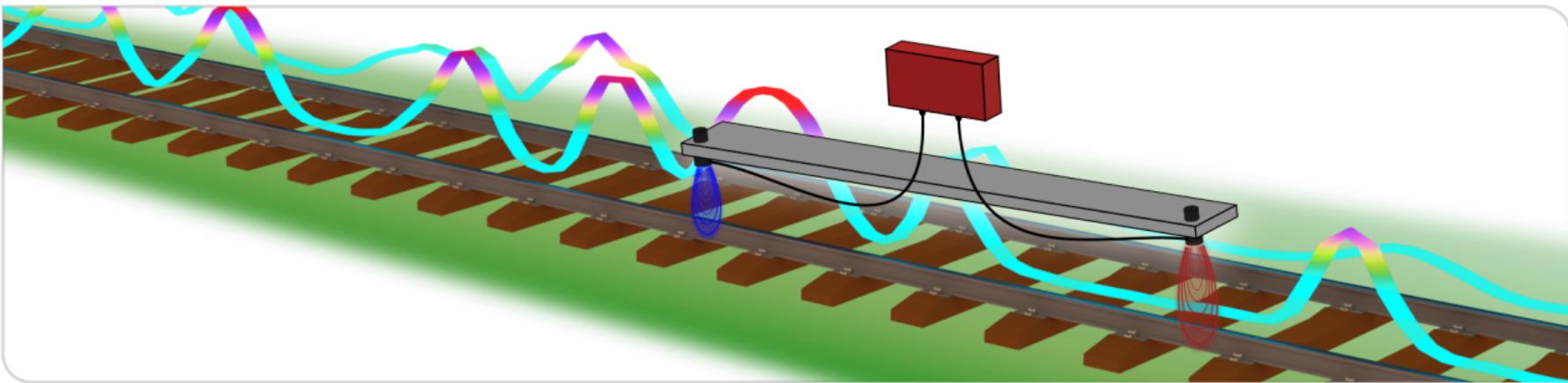


Localization of Railway Vehicles using the Ferromagnetic Fingerprint of Rails

2nd iLoc Workshop, ITSC23

Bernd Kröper | 24.09.2023



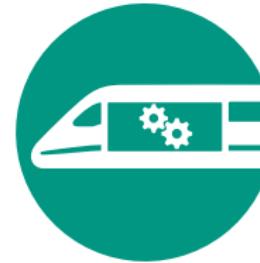
Motivation

accurate and
highly available



Motivation

accurate and
highly available



pure onboard,
stand-alone

Motivation

accurate and
highly available



DIS: Difference
Inductance Sensor



pure onboard,
stand-alone

