Navigation and Position Integrity for Inland Marine Transport Vessels

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Motivation

In this project, the quality of GNSS measurements on vessels is evaluated to determine challenges such as crossing under bridges, reflections and moving baselines. To achieve information about possible influencing factors, three aspects have been investigated; the **ship geometry**, **signal analysis** and the **ship trajectory**. The data were collected based on a scientific program in which the MS Jenny (MS Wissenschaft, research topic seas and oceans) took a tour through Germany on the Mittellandkanal. This data are the basis of a project seminar at the Institut für Erdmessung, Leibniz University Hannover.

(a) back view (b) in motion (c) front antenna

Figure 1: Impressions of the MS Wissenschaft, the ship utilized for this project.

Design and Realization of the Experiment

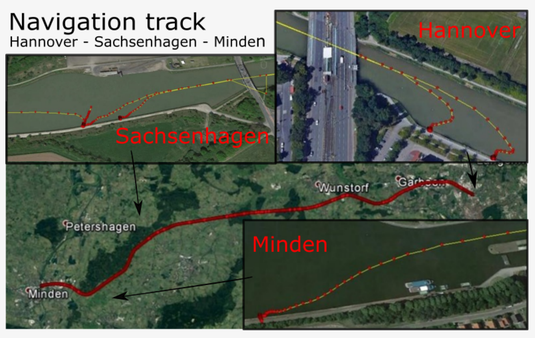


Figure 2: Navigation track for the complete data set.

Track Subdivision

- Five sessions of static and kinematic parts,
- Depart: Hannover harbour (one hour static part)
- Break: Sachsenhagen (approx. seven hours static part)
- Destination: Minden harbour (five hours static part)

Used Equipment

- Baseline realized with two receivers at the back and front of the vessel
- Front: NovAtel Pinwheel Antenna (NOV703GGG) with Javad QUA_G3D SIGMA
- Back: NovAtel Pinwheel Antenna (NOV703GGG) with NovAtel Span SE receiver

Design of the Local Geometry

- Ship geometry is important in order to study multipath effects of GNSS signals, especially when the ship passes under bridges. Effects like diffraction, scattering and reflection from different surfaces of the ship itself could degrade the GNSS signal.
- Investigation of the vessel's geometry and the skipper's cabin height
- Geometry determination with RTK, for independent solutions also tacheometry
- Closed loop network between baseline points and points in the harbour
- Triangulation for coordinate network adjustment

Fundamentals for Navigation Approaches

- Navigation of the ship is feasible via a moving baseline.
- Realization of the moving baseline by two points equipped with GNSS antennas as far away from each other as possible.
- For the interpretation of the data the length of the baseline has to be determined in advance.

Ship Geometry

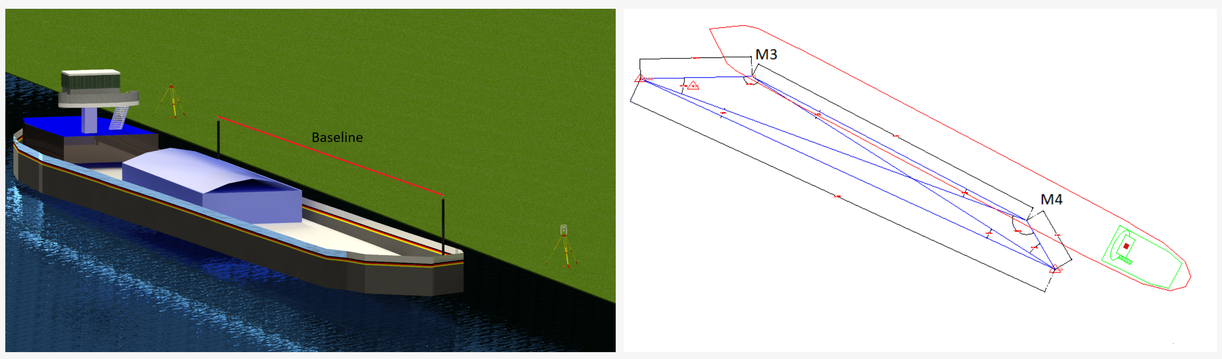
Table 1 shows the results of the different methods for the length of the baseline and the accuracy.

