Results and lessons learned from the NAVITEC 2024 Resilient GNSS Challenge

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Introduction

Background information

NAVITEC 2024 ‘Resilient GNSS Challenge’

The Resilient GNSS Challenge was organized by the European Space Agency, hosted during the 11th ESA Workshop on Satellite Navigation Technologies.

MOTIVATION:

GNSS is vulnerable to multiple forms of Radio Frequency (RF) interference, including unintentional phenomena as well as intentional threats, such as

- **Jamming**, transmitting interfering RF signal – i.e. denial of service.
- **Spoofing**, transmitting counterfeit GNSS-like plausible signals.

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Jammertest 2024

Description

An open-air GNSS/PNT resilience campaign held in Norway over more days in September 2024, enabling live jamming, meaconing, and spoofing trials against real receivers and systems.

PURPOSE:

Jammertest event aims to promote international collaboration, share best practices, & develop common solutions that can help mitigate the impact of emerging GNSS threats.

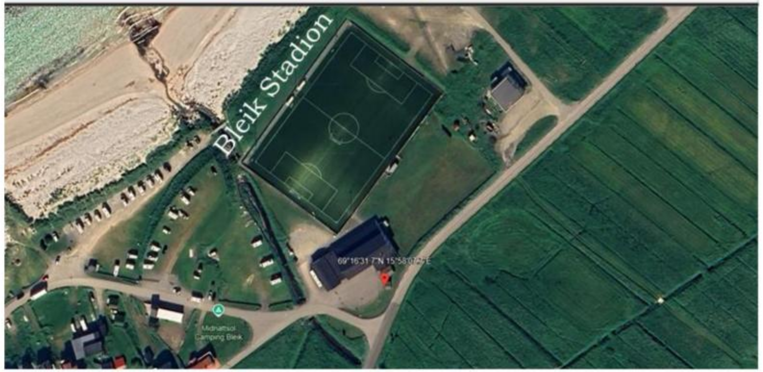
Photos: David Jensen

Description
‘Resilient GNSS Challenge’

Description 'Scenario 1'

Static Receiver Under Coherent Spoofing

User is located near Bleik Stadion, while the spoofed trajectory is given in red dashed line.



Flying (route 4): "drone scenario", Section 2.3.12 of Jammertest 2024.

GNSS	Band (Code)	Freq. [MHz]
GPS	L1 (1C)	1575.42
	L5 (5Q)	1176.45
GAL	E6 (6C)	1278.75
	E5a (5Q)	1176.45
	E5b (7Q)	1207.14
	E5 (8Q)	1191.795
BDS	B2a (5P)	1176.45
	B3 (7I)	1207.14

