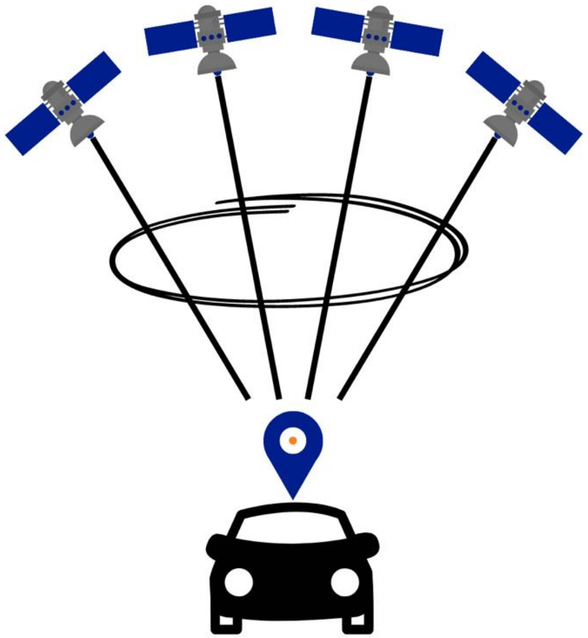
NAVISP-EL1-066 ESA Contract 4000139705/22/NL/CS

GOOSE-VTL
Deeply Coupled GNSS Vector tracking loop robust solution for autonomous vehicles

Final Presentation
Virtual; 13.05.2025



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TeleOrbit GmbH, Nürnberg, Germany

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Fraunhofer IIS, Nürnberg, Germany

Mohamed Bochkati, Prof. Thomas Pany

Bundeswehr University, München, Germany

Agenda

1. Welcome and Introduction (Nicolas Giron, ESA)

2. Project Implementation and Results:

    1. Context and Objectives (Daniel Seybold, TOG)
    2. GOOSE-VTL architecture (Szu-Jung Wu, FhG-IIS)
    3. Simulation and Field Test Results (Szu-Jung Wu, FhG-IIS)
    4. Conclusions (Daniel Seybold, TOG)
    5. Exploitation Plan (Daniel Seybold, TOG)
    6. Benefits of working with ESA (Daniel Seybold, TOG)

3. Q&A (Nicolas Giron, ESA; all)

Context, Rationale, and Objectives

"GNSS fusion with multiple sensors is nowadays a must when addressing positioning in stringent urban environment affected by combination of multiple signal reflection and attenuation combined with low number of visible GNSS satellites (e.g. urban canyons)." (ESA SoW)

History:

- ✓ *Previous Vector Tracking developments at Fraunhofer IIS that were promising but needed refinement*
- ✓ *Proven expertise at Bundeswehr University Munich in deeply- and ultra-tightly coupled GNSS/INS systems*
- ✓ *Fraunhofer IIS' + TeleOrbit's interest in constantly adding new features and capabilities to dedicated hardware (GOOSE© receiver)*

Interests:

- ➢ *Collaborating as a strong team with complementary skills*
- ➢ *Extend knowledge in fault detection and isolation strategies*
- ➢ *Develop strong platform for urban navigation (mainly (semi-)autonomous vehicles)*

GOOSE-VTL Project Team

TeleOrbit GmbH is a privately owned engineering, marketing, and sales company providing innovative satellite navigation technologies and solutions incorporating satellite navigation, satellite communication and geoinformation.
The SME company's HQ is located in Nuremberg, Germany.

Fraunhofer Institute for Integrated Circuits IIS is one of the world's leading application-oriented research institutions for microelectronic and IT system solutions and services.
The Fraunhofer localization and navigation departments are located in Nuremberg, Germany.

University of the Bundeswehr Munich focuses on advanced navigation, including GNSS, sensor fusion, and algorithms. Since 1983, they've contributed to GPS and Galileo, including signal design and multi-sensor systems. They are also global leader in deeply-coupled navigation systems.

NavCert GmbH was an ISO 17025 accredited laboratory and ISO 17065 certification body offering technical expertise in the field of assessment, expert opinion and mandatory and voluntary certification in the area of GNSS based components, systems and services, as well as eCall, UAS and EETS.
Its core business activities were within the fields of positioning, navigation and timing and respective applications.
NavCert filed for bankruptcy in early 2024 and left the consortium.

GOOSE-VTL Project Team

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Technical Officer	Contracts Officer
Nicolas Giron	Maria Papaioannou

GOOSE-VTL
Quality Manager
Jürgen Seybold, TOG

GOOSE-VTL
Project & Contracts Manager
Daniel Seybold, TOG

GOOSE-VTL
Systems Engineer
Matthias Overbeck, FhG

Task 0 = WP 0000	Project & Quality Management	Daniel Seybold, TOG
Task 1 = WP 1000	State-of-the-art and technology survey	Mohamed Bochkati, UniBw M
Task 2 = WP 2000	Architectural Design	Matthias Overbeck, FhG
Task 3 = WP 3000	Detailed Design and preparation of experimentations	Szu-Jung Wu, FhG
Task 4 = WP 4000	Implementation and integration in a Software Defined Receiver	Szu-Jung Wu, FhG
Task 5 = WP 5000	Experimentations and characterisation of performances in simulated environment	Himanshu Gupta, FhG
Task 6 = WP 6000	Experimentations and characterisation of performances in real environment	Himanshu Gupta, FhG
Task 7 = WP 7000	Conclusions and assessment of achievement and identification of future work	Jürgen Seybold, TOG
Task 8 = WP 8000	Exploitation of innovation	Daniel Seybold, TOG

