Train-Localization in Tunnels using Magnetic Signatures

INTELLIGENT MAGNETIC POSITIONING FOR AVOIDING COLLISIONS OF TRAINS

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Intelligence on Wheels (IoW) & German Aerospace Center (DLR)
Motivation

Improving safety and efficiency …

- Wolfsburg (D) 1.4.21
- Süderlügum (D) 20.4.21
- Arch (CH) 23.4.21
- Cazis (CH) 8.4.21
- Světec (CZ) 4.4.21

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• TrainCAS Virtual Infrastructure
• Collision Avoidance based on Location Beaconing via Train2Train Communication

… of future railway transportation
Why Localization with Magnetic Signatures?

- **GNSS**: Will not work in deep tunnels as satellites are not received.
- **MAG**: Using distortion of the Earth's magnetic field as signatures for positioning.
- **IMU**: Becomes less accurate for localization over long distances.
Research Questions

- Which sensor positions are most suitable?
  - Noise analysis
  - Understanding contributions to the signature
  - Cross section dependencies
- What is the influence of magnetic track brakes?
- How about the long term stability of magnetic signatures?
- How good is the velocity determination from synchronized sensors without map?
- Which accuracy can be achieved with magnetic localization alone and if fused with other sensors?
Measurement Campaign
Campaign Overview (early 2021)

- **Berlin**
  - Urban and suburban, bridges, underpasses, crossing road and rail traffic
- **Göttingen – Kassel**
  - High speed, tunnels incl. switchways, cargo trains
- **Dasing – Radersdorf**
  - Rural, not electrified, single track

- 2.242 km in 8 measurement days (with track repetitions)
- 1.450 km of magnetic track signatures recorded
- 98 km trajectories referenced by Leica-stations (cm accuracy range)
Magnetic Sensor Arrays
Antenna and sensor relative positions
Data Analysis
Reference Trajectories

- No PVT 8.1%
- GNSS Standalone (3.5%)
  - SBAS (15.0%)
  - DGPS (73.4%)
- Leica1 (3.2%)
- Leica2 (1.1%)

of 2.242 km
Expl: Grunewald – Wannsee Features

Underpasses

Suburban
Expl: Grunewald – Wannsee
Other trains

Cargo train

Regio Dosto
Expl: Kassel – Göttingen: High Speed and Long Tunnels!
Expl: Kassel – Göttingen
Magnetic Track Brake

Cargo train braking from 200km/h

Track brake

Bridge
Expl: Friedberg
Long term stability

ICE 2021

BRB 2014

Cabin $B_N$

normalized $(B_H - B_H^*)$

$Y1\rightarrow Y5$

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Magnetic Localization
Magnetic localization

Magnetic field

Velocity

Digital Map

Magnetic train localization building blocks

Signature Processing → Signature Similarity → Signature Location → Quality Check

Location Propagation → Reference Signatures

Along-track Update → Cross-track Weighting → Pruning

Most Likely Output

1D track position

Magnetometer

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Along-track accuracy

Along-track Error Distribution (CDF) of Day4, DLR2 Array

1.5m inside
1.8m outside

DLR2 Array

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Track-selective magnetic localization

- Along-track localization: positioning availability with detected and excluded distortions is > 98%
- O, X is from a detector, not from data labeling
Track-selective magnetic localization

- Cross-track: switch & track identification inside tunnel
- $O, X$ is from a detector, not from data labeling

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Comparision with wrong track (opposite track)

Comparision with same track

Easy detectable

Run C: test signature

Run A: reference signature

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Integration
Magnetic Odometry integrated into TrainCAS

Example:

Speed estimation inside Leinebuschtunnel (1.740m) with magnetic odometry speed error < 1.7 km/h (RMSE) in tunnel, even less along the entire track outside tunnels.
Magnetic Localization integrated into TrainCAS

Example:

Localization error inside Leinebuschtunnel (1.740m) with magnetic localization < ~20m
Summary and Outlook
Findings

- Localization accuracy in along-direction is comparable to GNSS (95%: 1.5m sensor outside, 1.8m sensor inside)
- 100% track-selectivity: It is possible to re-identify the correct track and a track change at a switch, also inside tunnels of arbitrary length
- Other trains causing distortions: can be handled with fault detection
- Speed error was below 1.7 km/h (RMSE) in integrated system with support of magnetic signatures

Conclusion

- Magnetic signatures are a major improvement to train localization and odometry
- Best results if magnetic odometry & localization combined with GNSS, IMU and digital track map for continuous train localization and integrity monitoring