Table 1: Reference baseline length and associated accuracy

	RTK			Tacheometer [m]
	Hannover	Minden	Combined solution	H-M-adjustment
baseline length [m]	57.345	57.347	57.346	57.342
accuracy [m]	0.020	0.006	0.021	0.008

- The estimated baseline length via polar measurements is obtained to 4 mm with the RTK solution.
- Accuracy of the estimated baseline from RTK is based on the accuracy of the single points calculated using error propagation law (Hannover [H1: 0.016 m, H2: 0.011 m], Minden [M3: 0.003 m, M4: 0.005 m]).
- Accuracy of the baseline from polar measurements comes from least squares adjustment of the coordinates network.
- As final, the estimated baseline from tacheometer is used (**57.342 m**). The RTK result serves as an evidence check.

Fig. 3 illustrates the 3D model and the 2D network of the ship using estimated 3D coordinate points.



(a) 3D Model (b) 2D network

Figure 3: 3D and 2D visualisation

Target Trajectory I

- The target consists of two points on the vessel ("baseline").
- Positions are determined by two different receivers.
- GPS observations are used for post processing.

Services and Approaches

- Different methods and tools of post processing were used to analyze the observed data.
- For Precise Point Positioning (PPP), different online services are applied such as MAGIC GNSS, NRCAN and GAPS.
- For differential GPS (DGPS), which includes reference stations, tools such as AUSPOS online service and NovAtel GrafNav are utilized.

Target Trajectory II

- Table 2 shows the results of the different positioning tools in determining the length of the baseline.

Table 2: Baseline length in the static parts.

Station/Service	AUSPOS	NRCANADA	MAGIC GNSS	GrafNav
Hannover [m]	-	57.345	57.270	57.340
Sachsenhagen [m]	57.341	57.323	57.342	57.329

- The length of the baseline in the kinematic part from Hannover to Sachsenhagen by using GrafNav is shown in figure 4.

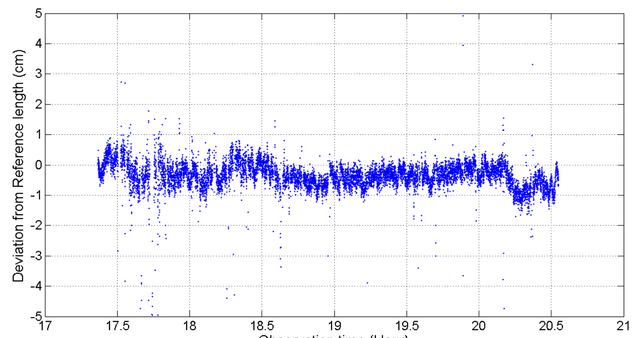
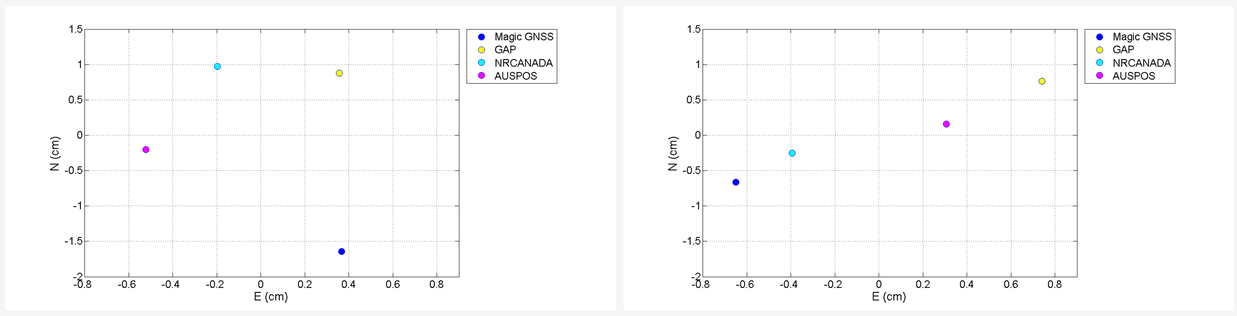


Figure 4: Deviation of the length of the baseline from reference baseline in kinematic part.

- In figure 5, a comparison of positioning the targets using different tools for one of the static parts (Sachsenhagen) is shown.