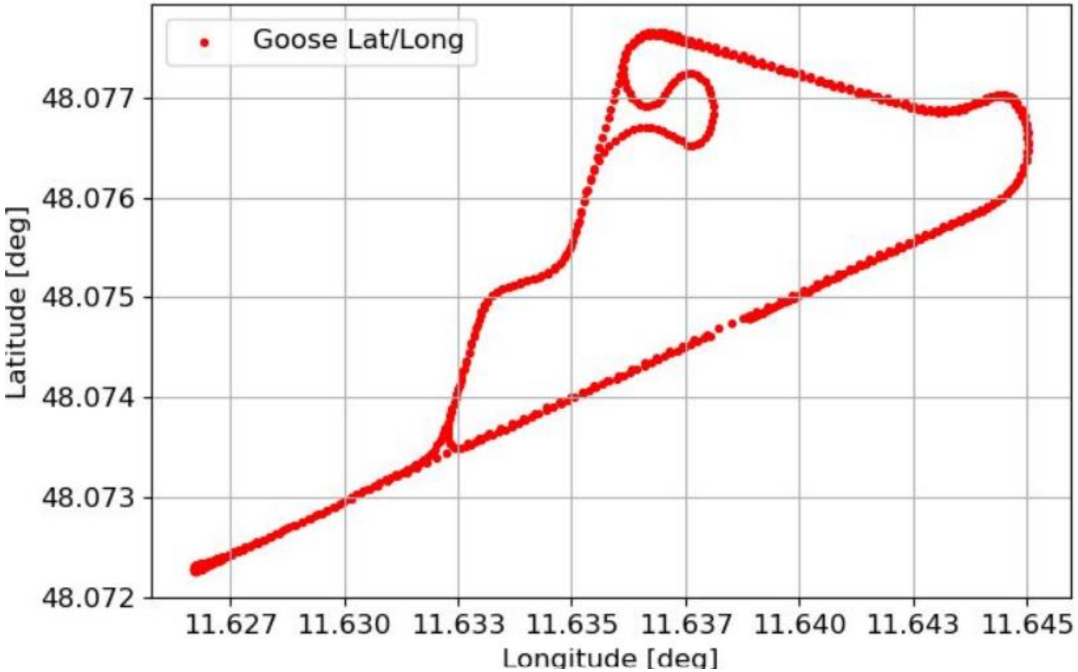
GOOSE-VTL Project Schedule

GOOSE-VTL Project Schedule			28 Months Overall																											
		2022	2022	2023												2024												2025		2025
Workpackages		11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
WP 0000	Project & Quality Management		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
WP 1000	State-of-the-art and technology survey		■	■	■																									
WP 2000	Architectural Design			■	■	■																								
WP 3000	Detailed Design and preparation of experimentations					■	■	■	■	■																				
WP 4000	Implementation and integration in a Software Defined Receiver							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
WP 5000	Experimentations and characterisation of performances in simulated environment										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
WP 6000	Experimentations and characterisation of performances in real environment													■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
WP7000	Conclusions and assessment of achievement and identification of future work																	■	■	■	■	■	■	■	■	■	■	■	■	
WP8000	Exploitation of innovation																			■	■	■	■	■	■	■	■	■	■	
P roject Milestones:		NM/ KOM			PM#1	KPT1		PM#2	MTR	Close Out		PM#3		PM#4			KPT2					PM#5					FR			Close Out

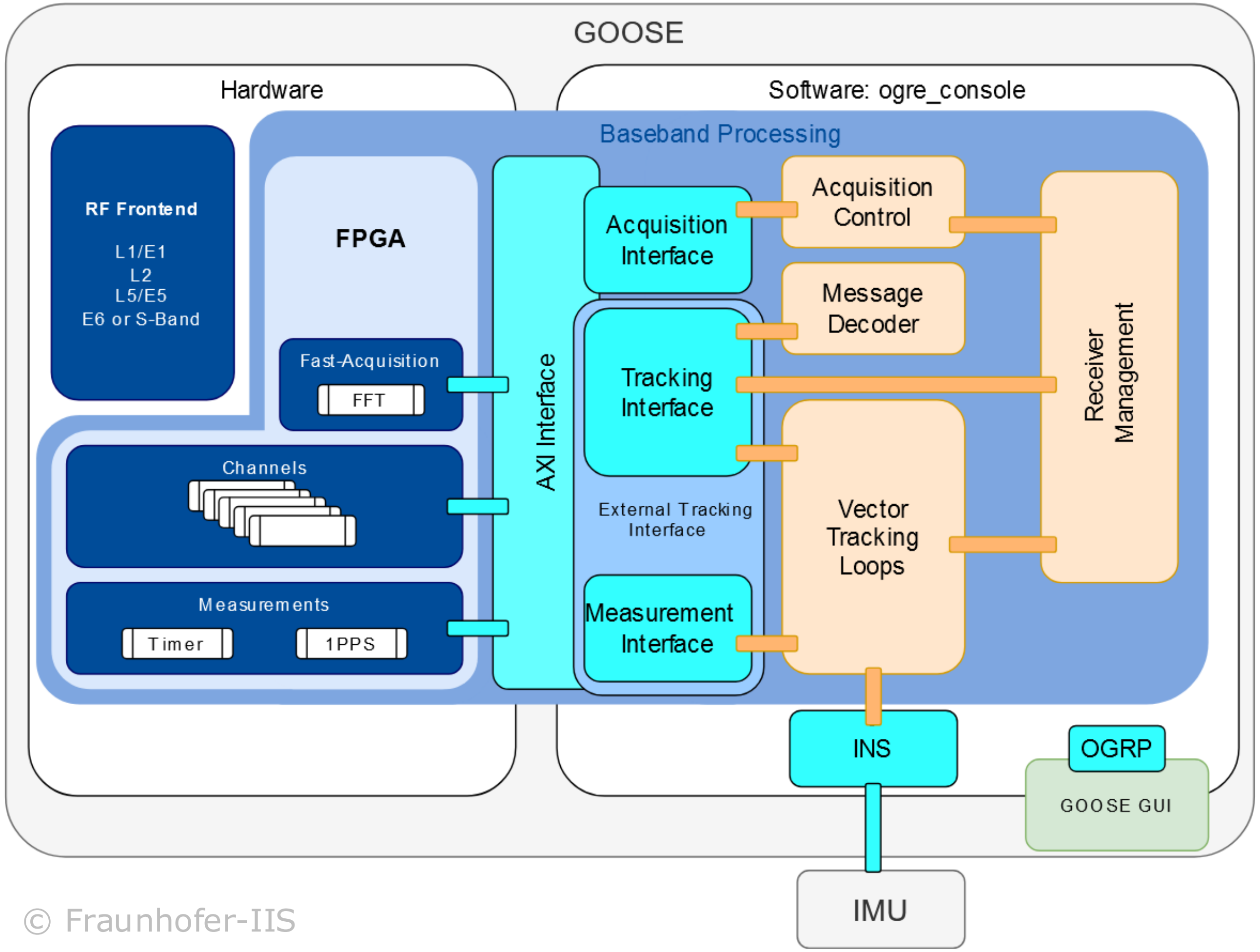
NM = Negotiation Meeting
KOM = Kick-Off Meeting
PM#1 - #5 = Progress Meetings 1 – 5
KPT1 + 2 = Key-Point Meetings 1 + 2

MTR = Mid-Term Review
FR/CO = Final Review / Close-Out

Outcome of the Project



GOOSE-VTL Architecture



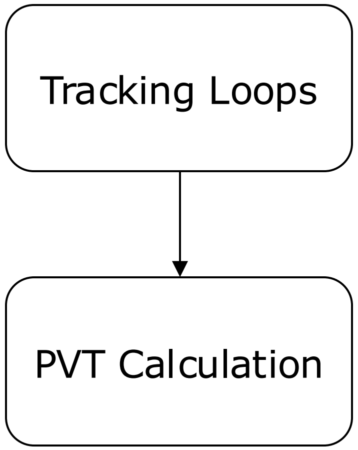
GOOSE© Receiver v2

- Hardware-Accelerated SDR
- Open Software Interface
- Digital Record and Replay

GOOSE-VTL Architecture

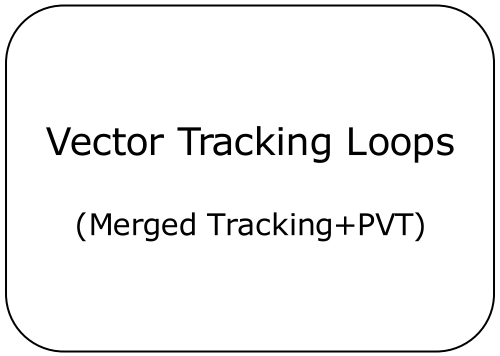
Baseline

Scalar Tracking (ST)