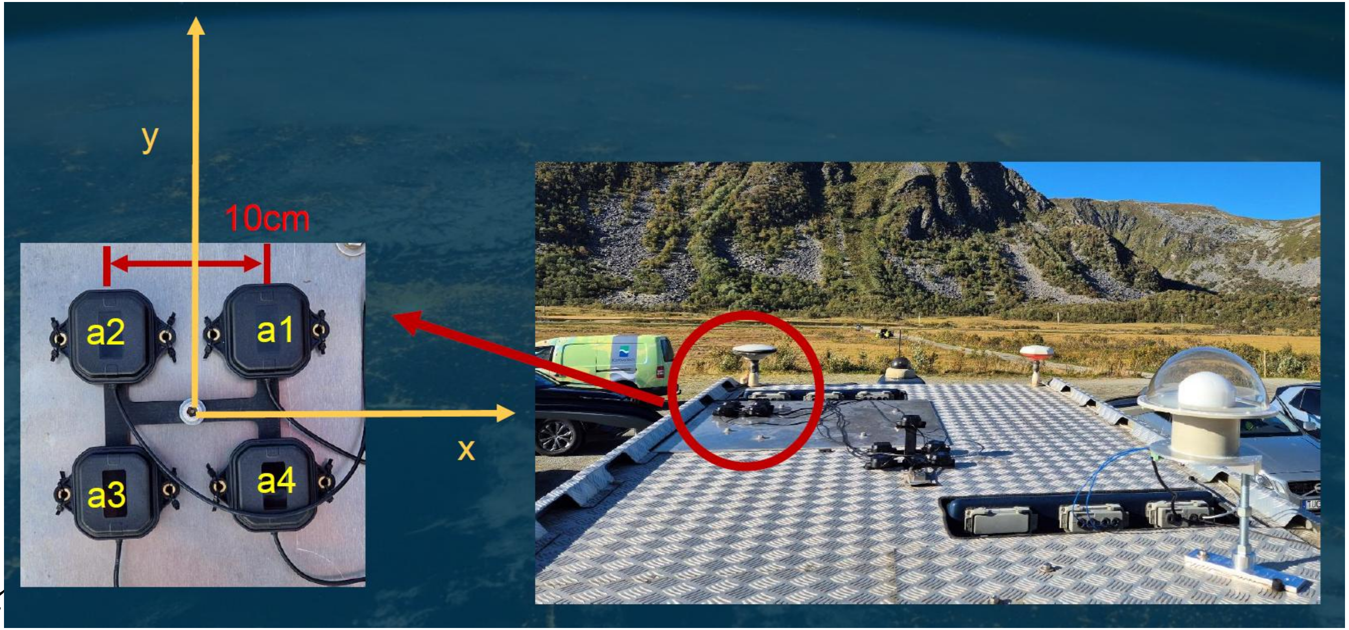
PERIOD [11-Sep-2024]:
i.e., 15:13:30 till 15:23:00

Description ‘Scenario 2A’

See Section 2.6.2 of the Jammertest 2024

Spoofer Angle-of-Arrival Estimation

A 2x2 patch antenna array tracking GPS L1 C/A band at 1 Hz.



Dataset provided:
No IQ samples, only RINEX observations were made available.

Detection performed at measurement level!

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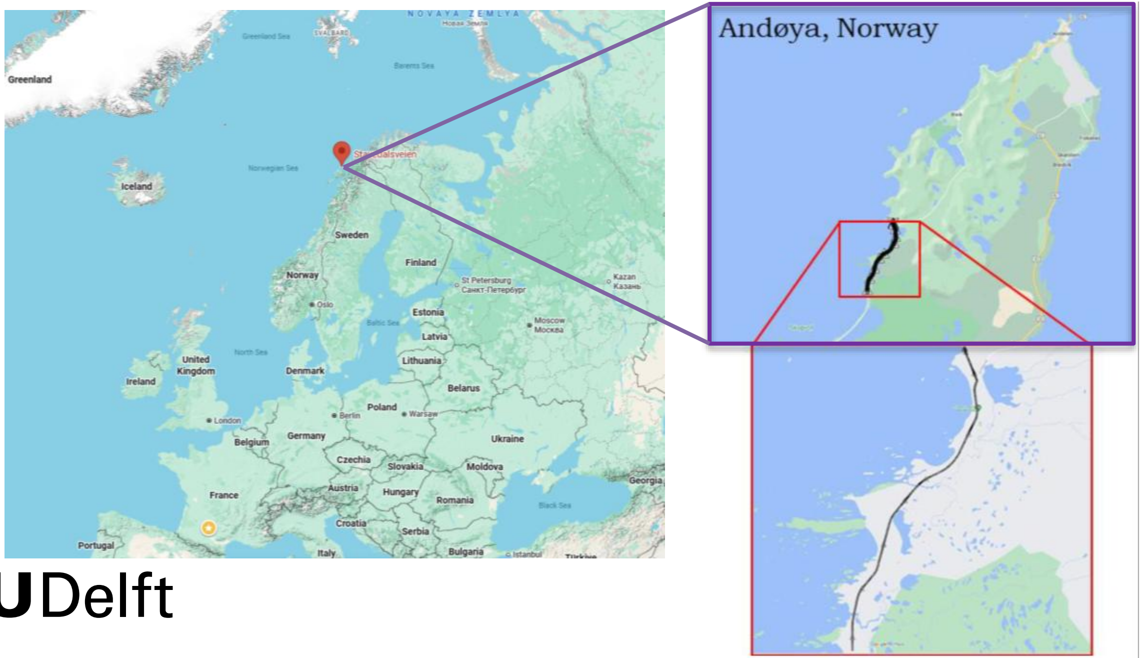
Description ‘Scenario 2B’