(a) Front Antenna (b) Back Antenna

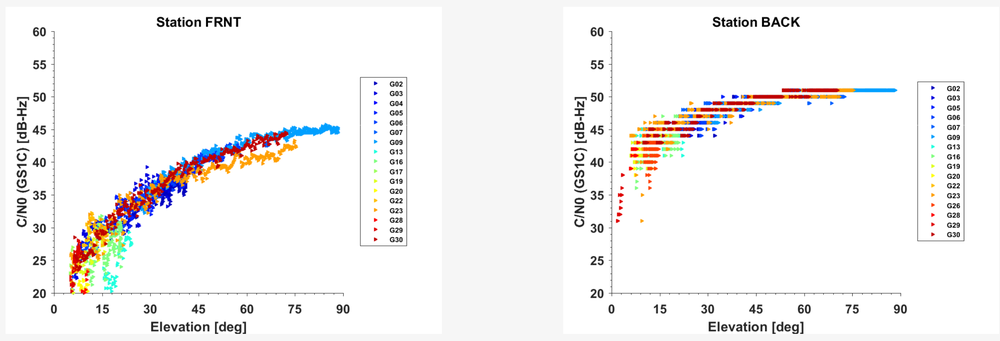
Figure 5: Horizontal position deviation from mean in Sachsenhagen.

Signal Analysis

- For further signal analysis, only the static parts have been evaluated.
- In the back, 38484 epochs were recorded and 64710 epochs in the front at a 1 second interval each.
- In the following examples, $\mathrm{C/N_0}$ curves (fig. 6) and multipath linear-combinations (fig. 7) in Sachsenhagen are shown.

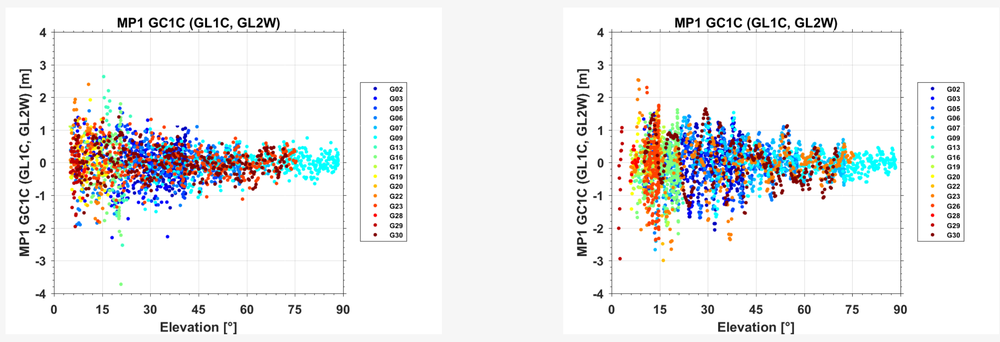
Findings

- Difference in $\mathrm{C/N_0}$ level between back and front station due to different receiver properties.
- Different resolution of $\mathrm{C/N_0}$ curves of individual receivers. Higher resolution of the receiver at the front antenna.
- No significant periodic variations or oscillations detectable.
- The MP1 graphs vary between ± 1 m (± 2 m for elevation $< 20°$), low reflections and multipath effects are present, provided by the ship itself.



(a) $\mathrm{C/N_0}$ of front antenna (b) $\mathrm{C/N_0}$ of back antenna

Figure 6: Signal strength of GPS signal GS1C w.r.t. elevation for front and back antenna in Sachsenhagen



(a) MP1 of front antenna (b) MP1 of back antenna

Figure 7: Multipath linear combination of GPS signals (GL1C-GL2W) w.r.t. elevation for front and back antenna in Sachsenhagen

For further kinematic signal analysis it is important to know how the ship itself effects the signal quality. But since only low reflections and multipath effects are visible for the static part one can expect that signal interruptions or high reflections and multipath effects during the movement will be caused by bridges.

Conclusion and Outlook

The analytical investigation for the first part of the project seminar program shows

- a precise determination of the baseline length from tacheometry as reference,
- the ship geometry, especially the highest point, is important for passing under bridges due to different platform heights,
- the ship geometry is not critical for signal reception in our project,
- besides, the target trajectory PPP (static and kinematic) is used as reference for further investigations.

Further investigations

- Studying the navigation of the inland vessel with the concept of a moving baseline.
- Applying virtual receiver concept to the bridge crossing of inland vessels to support continuous navigation solution (different to dead reckoning).
- Studies of the GNSS signals during bridge crossings (reflection, diffraction, scattering).
- Challenges in determining the clearance between inland vessel's cabin and bridges.

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