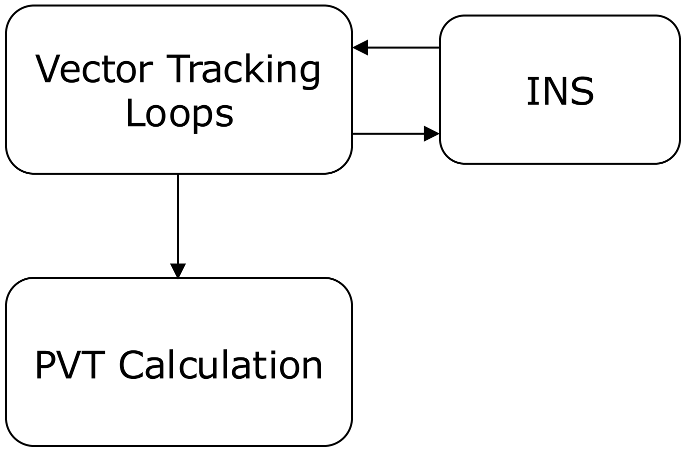


Proposed Methods

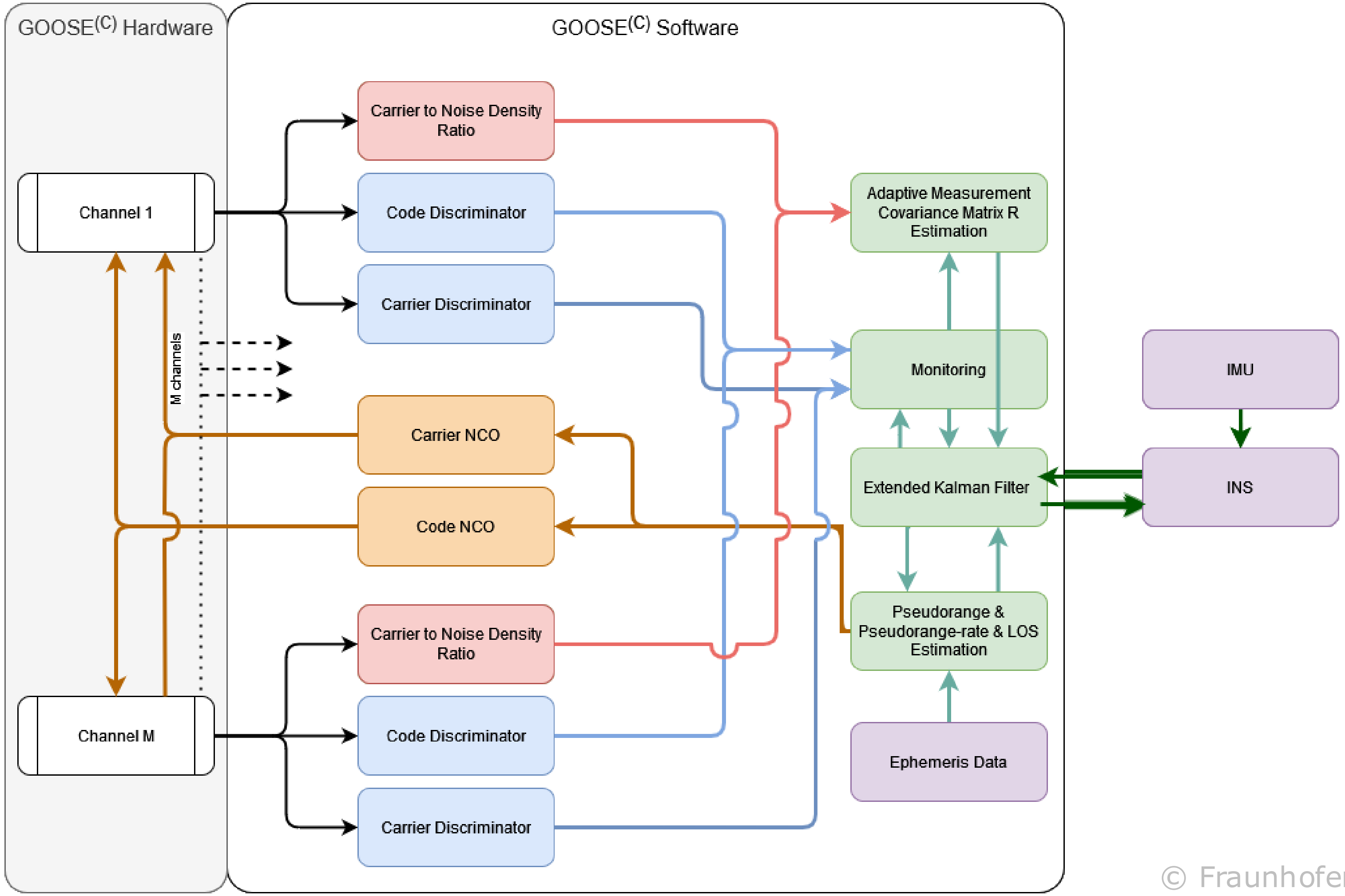
Vector Tracking (VT)



Deep Coupling (DC)



GOOSE-VTL Architecture



GOOSE-VTL Architecture

Monitoring:

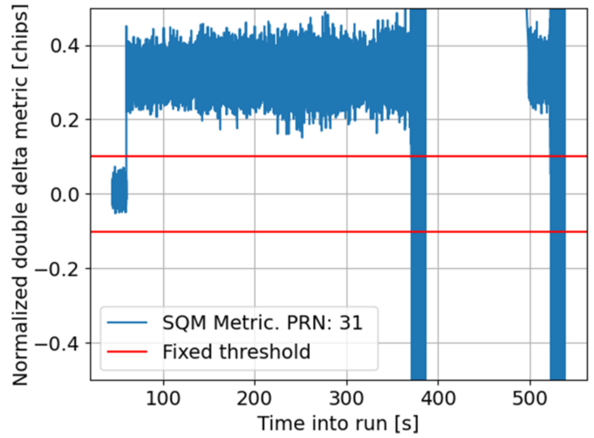
- Elevation mask
- CN0 test
- SQM detection
  - Double-Delta metric