Dynamic Receiver Positioning

User was initially static, then started moving along Stavedalsveien (FV7702) at around 40 km/h.



GNSS	Band (Code)	Freq. [MHz]
GPS	L1 (1C)	1575.42
	L2 (W/L)	1227.60
	L5 (5Q)	1176.45
GAL	E1 (1C)	1575.42
	E6 (6C)	1278.75
	E5a (5Q)	1176.45
	E5b (7Q)	1207.14
	E5 (8Q)	1191.795

PERIOD [12-Sep-2024]:
i.e., 08:46:00 till 08:59:59

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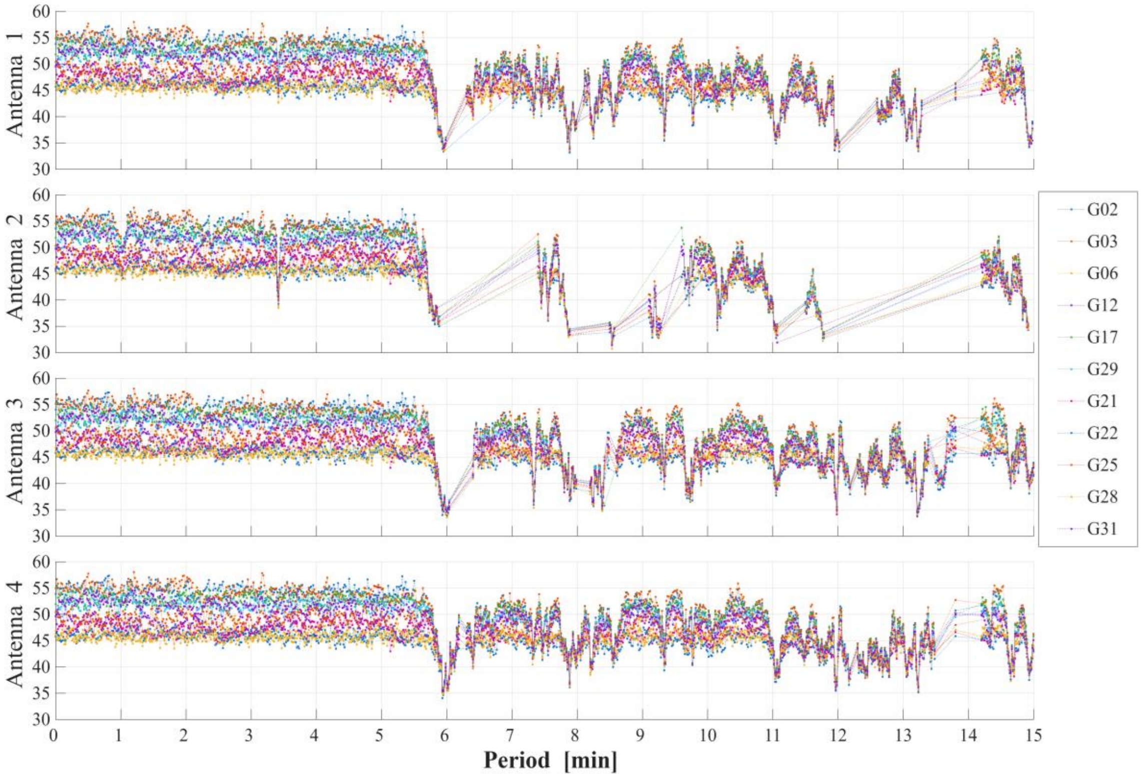
Results and solutions

Preliminary considerations

Use of Carrier-to-Noise Density Ratio (C/N0) [dB-Hz]

Example of Scenario 2A, with four antennas in the 2x2 patch array system.



