University of Stuttgart
Germany

Institute of Engineering Geodesy

Investigation regarding Different Antennas combined with Low-cost GPS Receivers

FIG Working Week 2013

TS 05C - GNSS Positioning and Measurement I

Commission 5

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Structure

- **Introduction**
- **Low-Cost GPS Monitoring System at IIGS**
- **Quality Analysis**
- **Conclusions and Outlook**

Introduction

Monitoring is one of the main tasks in engineering geodesy, the trend in monitoring is the automation and continuity of measurements

→ instruments should permanently be set on the monitored objects and the investments would be high

Leica (2013)

Advantages of the GNSS receivers:

- can be used under all weather conditions
- direct line-of-sight is not necessary
- data collection and processing can be realized automatically and continuously

Disadvantages of the GNSS receivers:

- difficulty in shadowing environment
- geodetic receivers are expensive (>20 000€)
  → not suitable in case of many points

→ **Low-Cost single-frequency receivers**
(e.g. u-blox <100€)?

Schwieger (2009)

Introduction

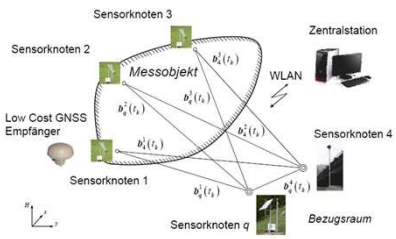
Test study with u-blox GPS receivers at University of Stuttgart, ETH Zürich und TU Graz

Schwieger (2009), Uni Stuttgart

Lanzendörfer (2007), TU Graz

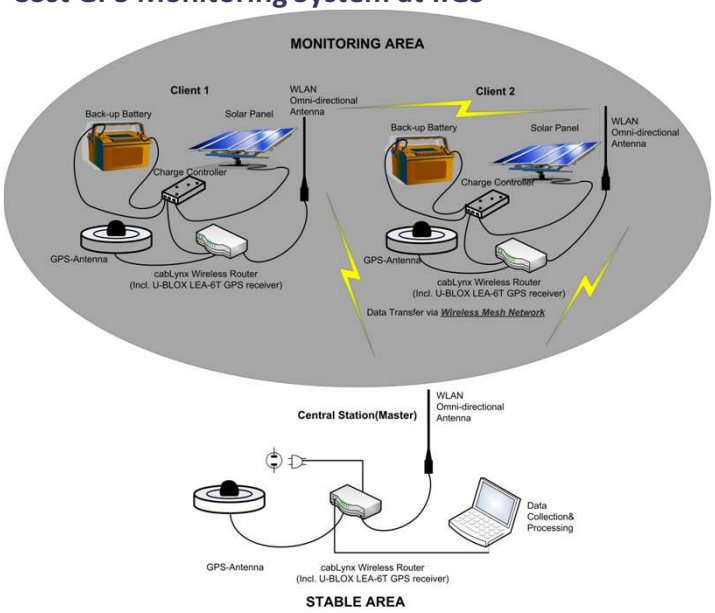
Limpach (2009), ETH Zürich

The University of Armed Forces Munich with Novatel GNSS receivers (about 1200€)