$$m_{SQM} = \frac{(I_{ve} - I_{vl}) - (I_e - I_l)}{I_p}$$

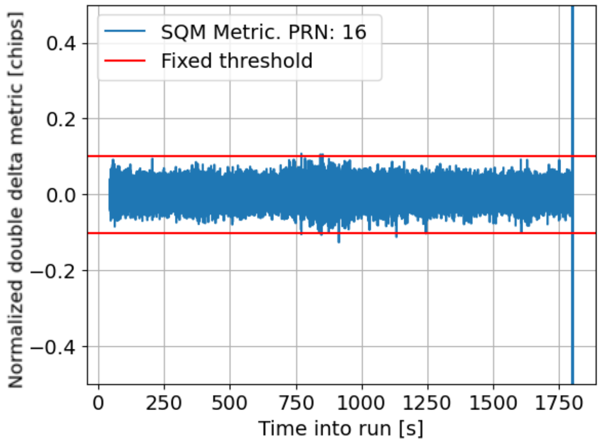
  - Sliding window approach

$$\text{Detection} = \begin{cases} 1, & if \sum_{i=1}^{N} (m_{SQM} > threshold) \geq M \\ 0, & otherwise \end{cases}$$

With multipath effect

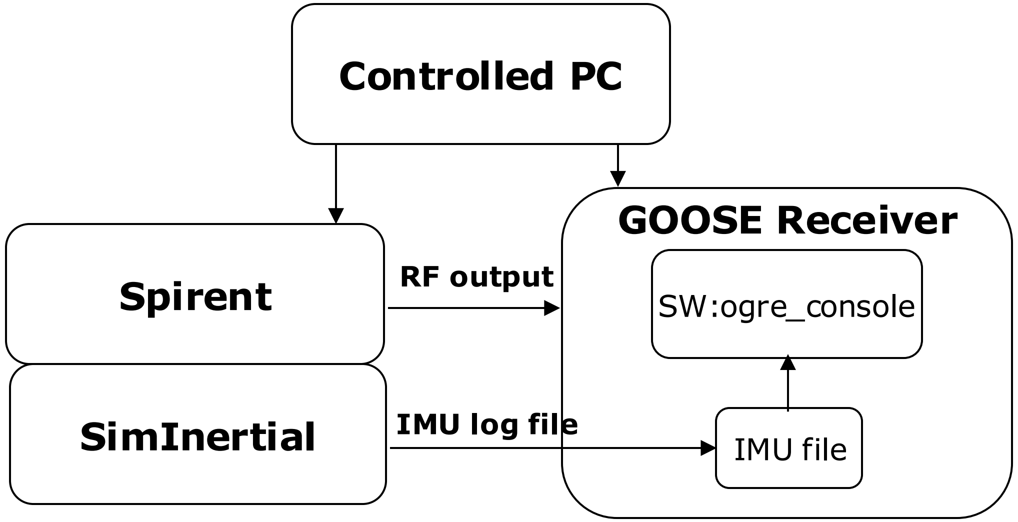


Without multipath effect

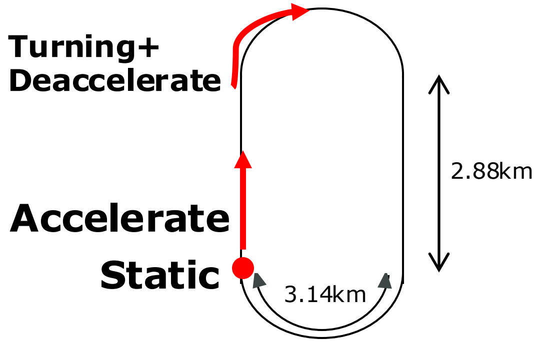


Simulation and Field Test Results

Simulation Test Setup



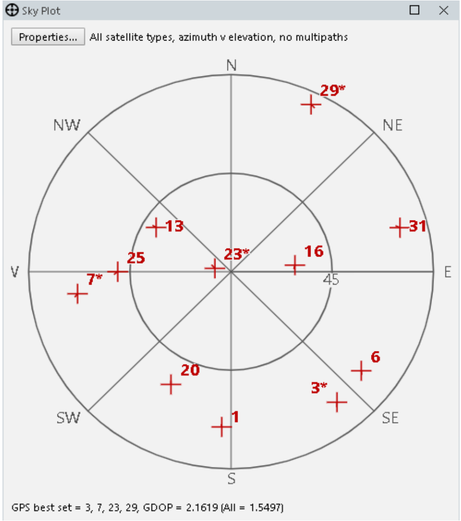
- Motion files:
  - Arena trajectory with varying velocity and heading
  - Standstill
  - Acceleration
  - Turning
  - Forward driving

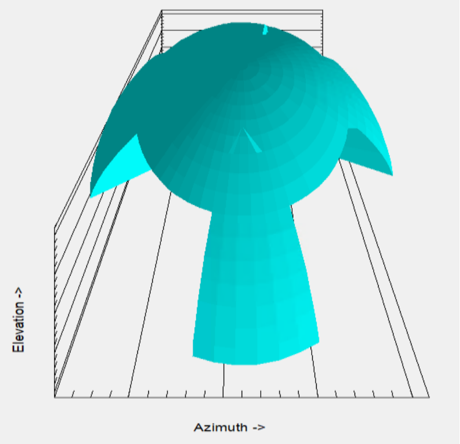


Simulation and Field Test Results

Simulation Test Setup

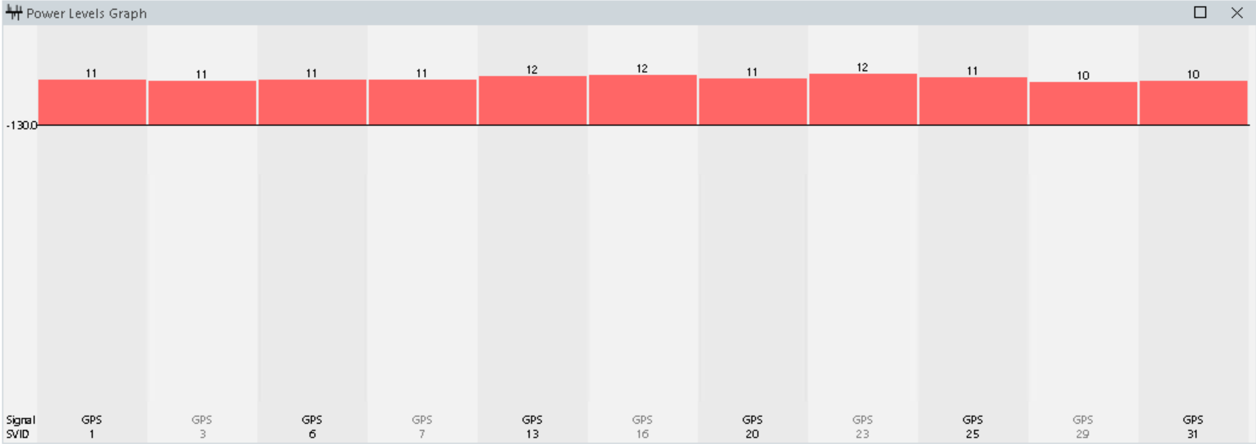
- Antenna pattern files
  - Open sky
  - Urban