Motivation

accurate and
highly available

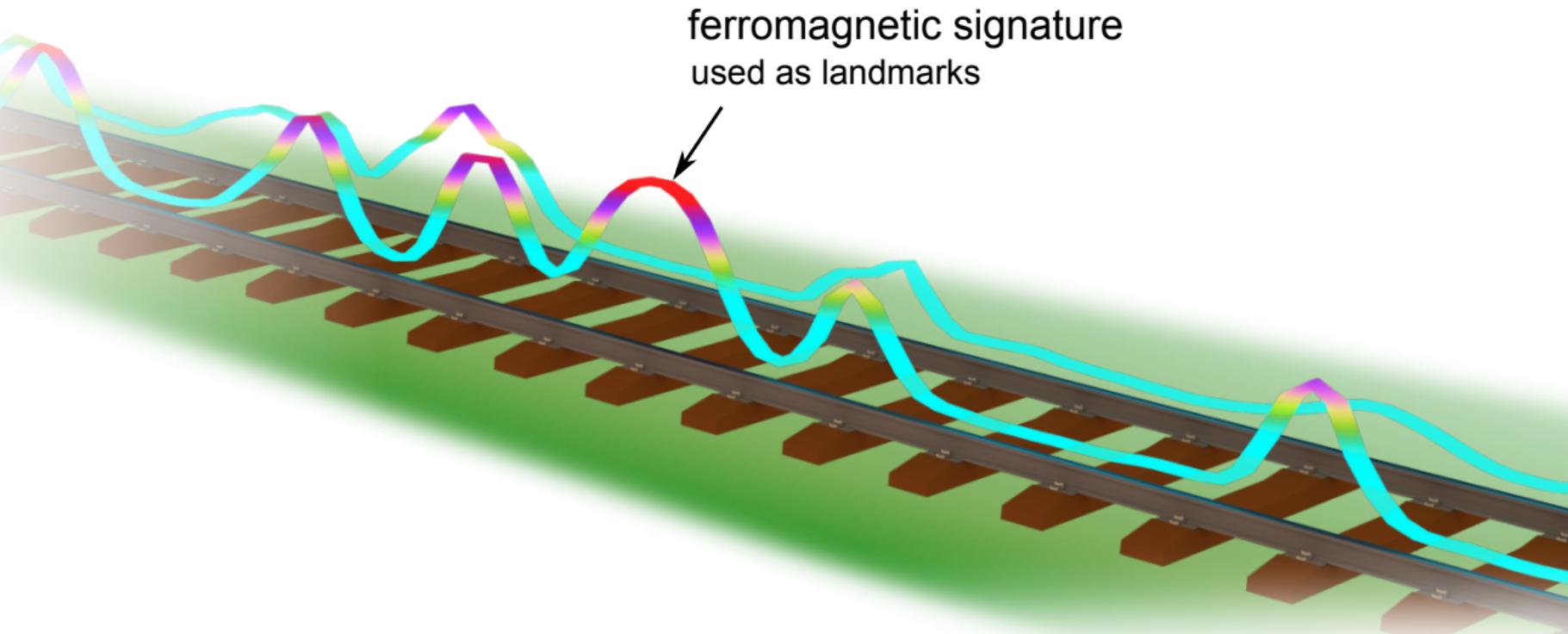
orthogonal
measurement
principle



DIS: Difference
Inductance Sensor

pure onboard,
stand-alone

Difference Inductance Sensor (DIS)



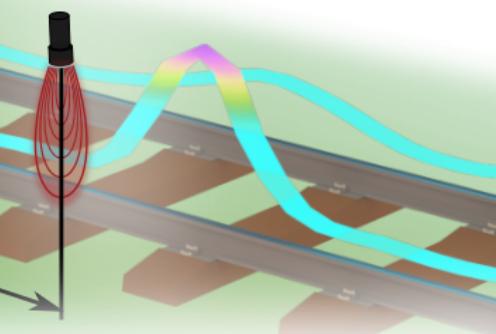
Difference Inductance Sensor (DIS)



ferromagnetic signature
used as landmarks

sensor head A & B
pickup ferromagnetic
signature below

d



Difference Inductance Sensor (DIS)