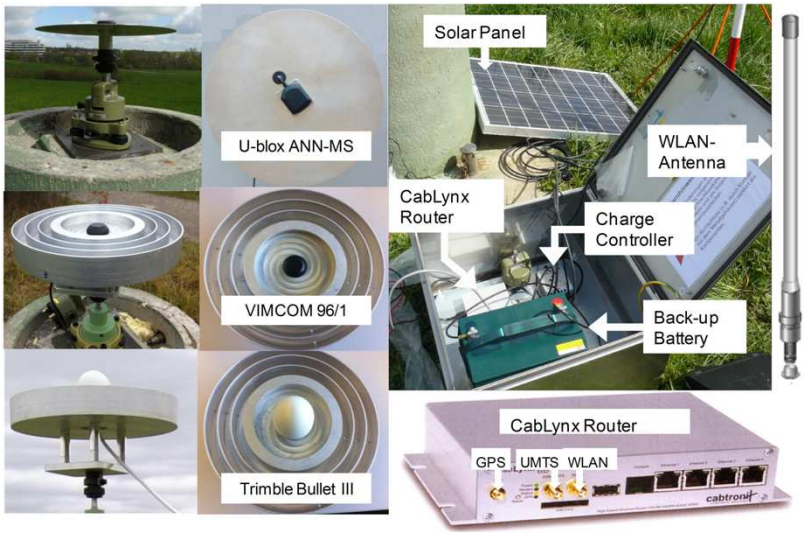


Heunecke (2011), Uni BW München

Low-Cost GPS Monitoring System at IIGS

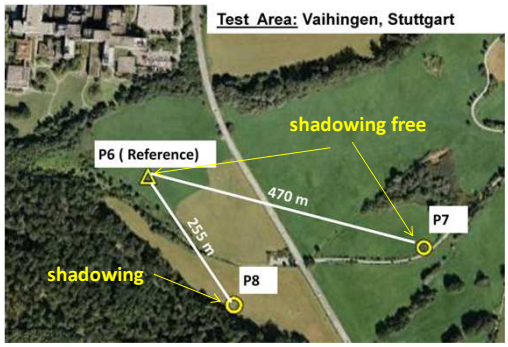


Components of one autonomous Station



<100€!

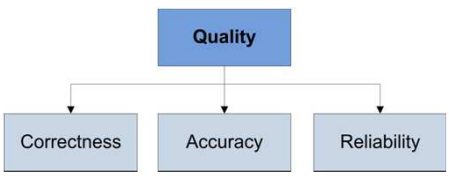
Quality Analysis- Test Scenario



Session	Datum	Observation Time	Antenna Type + shielding	Baseline
1	18.11.11	11:38-12:54	U-blox(ANN-MS) + ground plate	PF6-PF7
2	02.11.12	12:32-13:43	Vimcom (96/1) + Choke-Ring	
3	02.11.12	14:08-15:09	Trimble (Bullet III) + Choke-Ring	
4	18.11.11	11:38-12:54	U-blox (ANN-MS) + ground plate	PF6-PF8
5	02.11.12	10:51-11:53	Vimcom (96/1) + Choke-Ring	
6	02.11.12	09:23-10:24	Trimble (Bullet III) + Choke-Ring	

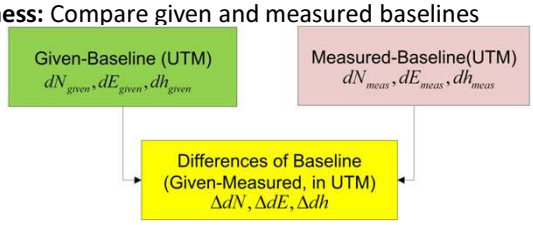
Quality Analysis- Data Processing Procedure

- **TEQC (UNAVCO)**
  - Conversion of format (e.g. UBX-RINEX)
  - Edit of RINEX file (e.g. coordinates, antenna type, antenna height) ….
- **WA1 (WASOFT)**
  - Baseline calculation
  - **Solution File** (coordinates, solution type, quality indicator…)
    Solution type: „FloatDGNSS“, „FixedL1“…
    Quality solution: „low“, „medium“, “high“ (percentage of fixed ambiguity, number of satellites, PDOP …)
  - **Log File** (calculation steps of baseline processing)

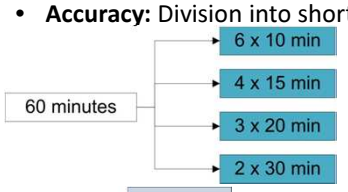


Quality Analysis- Data Processing Procedure

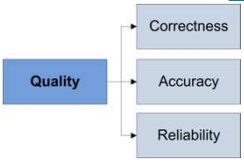
- **Correctness:** Compare given and measured baselines



- **Accuracy:** Division into short time intervals



In which time interval a reliable and accurate result can be delivered for a near-real-time system?



Mean Value of $\Delta dN, \Delta dE, \Delta dh$

Standard Deviation of $\Delta dN, \Delta dE, \Delta dh$

$$\frac{number\ of\ time\ intervals\ with\ fixed\ solutions}{total\ number\ of\ time\ intervals}\ [\%]$$

Original Results* – Baseline PF6-PF7 (Session 1, 2 and 3)