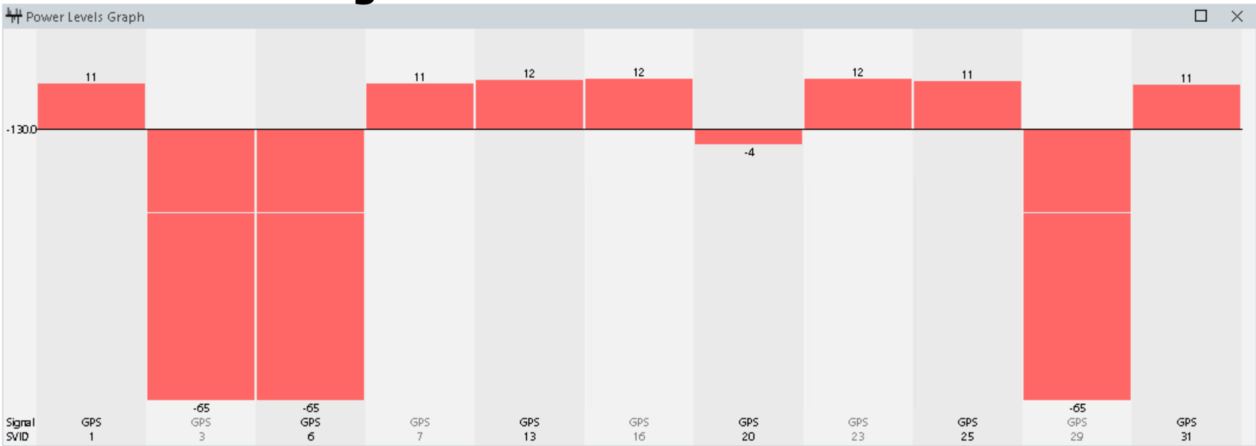


Antenna pattern for urban scenario

Power level of signals in open sky scenario

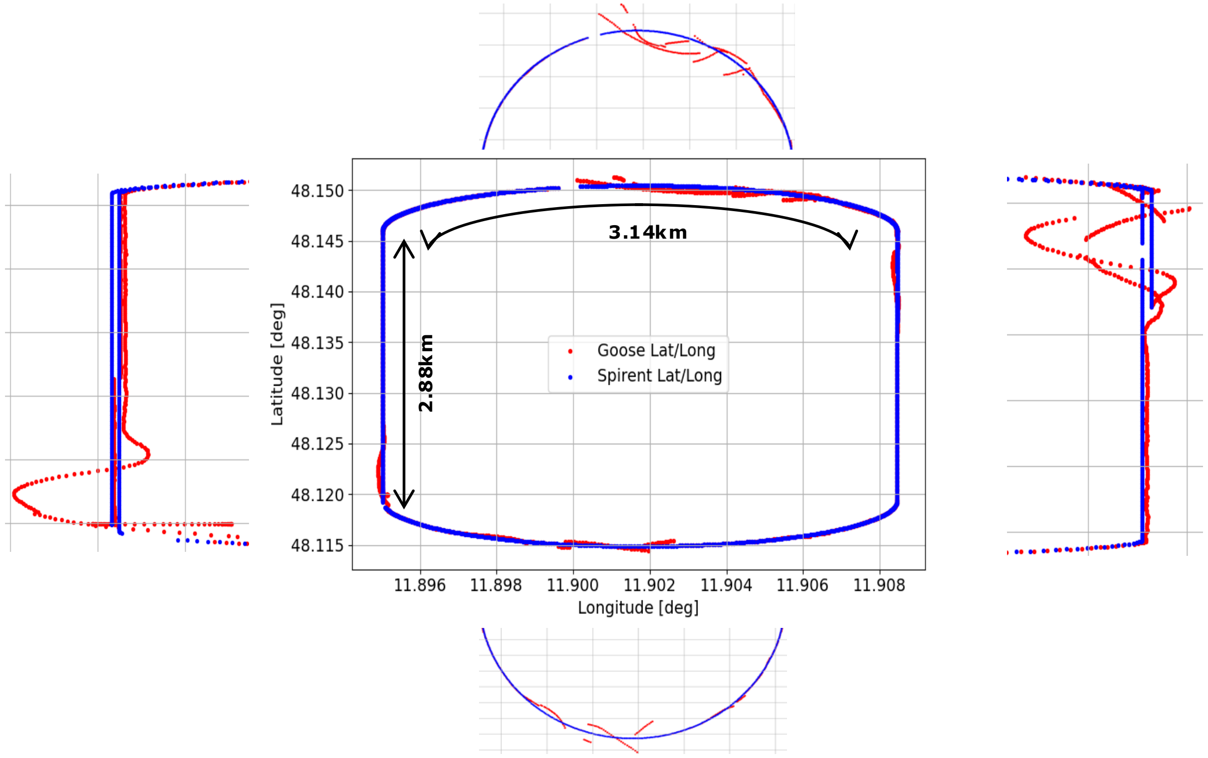


Power level of signals in urban scenario



Simulation and Field Test Results

Simulation Test Result (Urban + Multipath)