Remark

First 5-6 minutes stable C/N0 show user is static, while a high correlation indicates that L1 signal was spoofed!

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Results for ‘Scenario 1’

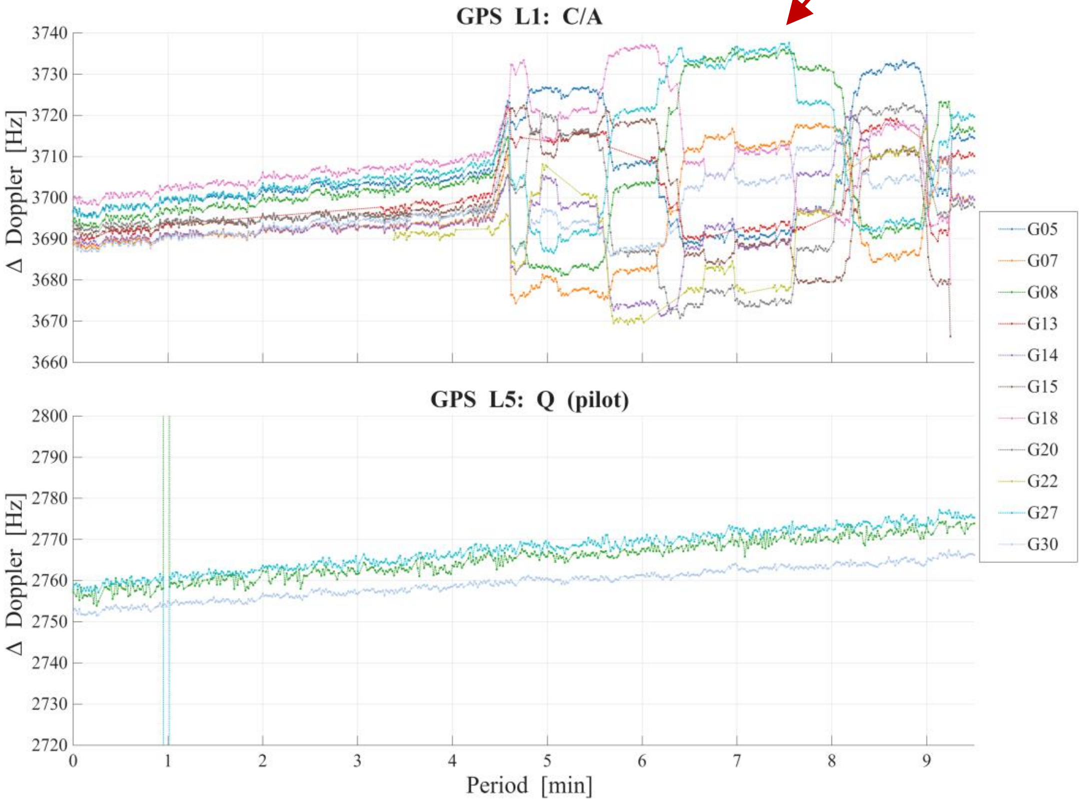
Fake drone-like motion spoofed.

Analysis of Doppler differences

One reference receiver used to identify signals that were completely spoofed.

For nearby receivers, should reflect relative motion plus differences of clock drifts.

Inconsistent behaviours!



