A Virtual Receiver Concept for Continuous GNSS based Navigation of Inland Vessels

- NAVITEC 2018 • ESA/ESTEC • Noordwijk -

Session: Precise Positioning

Tobias Kersten, Le Ren and Steffen Schön | Thursday, December 6th, 2018
Motivation • Inland Vessel Transport

Inland Waterway Transport (IWT)
- reliable, almost safe, eco-friendly and profoundly effective
- reducing traffic stress on rail and motorways
- future: combined transport (rail, waterway, motorway, regional & local)

Present transport vessel navigation
- precise navigation by GNSS in real-time kinematic RTK mode
- requires mobile data infrastructures / interfaces (RTCM, NTRIP, OSR/SSR)
- navigation precision required / available: 2-5 cm / \( \approx \text{dm} \)
Motivation • Inland Vessel Transport

Inland Waterway Transport (IWT)
▶ reliable, almost safe, eco-friendly and profoundly effective
▶ reducing traffic stress on rail and motorways (IWT: 240 mill. tons per year)
▶ future: combined transport (rail, waterway, motorway, regional & local)

Present transport vessel navigation
▶ precise navigation by GNSS in real-time kinematic RTK mode
▶ requires mobile data infrastructures / interfaces (RTCM, NTRIP, OSR/SSR)
▶ navigation precision required / available: 2-5 cm / ≈dm
Uelzen (GER): Skipper died cabin and steel cable collides as vessel entered lock
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Surwold/Emsland (GER): Vessel collides with bridge, skipper died. Thick fog possibly the cause.

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Virtual Receiver (VR) for Inland Waterway Transport

Scientific key questions

▶ safety relevant applications (e.g. collision security, driver assistance) require high accuracy (carrier phase)

▶ carrier phase & code observables affected by discontinuities, interruptions or complete loss-of-lock

▶ evaluating benefits for code based navigation (combining receiver antennas, assisting/aiding carrier phase ambiguity resolution)

Virtual Receiver - observation domain

▶ provides enlarged field of view (individual antennas)

▶ usable on arbitrary rigid navigation platform (satellite, aircraft, ferry, vessel)\(^a\)

▶ requires lever arm definition (accurate and precise)

\(^a\)Kube et al. (2018, 2012); Schön and Alpers (2018); Kersten et al. (2018)
Concept - Virtual Receiver (VR)

Step 1 / 8

Side view

Bridge

Top view

lever arm
Concept - Virtual Receiver (VR)

Virtual Receiver - position domain

- **input** observables from individual receiver antennas
- **position** solution - robust by strengthened satellite geometry
- **angles** transport rate (specific approach for inland vessels)
- **synchronisation** coordinate observations of individual antenna locations

Specifications to present approach

- **cost effective** no Inertial Navigation System (INS)
- **heading** consider transport rate (in-situ by moving baseline)
Concept - Virtual Receiver (VR)

Step 2 / 8

Side view

defraction / scattering

lever arm

Top view

Bridge

lever arm
Concept - Virtual Receiver (VR)

Step 3 / 8

Side view

interruption / loss-of-lock

lever arm

Top view

Bridge

lever arm
Concept - Virtual Receiver (VR)

Step 4 / 8

Side view

interruption/loss-of-lock

Top view

Bridge
Concept - Virtual Receiver (VR)

Step 5 / 8

Side view

defraction / scattering

interruption / loss-of-lock

Top view

Bridge
Concept - Virtual Receiver (VR)

Step 6 / 8

Side view

Top view

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Concept - Virtual Receiver (VR)

Step 7/8

Side view

[Diagram showing satellite and bridge with annotations: defraction/scattering, lever arm]

Top view

Bridge

lever arm

lever arm
Concept - Virtual Receiver (VR)

Step 8 / 8

Side view

Top view

lever arm

Bridge
Dedicated studies - the vessel MS Jenny

Kersten et al. (2018)

**MS Jenny**

- overall geometry: 100 m length, 9.5 m width, 3.16 m depth
- two GNSS units alongside the vessel at bow (FRNT) and stern (BACK)
- datasets recorded in summer 2016 and 2018 (under investigation)
  - **static**: mooring point Hannover, duration 1 hour (Kersten et al., 2018)
  - **kinematic**: trip westward from Hannover, duration 2.5 hours
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Dedicated studies - trajectory for investigations

Experimental set-up

▶ sessions in 2016 (*static* and *kinematic*) investigated
▶ reference trajectory (double difference, phase based, NRCan and GrafNav)
▶ lever arm (FRNT - BACK) by tachymetre and RTK (57.346 m±2 cm)

Kersten et al. (2018)
Satellite visibility - kinematic session

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Findings for Virtual Receiver concept

- advantageous to strengthen the satellite geometry
- significant improvements for both, HDOP and VDOP
Code observables: position accuracy II - kinematic session

Results
Code observables: position accuracy II - kinematic session

Results

▶ static session
  ▶ available epochs: 100% (VR) and 99.9% (SA)
  ▶ HPE/VPE (VR): 0.70 m / 0.46 m
  ▶ HPE/VPE (SA): 1.02 m / 0.54 m

▶ kinematic session
  ▶ available epochs: 94.5% (VR) and 76.7% (SA)
  ▶ HPE/VPE (VR): 0.68 m / 0.48 m
  ▶ HPE/VPE (SA): 0.97 m / 0.71 m
Impact on carrier phases - kinematic session

(a) cycle slips in double differences

(b) repaired double differences

(c) GPS satellite G11

(d) GPS satellite G27
Impact on carrier phases - kinematic session - GPS G27

(a) cycle slips in double differences

(b) repaired double differences

(c) GPS satellite G27
Impact on carrier phases - kinematic session - GPS G11

(a) cycle slips in double differences

(b) repaired double differences

(c) GPS satellite G11
Summary and outlook

Summary

▶ concept of Virtual Receiver approach presented, which strengthens the satellite visibility / navigation geometry by up to 50%
▶ code-position accuracy (13-16%) improved
▶ number of epochs with valid solution (94% (VR), 77% (SA)) improved

Outlook and further work

▶ promising approach to avoid faults of the carrier phase ambiguity resolution due to enhanced observation continuity (ambiguity bridging)
▶ receiver clock modelling with chip scaled atomic clocks (CSACs) looks promising to derive reliable positions with special focus on the height component (Krawinkel and Schön, 2018)
▶ identify bridge (e.g. building structure) by characteristics of GNSS signal distortion
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Satellite visibility - static session

# satellites

mean/min/max (SA): 8 / 7 / 10
mean/min/max (VR): 17.3 / 15 / 19
Code observables: position accuracy - static session

![Graphs showing HDOP and VDOP over time](image)

- **HDOP**
  - HDOP SA
  - HDOP VR

- **VDOP**
  - VDOP SA
  - VDOP VR

**GPS Time [hours]**

- 16:30
- 16:45
- 17:00
- 17:15
- 17:30

**HDOP**

- 0
- 1
- 2
- 3
- 4

**VDOP**

- 0
- 1
- 2
- 3
- 4