ETH zürich

Development and evaluation of a geodetic measurement system for IMU-based high-precision azimuth transfer

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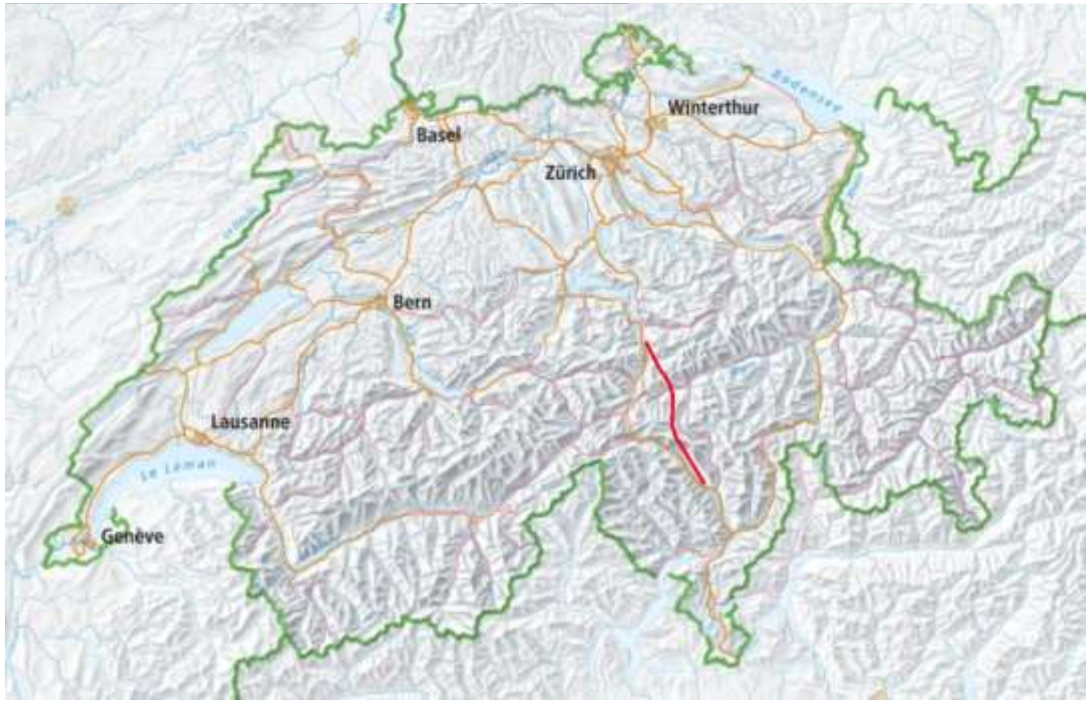
IGP