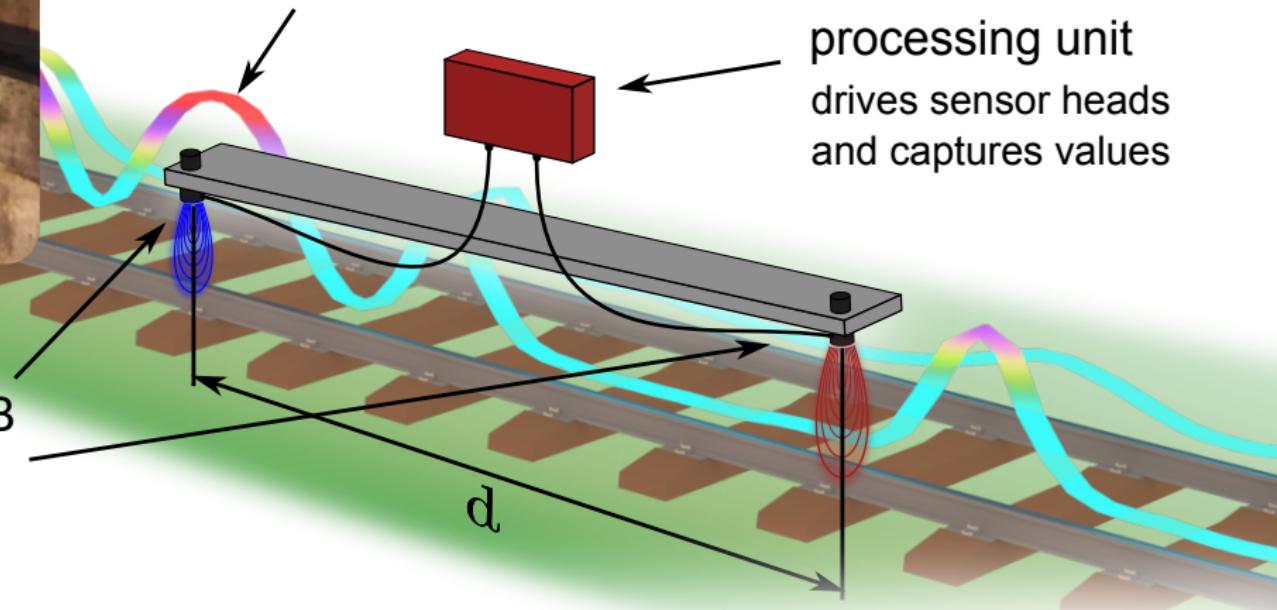


sensor head A & B
pickup ferromagnetic
signature below

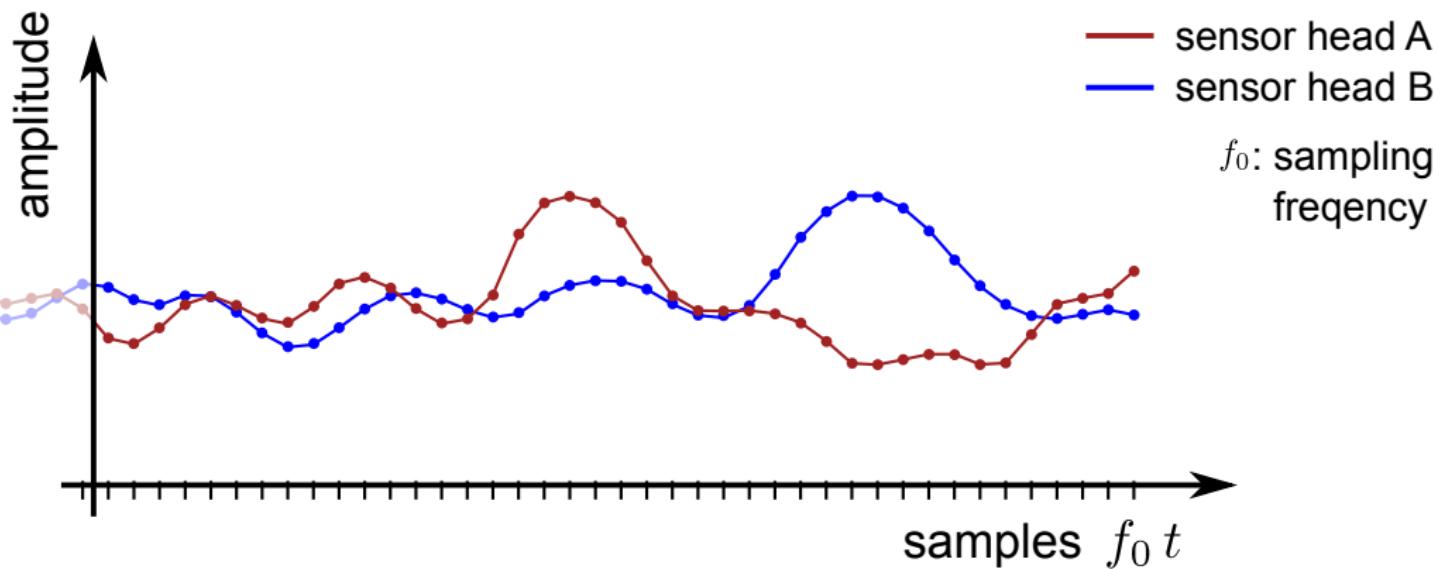
ferromagnetic signature
used as landmarks