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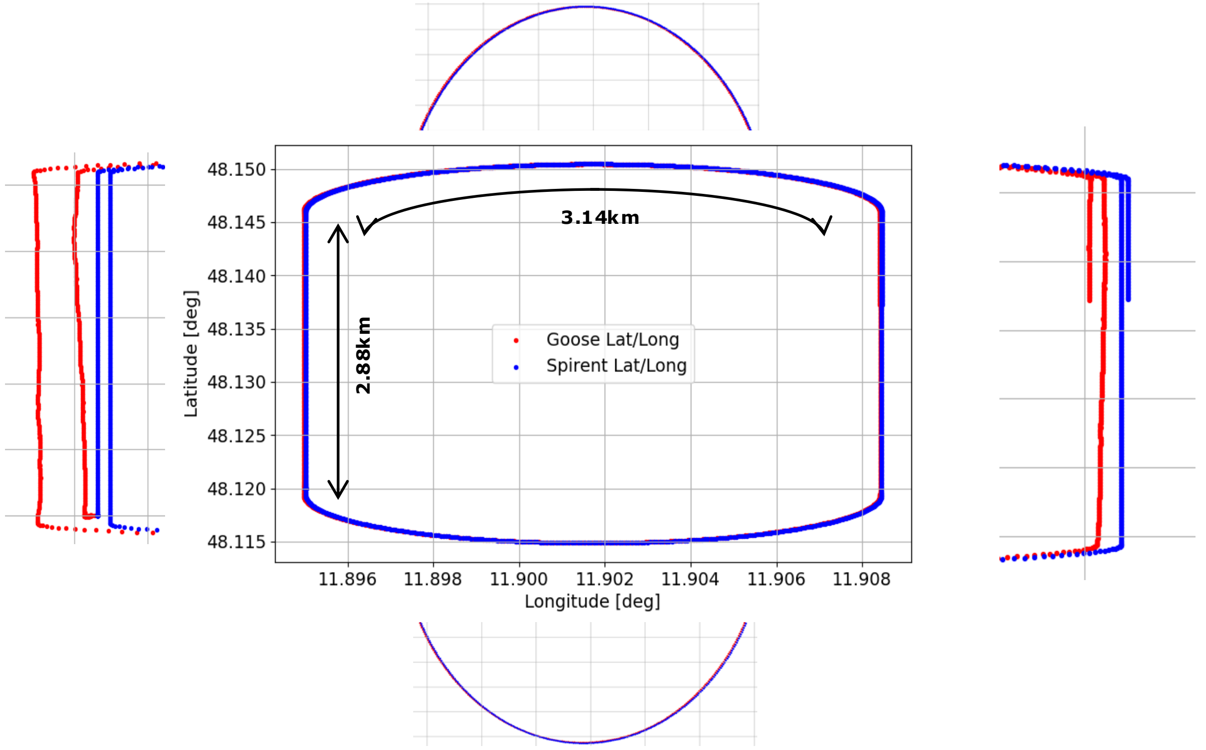
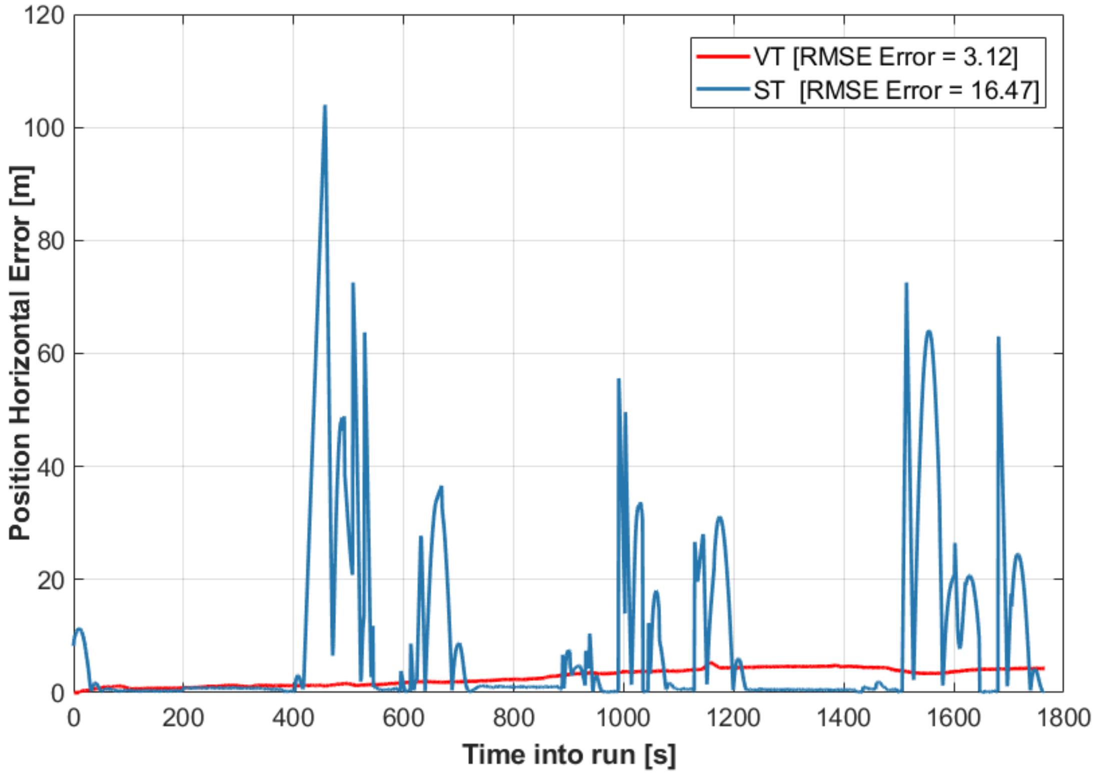
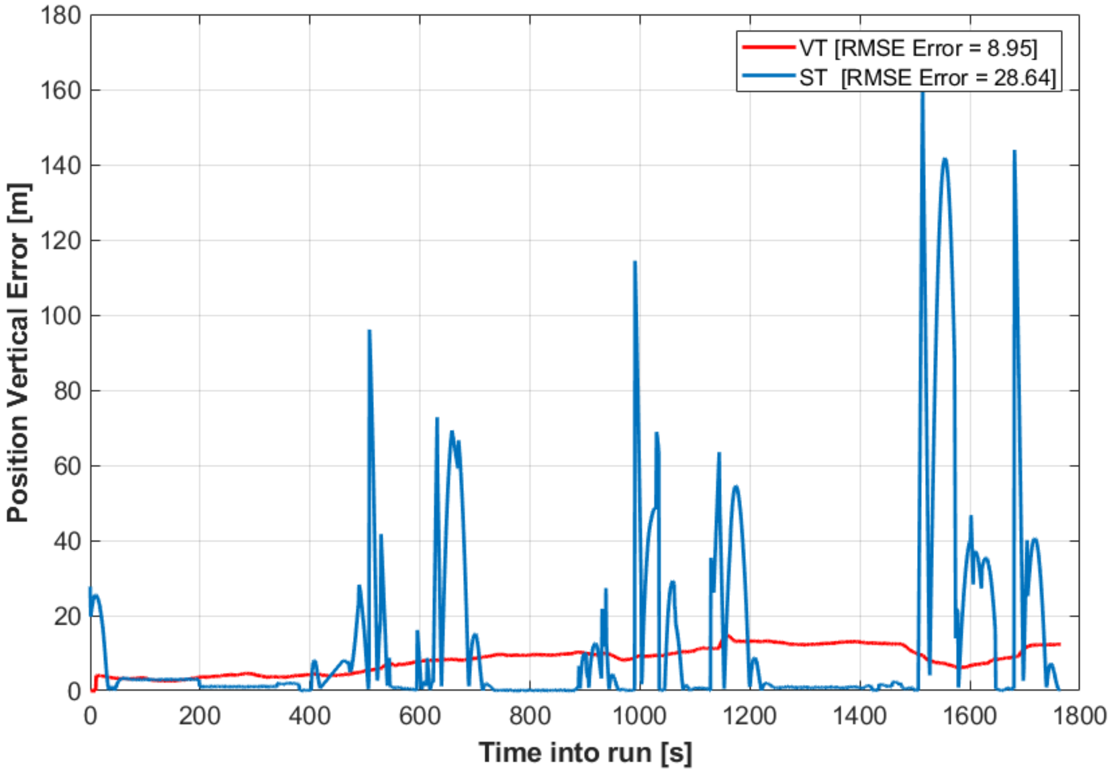