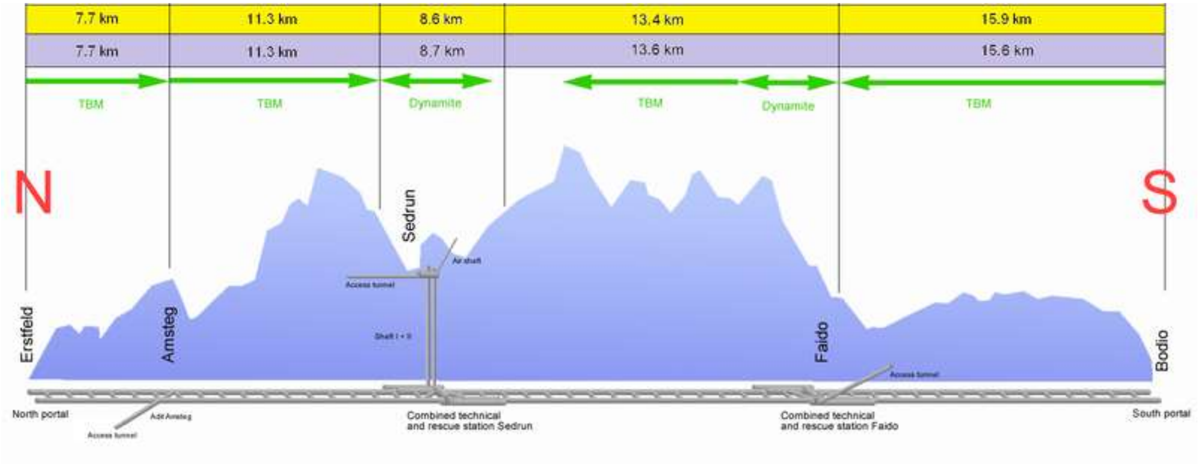
Introduction: Gotthard Base Tunnel

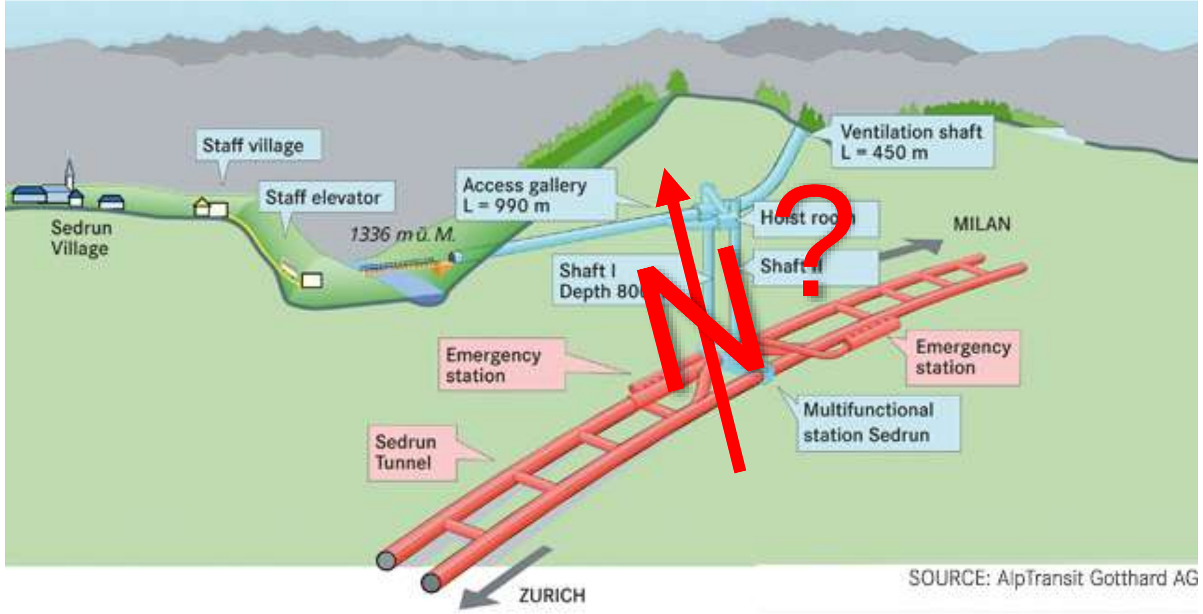


- Important connection between North-South for freight and public transport
- Shift freight from truck to trains

Longest & deepest railway tunnel in the world 57.1 km
Construction: 1999 – 2016

Introduction: Intermediate Access Sedrun





- Construction in 5 individual sections
- Starting from 5 sites simultaneously
- 3 intermediate construction sites accessed by connection tunnels

Multifunctional Station Sedrun accessible over

- ca. 1km tunnel and 800m vertical shaft
- Geodetic not trivial
  → one challenge: azimuth determination

Introduction: North Seeking Gyro

Combination of a theodolite and a declination gyroscope

Pros

- Direct determination of astronomic north based on Earth rotation
- No external reference needed (GPS, fixpoint network, stars)

  → works underground

Cons

- Technically sophisticated
- High investment & maintenance cost
- No independent control