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Results for ‘Scenario 1’

Doppler-based kinematic positioning

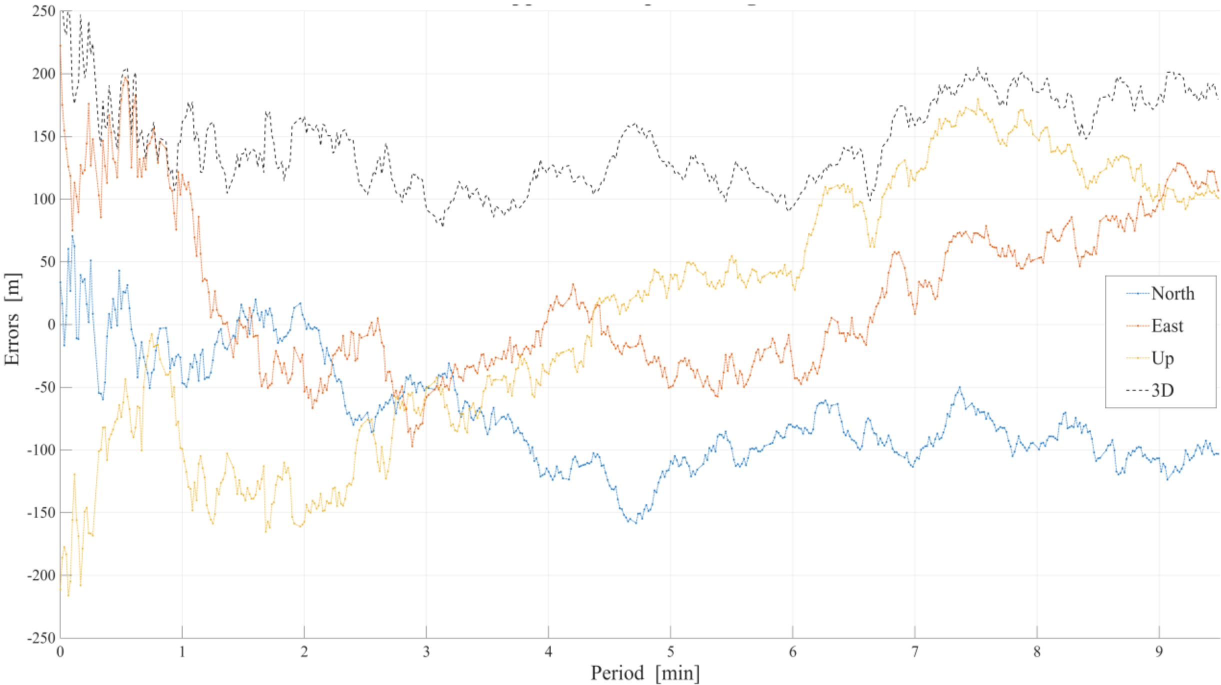
Based on the model originally developed by Psiaki (2021), while using a KF.

Measured Doppler shift:

$$D^{s} = -\frac{1}{\lambda}\frac{d\Delta\rho^{s}_{\mathrm{ADR}}}{dt_r}$$

for ρ^{s}_{ADR} as accumulated delta range w.r.t. $s$atellite.

Code/phase data not usable since affected by spoofing.



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Results for ‘Scenario 2A’

Spoofer Azimuth Estimation

For each satellite, between-receiver SD carrier-phase L1 observations

$$\Delta\phi_{ab}^{s}(k) = \phi_{a}^{s}(k) - \phi_{b}^{s}(k) = \frac{2\pi}{\lambda} b_{ab}^{T} u^{s}(k) + B_{ab}^{s}(k) + \epsilon_{ab}^{s}(k)$$

where $u^{s}(k)$ is the unit direction vector to the signal source, b_{ab} is the 2D baseline vector, and $B_{ab}^{s}(k) = \bar{B}_{ab}^{s}$ as constant SD phase ambiguity term.

Key Assumption:

The direction is identical for every ‘PRN’ when the signals are spoofed by a single transmitter, i.e. the spoofer.