VT

Simulation and Field Test Results

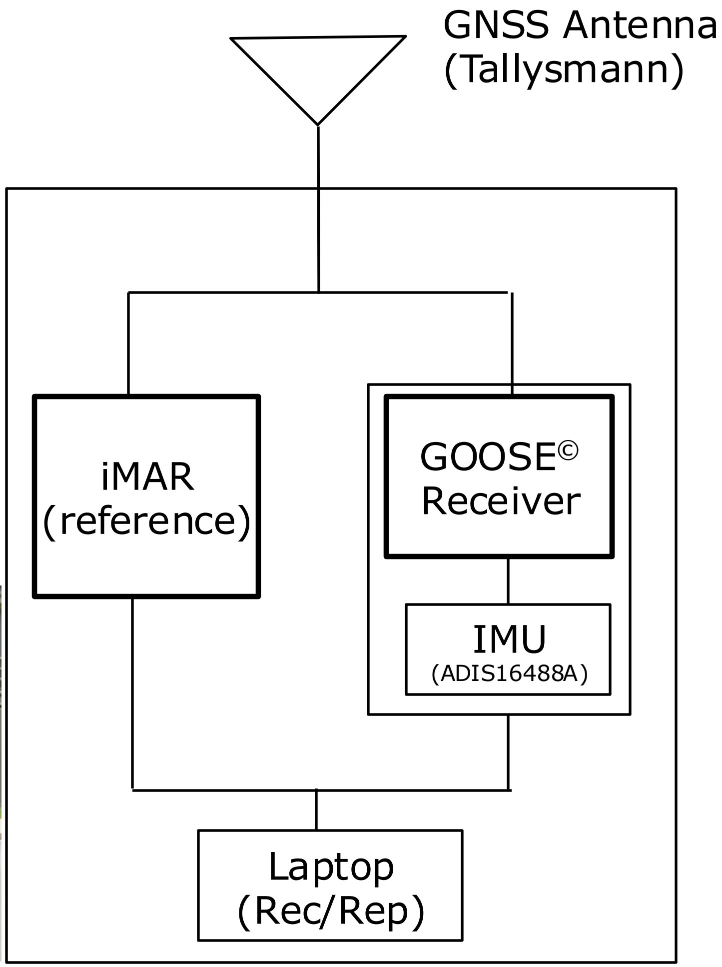
Simulation Test Result (Urban + Multipath)





Simulation and Field Test Results

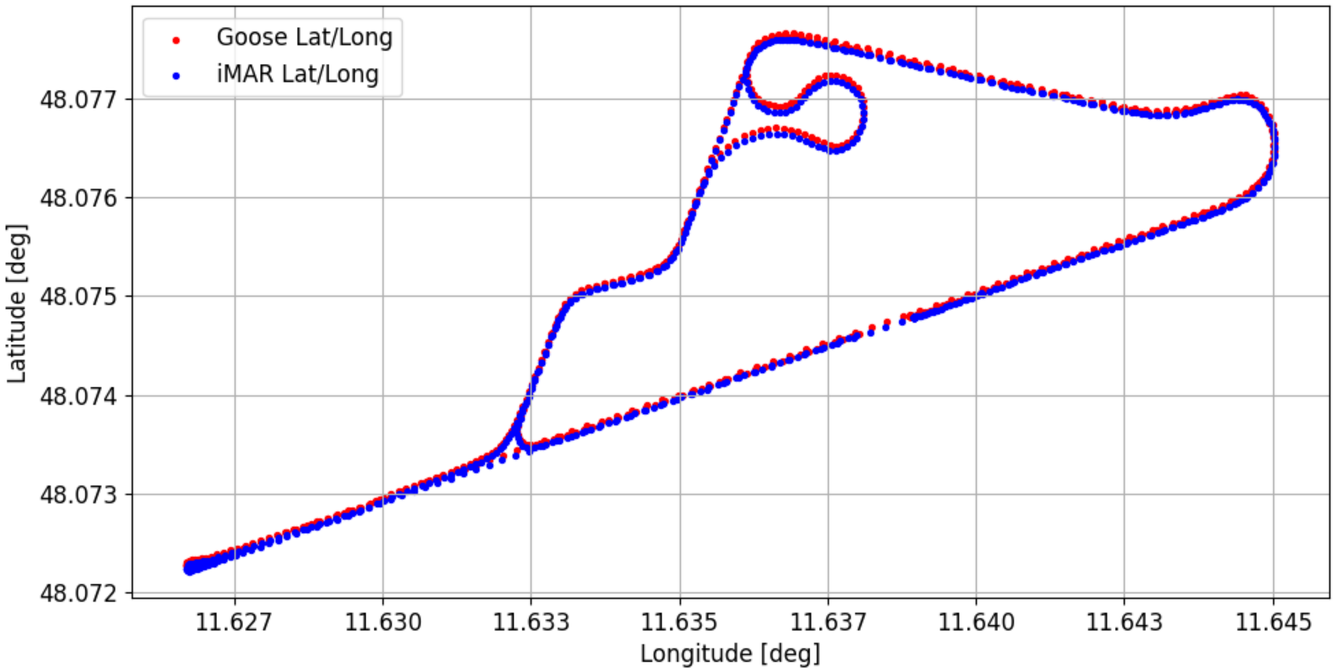
- Setup for the field tests
  - GOOSE© v1 receiver
  - ADIS 16488 IMU
  - Reference data used from iMAR
- Analysis done by replaying the digital files (IF samples, IMU log-data) in the lab
- Test chosen for analysis:
  - Location: Munich University of the armed forces
  - Duration: 10 minutes
  - Antenna used: Tallysman