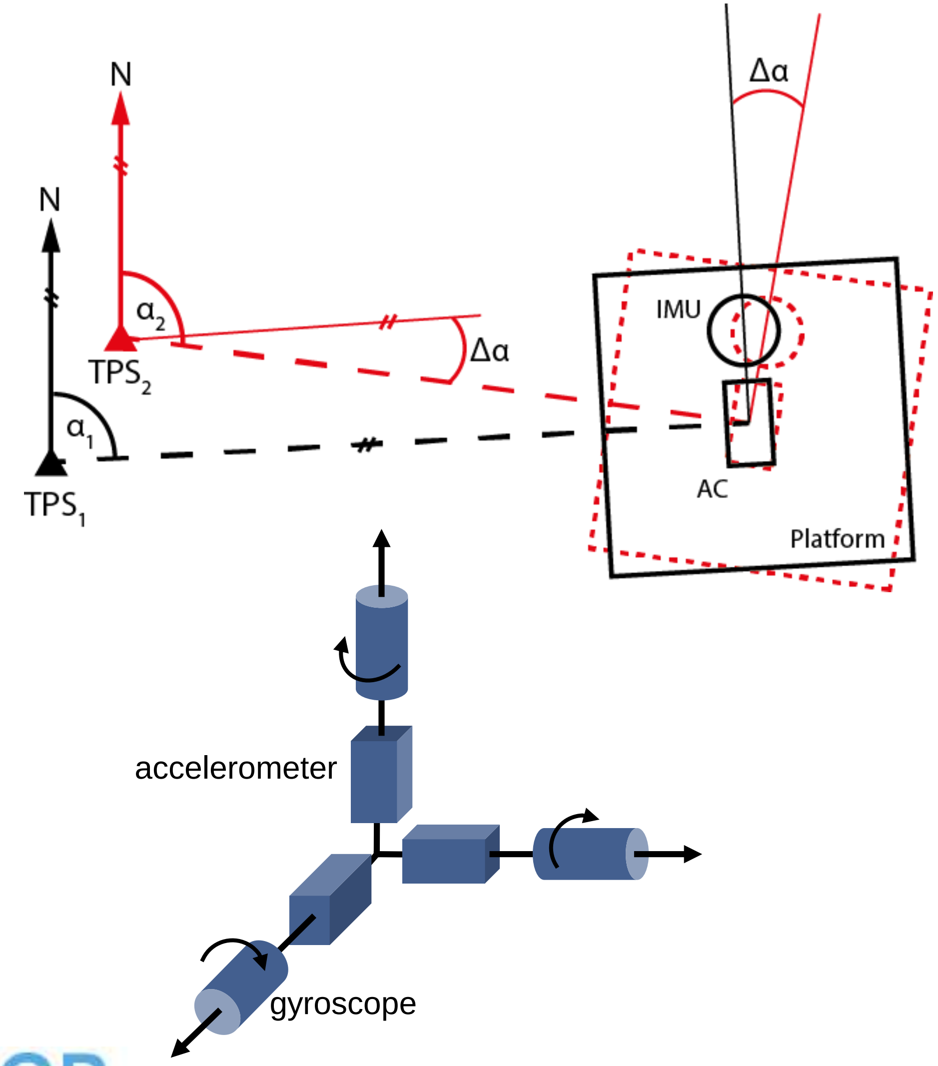
DMT

Motivation / Goals

- Development of an additional instrument for azimuth determination
- Prototypal IMU based azimuth transfer (ETH, TUM) in Sedrun showed promising results in 800 m deep shaft

