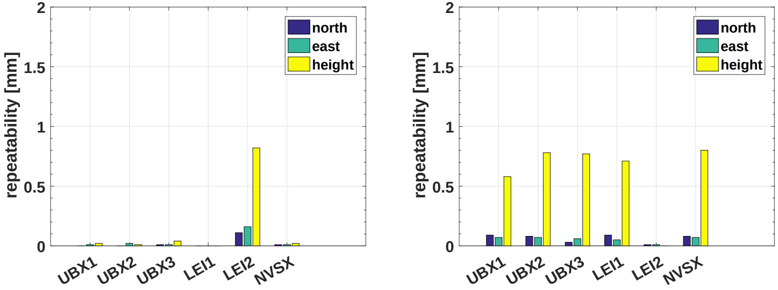




Observation statistics

- For 24 hour approx. 150 000 - 180 000 # of observations available
- Similar distribution of observations available
- Appprox. 6-8% less at the NVSX receiver (w.r.t. Ublox M8T)

Positioning Benchmark • GPS L1 Static Baseline Solutions

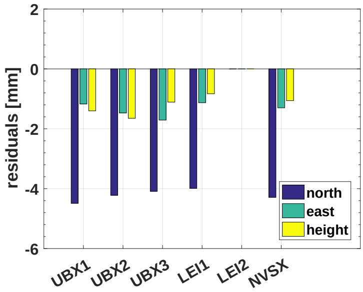


(a) 24 hour zero baseline **(b)** 24 hour short baseline

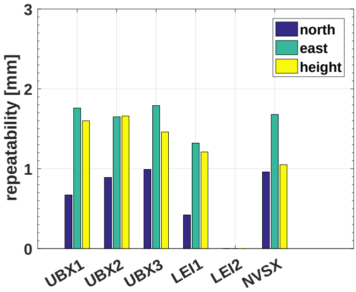
Summary

- Zero Baseline: expectable noise floor of coordinate repeatability
- Short Baseline: very good repeatability w.r.t. geodetic receiver quality

Positioning Benchmark • GNSS L1 Short Baseline Solutions (20 Minutes)



(a) 20 Minutes short baseline GNSS - Real Value Deviation



(b) 20 Minutes short baseline GNSS - repeatability

Summary

- Obtained position w.r.t. reference coordinates within noise and position repeatability
- Deviations from true values (reference coordinates) comparable to geodetic receivers
- Geodetic and single frequency receiver show quite similar noise properties

Summary Observation Domain

Carrier to Noise Ratio • C/N0

- Critical C/N0 values for Elevation $\leq 10^\circ$ for single frequency receiver
- 3 [*dB-Hz*] deviations @ mean Elevations (w.r.t. 1-2 [*dB-Hz*] for geodetic receivers)

L1 Double Differences

- Elevation range [90°-35°] show carrier phase noise of 2.5 [*mm*]
- Elevation range [35°-0°] elevation dependency, increased noise of 3-4 [*mm*] (meaningful cut-off angle $\geq 15^\circ$)
- Quantiles indicate normal standard distribution

Mod. Allan Dev. (τ =5sec)

- Allan Dev. show slope of White Phase/Frequency Noise (WPM/WFM)
- Geodetic receiver (short Baseline): 7 [*mm*] @ 1 sec
- Single frequency receiver (zero Baseline): 4 [*mm*] @ 1 sec

Summary Positioning Domain and Outlook

Position Domain • Zero Baseline

- 24 hour short / zero baseline test: single frequency receiver show very good repeatability w.r.t. geodetic receiver quality
- 20 Minutes short baseline: single frequency receiver provides nearly the identical solution as the geodetic receiver (GNSS case)

Outlook

- Adapting from static to kinematic application ($\approx$20 minutes, characteristic scan duration)
- Study of antenna noise and analysis of receiver/antenna combination

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Literatur

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Visible Satellites • GPS and GLONASS