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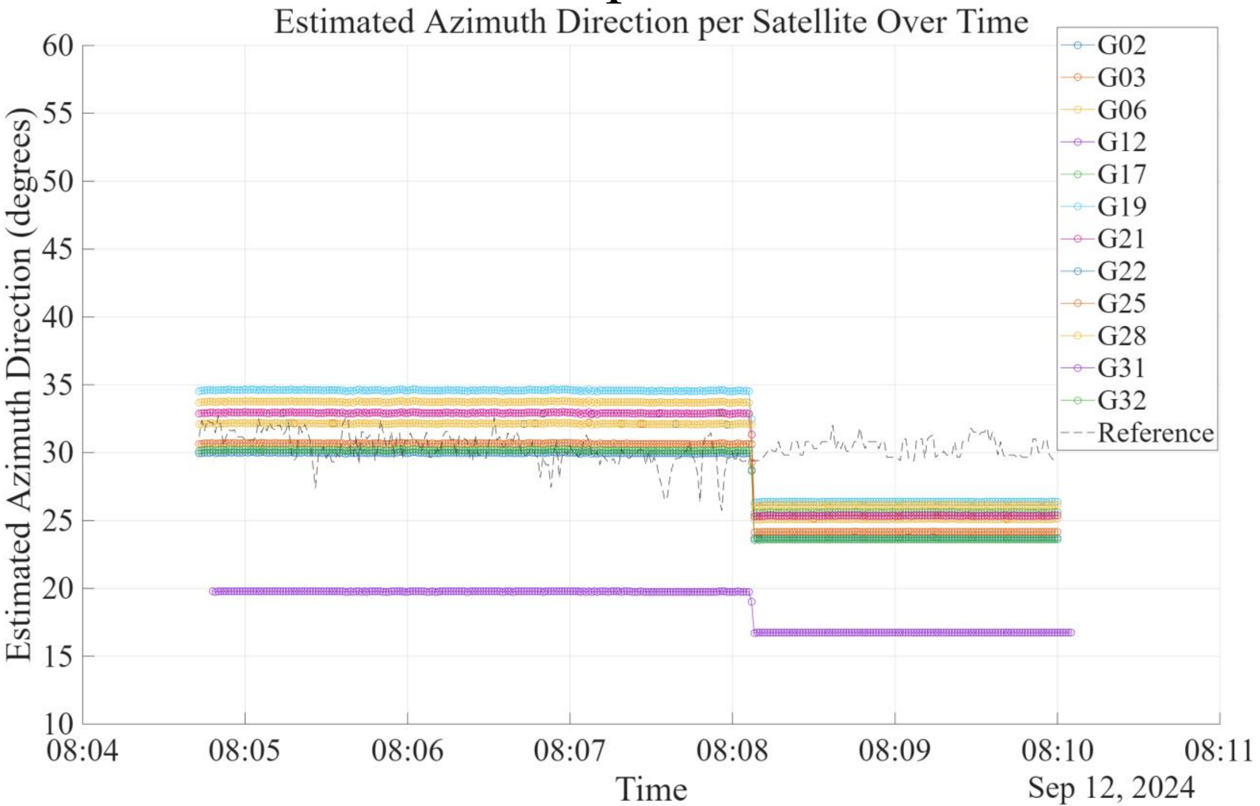
Solved via Weighted Least-Squares adjustment.

Results for ‘Scenario 2A’