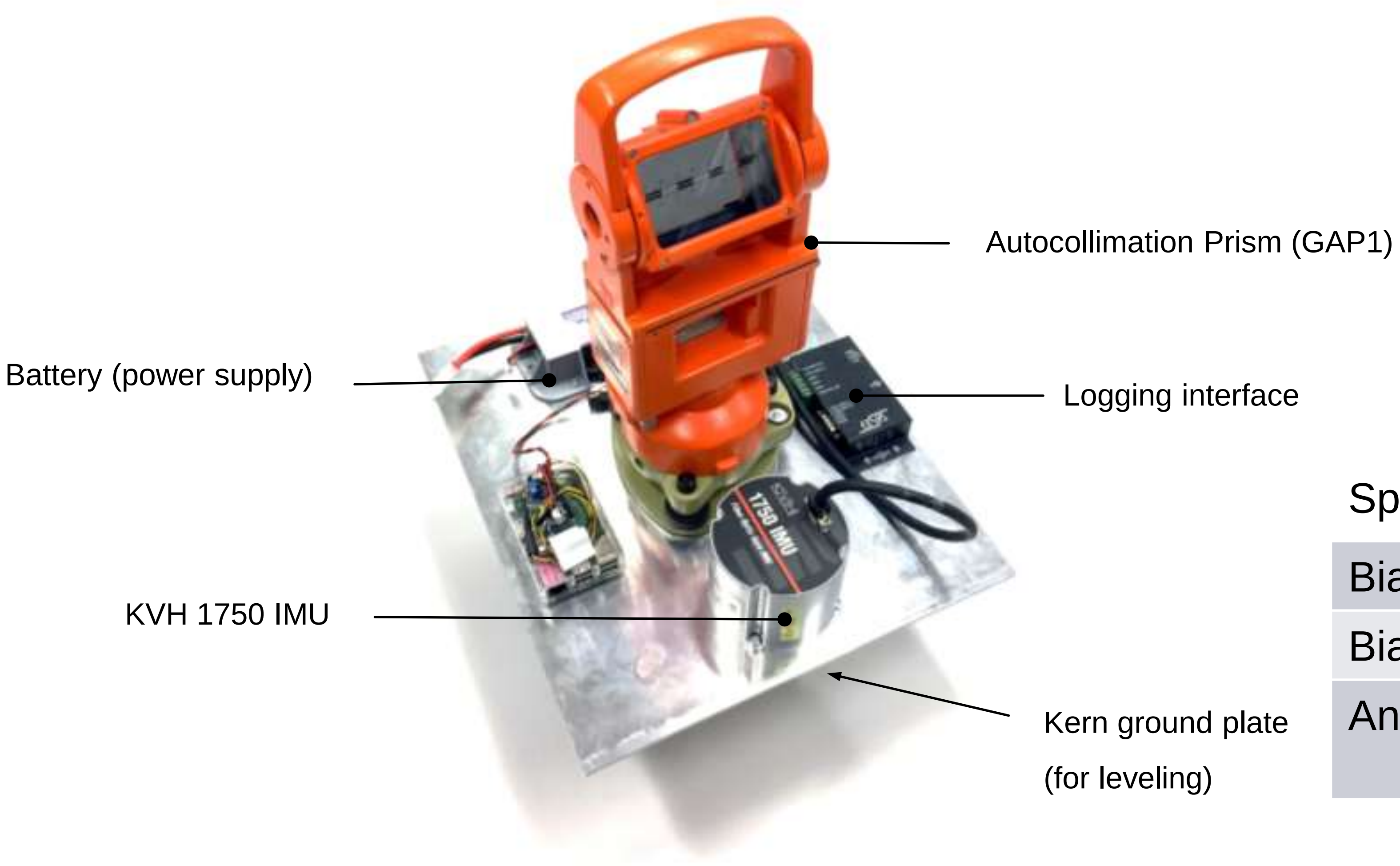
- ➢ Replacement with less expensive IMU
- ➢ Development of platform / software / measurement procedure for IMU based azimuth transfer
- ➢ Assessment of reachable accuracy in different situations (empirical measurements, simulation)

Measurement Principle



- Transfer of azimuth from geodetic network above ground to network below ground
- Measure orientation change between two resting positions of platform
- Orientation change = integration of angular rates (IMU)
- Azimuth transfer from network to platform via autocollimation prism & total station (above ground) and vice versa under ground
- Procedure is carried out several time in order to increase accuracy and reliability

Platform



Specification of KVH 1750

Bias offset [°/hr]	± 2
Bias instability [°/hr]	≤ 0.05
Angle Random Walk [°/hr/√ Hz]	≤ 0.7