Session No.	Time Interval	Mean [mm]			Standard Deviation [mm]			Reliability
		mΔdN	mΔdE	mΔdh	sΔdN	sΔdE	sΔdh	
Session 1 (U-BLOX)	10min	2.8	-3.0	13.3	0.8	2.1	4.7	100.00%
	15min	2.8	-3.1	13.3	0.7	2.3	4.9	100.00%
	20min	2.8	-2.9	13.4	0.5	2.2	3.8	100.00%
	30min	2.7	-2.0	13.4	0.2	1.1	3.7	100.00%
	60min	2.9	-2.3	14.7	-	-	-	100.00%
Session 2 (Vimcom)	10min	3.4	-7.4	7.8	0.8	0.8	1.0	100.00%
	15min	3.4	-7.4	7.7	0.5	0.6	0.5	100.00%
	20min	3.4	-7.4	7.8	0.7	0.9	0.5	100.00%
	30min	3.4	-7.4	7.8	0.1	0.5	0.4	100.00%
	60min	3.4	-7.4	7.7	-	-	-	100.00%
Session 3 (Trimble)	10min	2.8	-5.8	10.9	0.6	0.4	1.2	100.00%
	15min	2.8	-5.8	11.0	0.6	0.2	0.9	100.00%
	20min	2.8	-5.8	10.9	0.3	0.1	0.7	100.00%
	30min	2.8	-5.8	11.0	0.1	0.1	1.1	100.00%
	60min	2.7	-5.8	10.8	-	-	-	100.00%

*Note: elevation angle is 10° and no antenna correction was used.

Original Results* – Baseline PF6-PF8 (Session 4, 5 and 6)

Session No.	Time Interval	Mean [mm]			Standard Deviation [mm]			Reliability
		mΔdN	mΔdE	mΔdh	sΔdN	sΔdE	sΔdh	
Session 4 (U-blox)	10min	-0.7	-6.0	-3.3	1.6	2.8	10.4	83.3%
	15min	-0.9	-6.6	-5.3	2.2	2.6	8.1	75.0%
	20min	-1.2	-5.7	-2.7	1.5	1.8	8.3	100.0%
	30min	-1.4	-6.1	-3.6	2.4	1.2	10.0	100.0%
	60min	-1.1	-5.6	-2.4	-	-	-	100.0%
Session 5 (Vimcom)	10min	533.7	-314.4	-294.1	590.3	322.5	422.4	66.7%
	15min	457.5	-281.3	-325.7	559.1	305.7	436.3	100.0%
	20min	454.2	-214.5	-319.5	644.8	341.3	447.5	100.0%
	30min	399.9	-108.9	-210.1	-	-	-	50.0%
	60min	-	-	-	-	-	-	0.0%
Session 6 (Trimble)	10min	-1.2	-5.7	1.1	0.8	2.5	5.3	83.3%
	15min	-1.1	-5.6	1.4	0.5	1.9	4.5	100.0%
	20min	-1.1	-5.7	1.3	0.5	2.0	4.0	100.0%
	30min	-1.1	-5.6	1.4	0.1	1.8	4.7	100.0%
	60min	-1.0	-5.0	1.7	-	-	-	100.0%

*Note: elevation angle is 10° and no antenna correction was used.

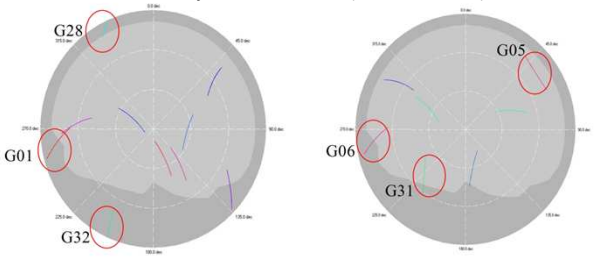
Results with inventions

- **Increasing the elevation angle (from 10° to 15°)**

The results do not change considerably ⟹ elevation angle 10°was set at the end

- **Elimination of Satellites (using Wa1 und LGO)**

Visibility of Satellites at P8 *(LGO, Leica 2013)*



Session 4 Session 6

Session 4	Session 6	
G32 & G28 (wa1), G01 (LGO)	G05 (wa1)	← eliminated
	G06 & G31 (LGO)	← Not eliminated

Results with inventions

- **Elimination of Satellites**

Improved results of the baseline P6-P8 by elimination of satellites

Session No.	Time Interval	Mean [mm]			Standard Deviation [mm]			Reliability
Session 4	10min	-0.8	-5.3	-2.0	1.5	3.0	9.9	100.0%
	15min	-1.1	-5.7	-2.5	1.9	2.7	8.7	100.0%
Session 6	10min	-0.9	-4.8	1.8	1.0	3.2	5.1	100.0%

- Reliability of all the time intervals is 100% after elimination of satellites
- Accuracy and correctness was not improved significantly
- Satellites with disturbed signal have great influence on the results
- Manual data handling is complicated and time consuming, so it is not suitable for near real-time automatic data processing
- To minimize „false alarms " for Monitoring applications:
  if the solution indicator is „low" or „medium" (float solution)
  ⇒ automatical exclusion

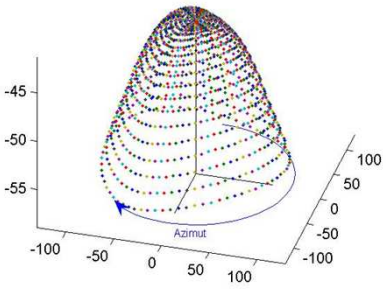
⇒ **Problem:** Too many exclusions in shadowing environment, resulting in data gaps.