Angle-of-Arrival estimation – per satellite



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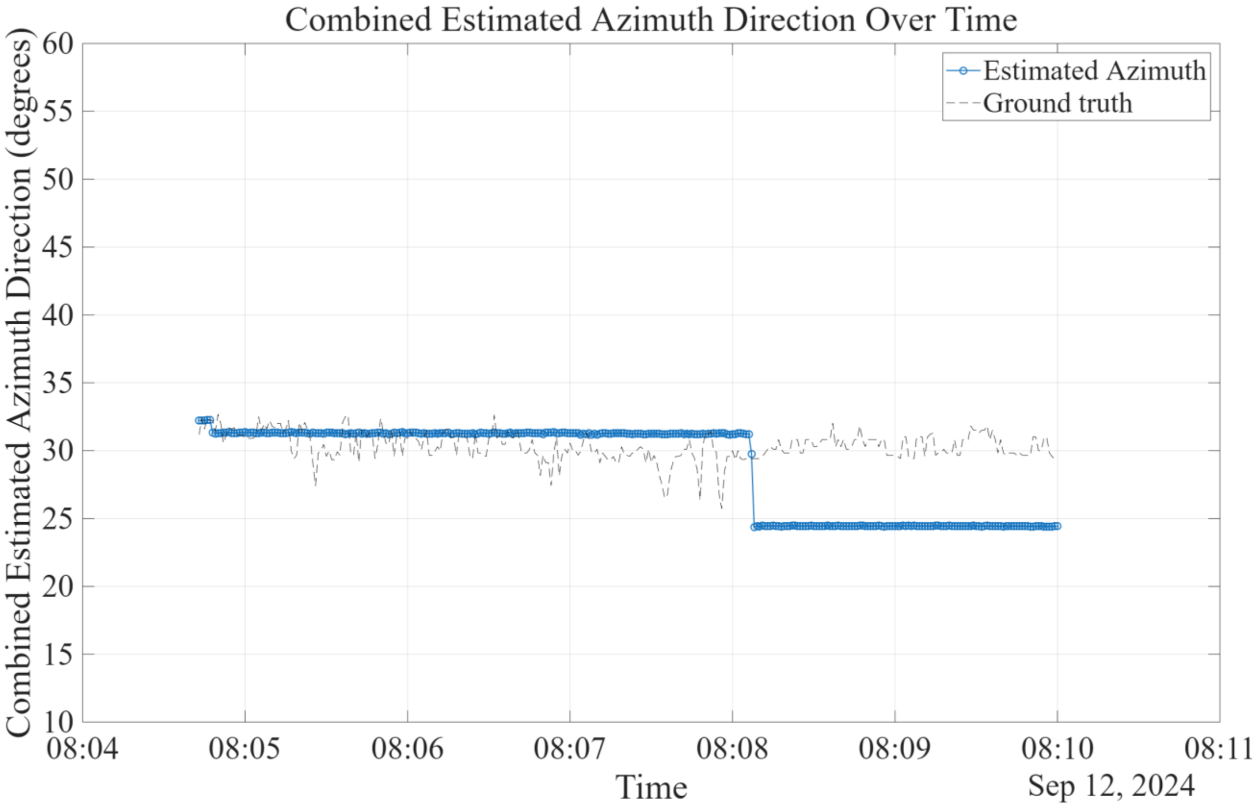
Results for ‘Scenario 2A’

Angle-of-Arrival estimation – combined



Results for 'Scenario 2B'

Dynamical user positioning

Authentic Galileo E5Q, E7Q, and E6C signals were identified by the analysis of C/N0, therefore triple-frequency ambiguity-float models were adopted.

PPP model:

$$p_{r,j}^{s} = \rho_r^s + \underbrace{(dt_r - dt^s)}_{\text{clocks}} + \underbrace{m_r^s \tau_r}_{\text{tropo}} + \underbrace{I_{r,j}^s}_{\text{iono}} + \underbrace{\left(d_{r,j} - d_{,j}^s\right)}_{\text{HW delays}} + e_{r,j}^s$$

$$\phi_{r,j}^{s} = \rho_r^s + (dt_r - dt^s) + m_r^s \tau_r - I_{r,j}^s + \left(\delta_{r,j} - \delta_{,j}^s\right) + \epsilon_{r,j}^s + \lambda_j N_{r,j}^s$$

RTK model:

$$p_{r1,j}^{s1} = \rho_{r1}^{s1} + e_{r1,j}^{s1}$$

$$\phi_{r1,j}^{s1} = \rho_{r1}^{s1} + \epsilon_{r1,j}^{s1} + \lambda_j N_{r1,j}^{s1}$$

The reference station used is 'AND100NOR', located around 17.5 km from user.