Processing

Real Data

Simulated Data

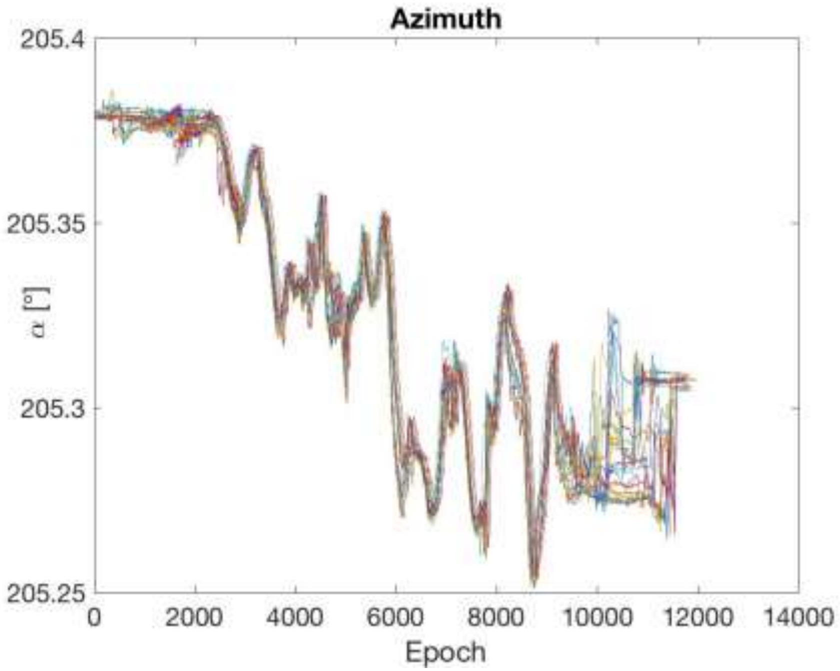
Motion Detection → Alignment → Integration → Statistics

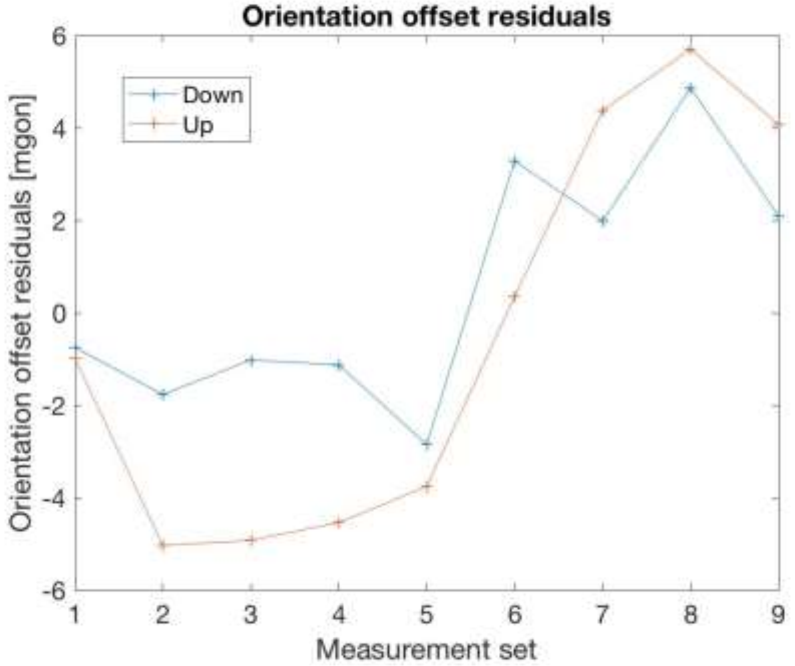
Based on acceleration

1D / 3D

True Trajectory → Take Derivative → Acceleration Angular Rate → Add Noise

Results: vertical shaft (elevator)