Applying Antenna Corrections

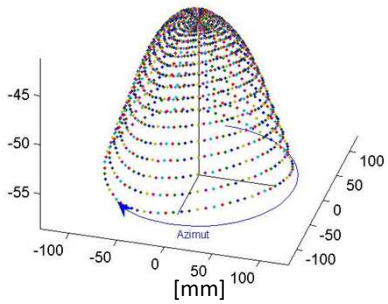
Individual calibration for Trimble Antennen with Choke-Ring (University of Bonn).

Antenna phase center variations

Reference



Rover



Antenna phase center offsets [mm]

```
G01                                          START OF FREQUENCY
   0.04      -0.05      176.51                NORTH / EAST / UP
G01                                          START OF FREQUENCY
   0.07       0.06      176.31                NORTH / EAST / UP
```

Results with Antenna Corrections

Session 3 and 6 (with Trimble) were re-processed with individual antenna corrections

Difference in results with and without calibration correction of the Trimble antennas

Session No.	Time Interval	Mean [mm]			Standard Deviation [mm]			Reliability
Session 3 (Trimble)	10min	0	0.3	-0.1	0	-0.1	0.1	100.0%
	15min	0	0.3	0	0	0	0.1	100.0%
	20min	0	0.3	-0.2	0	0	0.1	100.0%
	30min	0	0.3	-0.1	0	0	0.2	100.0%
	60min	0	0.3	-0.1	-	-	-	100.0%
Session 6 (Trimble)	10min	0.2	-0.4	-0.7	0	0.1	0.1	100.0%
	15min	0.2	-0.4	-0.6	0	0.2	0.2	100.0%
	20min	0.2	-0.5	-0.6	0	0.2	0.4	100.0%
	30min	0.2	-0.4	-0.6	0	0	0.5	100.0%
	60min	0.2	-0.3	-0.6	-	-	-	100.0%

- **Individual antenna calibration** improves the results in sub-mm
- **Type calibration** does not improve the results (because of the short baselines)

Quality Analysis - Summary and Discussion

- **Reliability:**
  - depending on shadowing conditions, 10 to 20 minutes is necessary to solve the ambiguities
- **Accuracy:**
  - An observation time of more than 20 minutes, does not lead to significant changes in the standard deviations ⟹ 20 minutes solution for near-real time system o.k.
  - Vimcom antennas are not suitable for shadowing environment
  - Trimble antennas with Choke-Ring are better than u-blox antennas with ground plate

Shadowing-Condition	Accuracy Trimble with Choke-Ring		Accuracy U-blox with ground plate	
	Horizontal Position [mm]	Height [mm]	Horizontal Position [mm]	Height [mm]
shadowing free	< 0.6	< 1.2	< 2.3	< 4.9
shadowing	< 3.2	< 5.1	< 3.0	< 10.0

- **Correctness:**
  - mm to cm, systematic error? Minimize by calculating temporal coordinate differences?

Discussion: - Is individual antenna calibration necessary?
- Is the Choke-Ring better than ground plate?

Conclusions and Outlook

Summary

- An automatic monitoring system using u-blox GPS receivers was presented
- Focus was on the quality analysis of this system

Chance

- Accuracy from sub-mm up to a few mm in horizontal position and height can be achieved by Trimble Bullet III antennas with Choke-Ring
- Differences of given and measured values (correctness) are up to 15 mm in horizontal position and height, more measurements and analyses are necessary

Difficulties

- Accuracy and reliability in shadowing environment are worst
- Manuel data handlings can improve the accuracy, but it is not suitable for an automatic near-real-time system

Future

- Improvement of the accuracy and reliability of this system (particularly in shadowing environment)
- Analysis of the antenna-shielding combination

Acknowledgement

The Wa1 software provider, Prof. Dr. Wanninger from Geodetic Institute, Technical University of Dresden is highly appreciated. The authors thank also Prof. Dr. Kuhlmann from the Institute of Geodesy and Geoinformation, University of Bonn for the antenna calibrations.
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