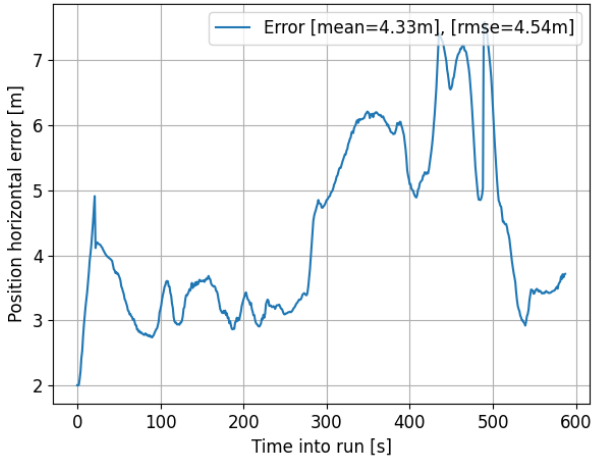


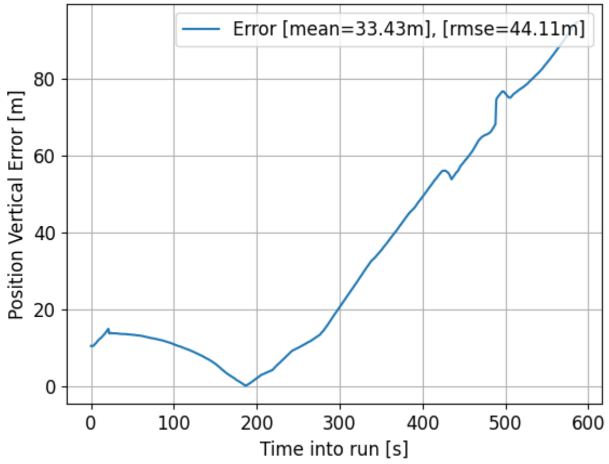
Simulation and Field Test Results

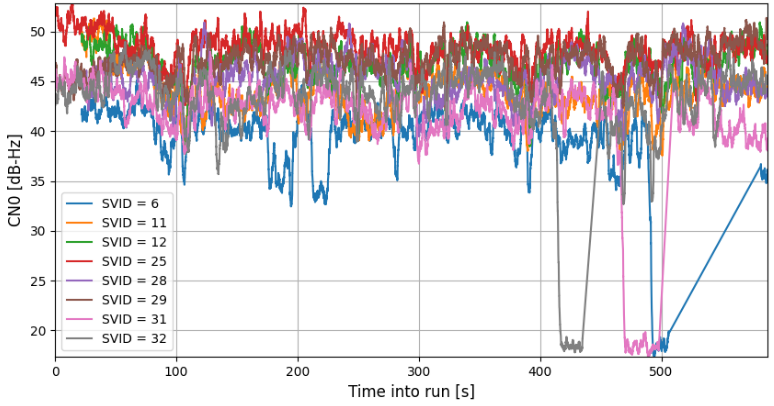
Field Test Result

Deep Coupling

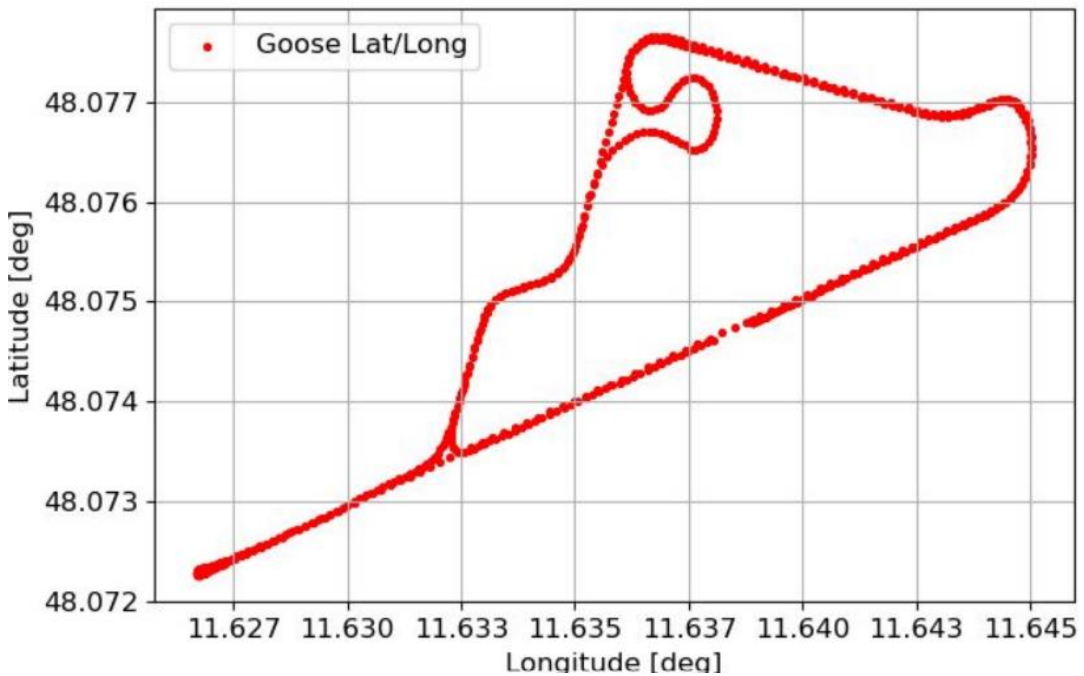








Conclusions, Exploitation, Feedback



Conclusions

Tech Strengths:

- Validated VT & DC architectures: Proven real-time GNSS processing in software-defined receivers.
- Robust performance in harsh conditions: VT ensures continuity in urban scenarios
- Multipath mitigation: SQM effectively detects/excludes distorted signals.
- GOOSEv2 integration: Enhanced performance from increased embedded processing vs. GOOSEv1 PC.

Further Development:

- GNSS-INS transition: Improve handover logic and enable seamless reacquisition in denied environments.
- Time sync improvement: Increase GNSS-INS synchronization precision (beyond 1 second).
- Higher update rates: Enhance Doppler accuracy and stability by increasing NCO/PVT update frequency.
- Smart SQM tuning: Dynamically adjust multipath detection thresholds based on environment.
- Improved simulation realism: Refine antenna patterns and include 3D urban models for better testing.

Conclusions

Risk Mitigation:

- Future regulation (esp. automotive): Already considered (future) regulatory requirements (e.g., CEN/CENELEC, ETSI and ISO)
- Technology: well-proven and flexible hardware (developed in-house at Fraunhofer IIS) allowed full control and access to test all necessary algorithms, etc.
- Market: analysed possible markets (automotive and beyond) which can benefit from GOOSE-VTL

Fields of Application:

- Making (autonomous) driving safer, more robust, and resilient
- Transfer developed technology to other markets like UAVs that also need reliable PNT data

Exploitation Plan

“Performance requirements of automated vehicles drive the evolution of robust high precision services for automotive” (EUSPA 2024)

➡ Automotive use case is interesting for research and commercialisation, but difficult to enter and to get funding might prove difficult

Possible way forward:

1. Collaboration with and direct funding from industry partner (Tier 1 &2, OEM, … (automotive) or other),
2. Co-funding from industry partner and additional support via NAVISP EL2 or ESA Business Applications,
3. Only internal funding plus NAVISP EL2 or ESA Business Applications.

Benefits of working with ESA

The benefit of working with ESA in this project was the fruitful collaboration with ESA's technical officer Nicolas Giron, who was able to give guidance and was very helpful and supportive throughout the project, boosting the results of GOOSE-VTL.

ESA with its many projects in all kind of topics is also always supportive in connecting us with new users, partners and research colleagues.

The project followed a well-structured format, with cumulative reporting of achievements throughout its duration, which helped keep us on track.

Overall, innovative research like in this project wouldn't be possible without the ESA NAVISP funding.

TeleOrbit
The Locating Company

THANK YOU!

TIME FOR THE Q&A

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