- Orientation offset SD = 3.5 mgon

Test setup:
27m long shaft (30s)
repeated 10 times

Results: horizontal shaft

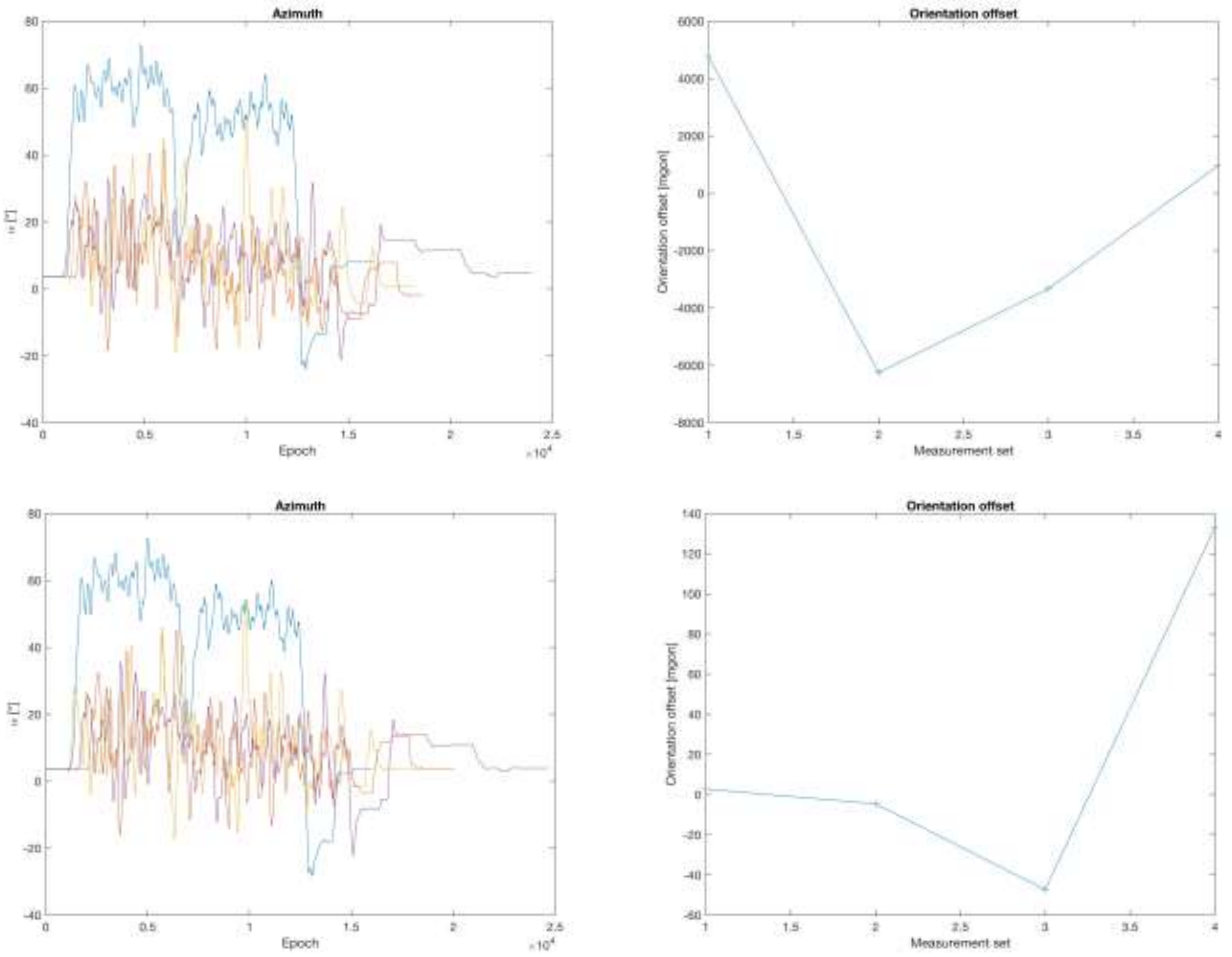
<u>1D-integration</u>

Mean Orientation offset: -0.96 gon
STD orientation offset: 4.80 gon

<u>3D-integration</u>

Mean Orientation offset: 21.1 **m**gon
STD orientation offset: 78.0 **m**gon

Test setup:
25m path, walked forth & back (60s), repeated four times



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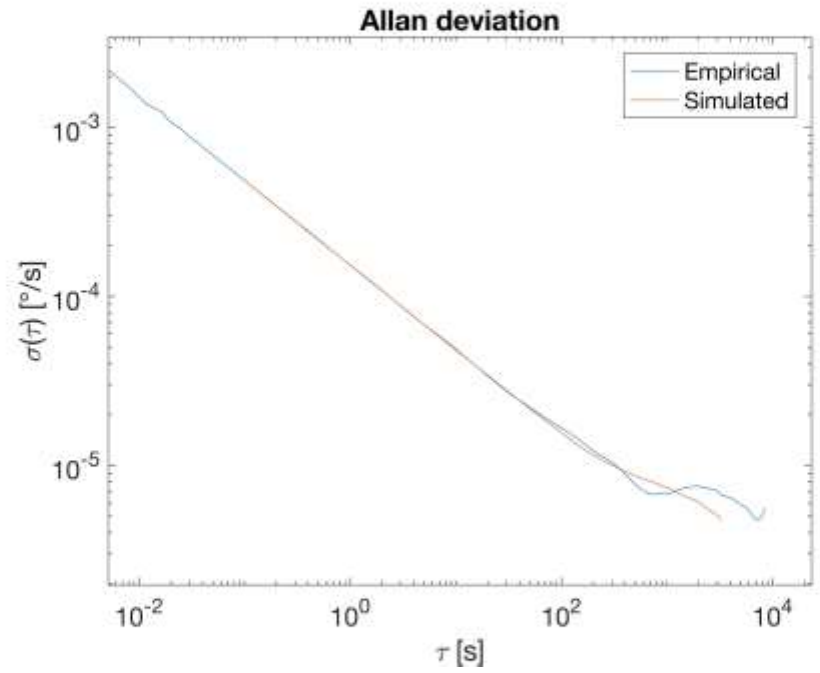
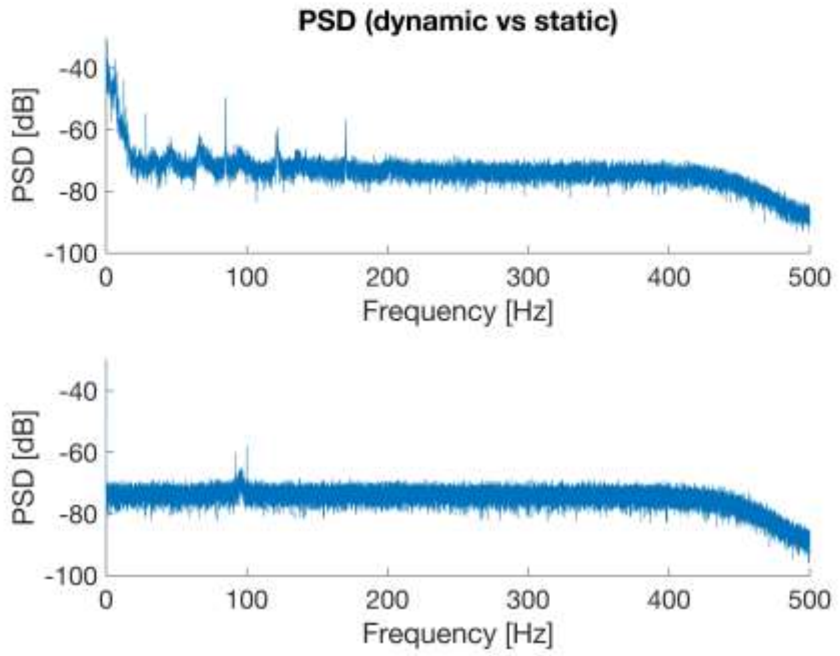
Conclusion

- Design & Implementation of IMU based azimuth transfer system
  - Measurement platform with IMU, autocollimation prism and acquisition hardware
  - Measurement Protocol
  - Data processing software: 1D / 3D integration, motion detection, alignment, user-friendly
- Simulation Tool for generating realistic IMU data for a given trajectory and IMU-specifications
- Relatively good agreement of empirical measurements and simulation (autocollimation uncertainty / vibration not considered)

➢ IMU platform can substitute a north-seeking gyro in some situations or provide additional independent control

Results: IMU noise / Spectral analysis





Further Experiments

- Horizontal shaft (trolley / hand held)
- 360°-rotation of levelled platform (scale factor)
- 360°-rotation of tilted platform (sensitivity of 1D integraiton)
- Effect of earth rotation (if tilted drift of 1D integration)