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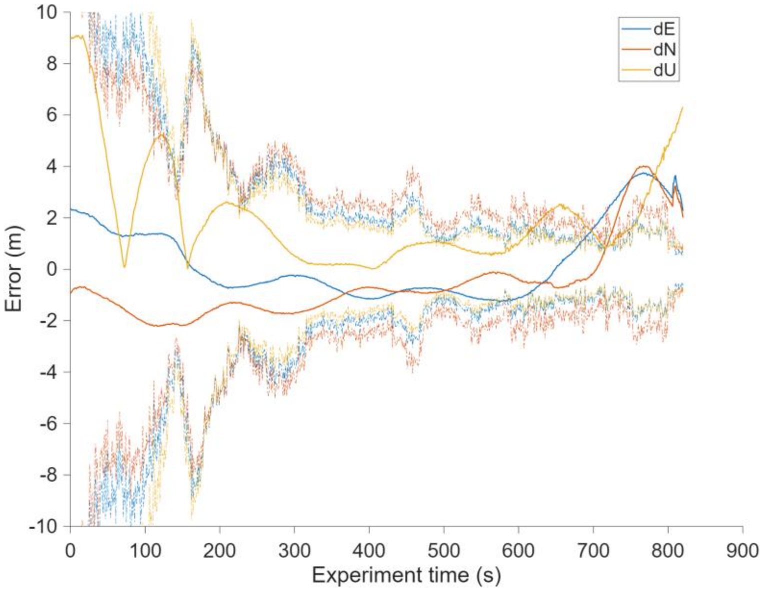
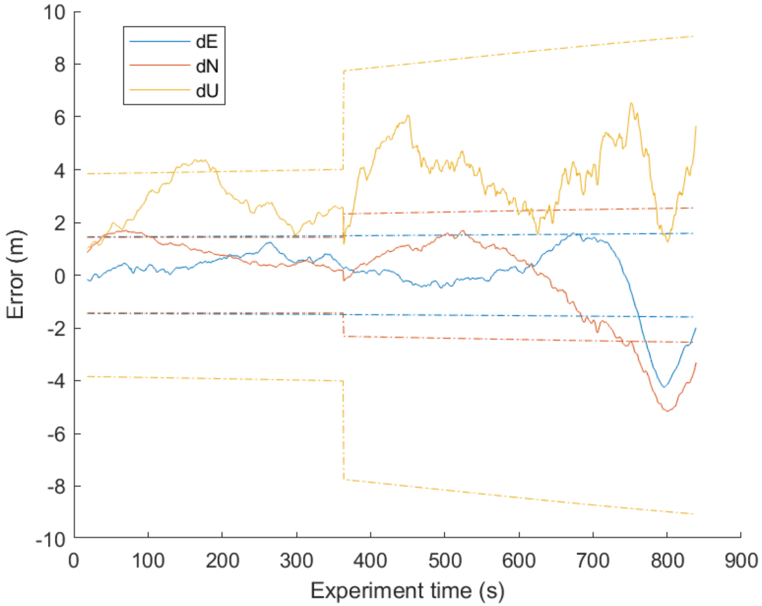
3σ-curves shown

Results for ‘Scenario 2B’

Numerical results: PPP [sequential filter] vs RTK [epoch-wise]



PPP



RTK

Conclusions

Summary

- We present the results from the **NAVITEC 2024 competition**, organized by the European Space Agency.

- The competition consisted of three problems, with
  - Scenario 1: concerning static receiver spoofed on GPS L1, affecting all code and phase data, thus requiring a Doppler-based positioning.
  - Scenario 2A: concerning AoA estimation for a 2x2 patch array system limited to GPS L1, with C/N0 as key metric for the assessment.
  - Scenario 2B: concerning multi-GNSS/multi-frequency dynamic user subject to spoofing on both GPS L1 and GAL E1 signals.

Summary

Overall, the positioning below meter level was very challenging, but both C/N0 and Doppler analysis turned out valuable for

1) Identifying signals most likely spoofed;
2) Inferring if receiver was static or moving.

ACKNOWLEDGEMENTS

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Questions?

Thanks for your attention

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TU Delft DLR esa Joint Research Centre JRC

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