processing unit
drives sensor heads
and captures values

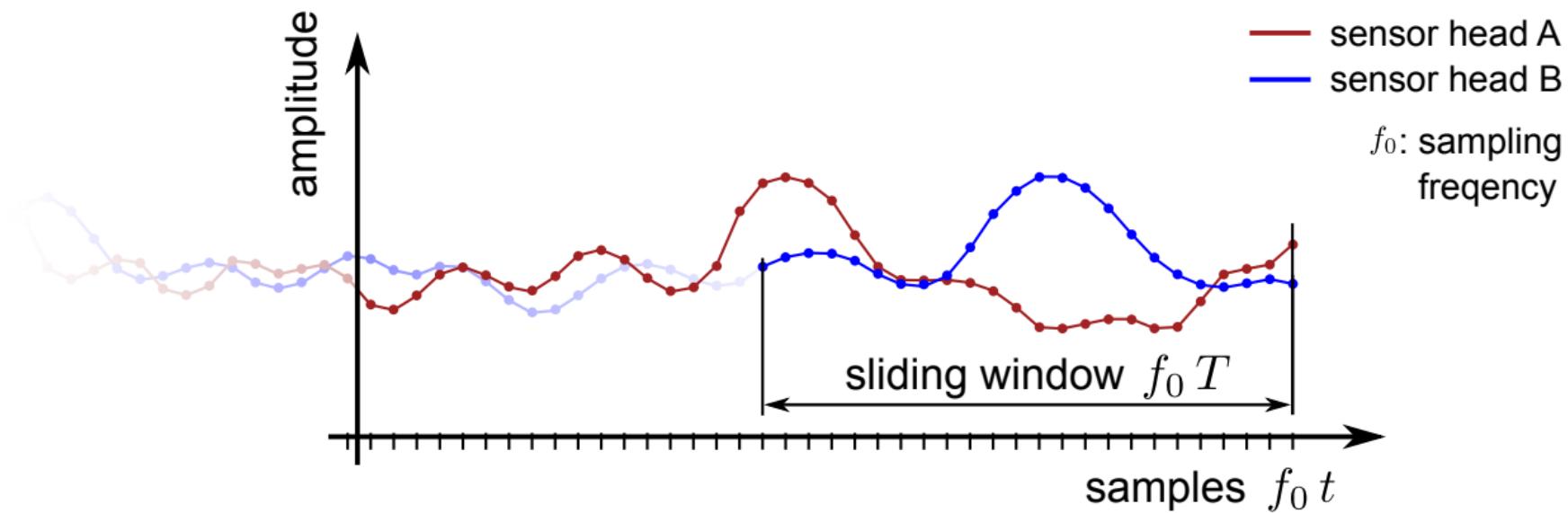
d



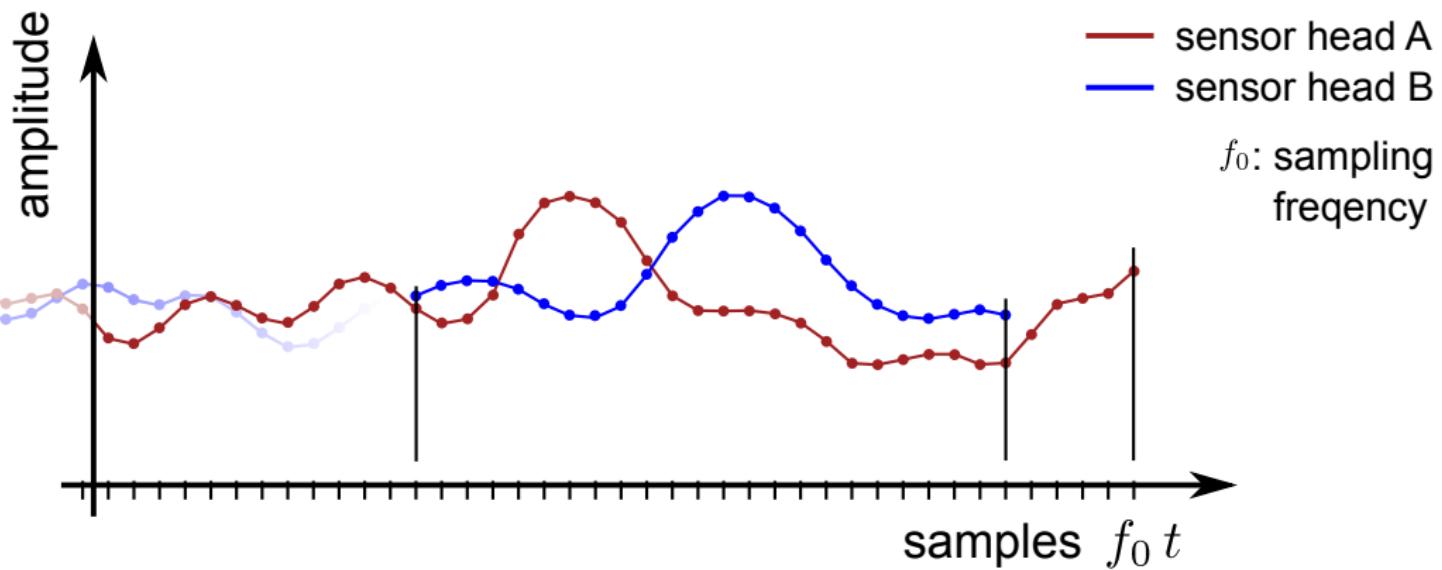
Velocity Estimation



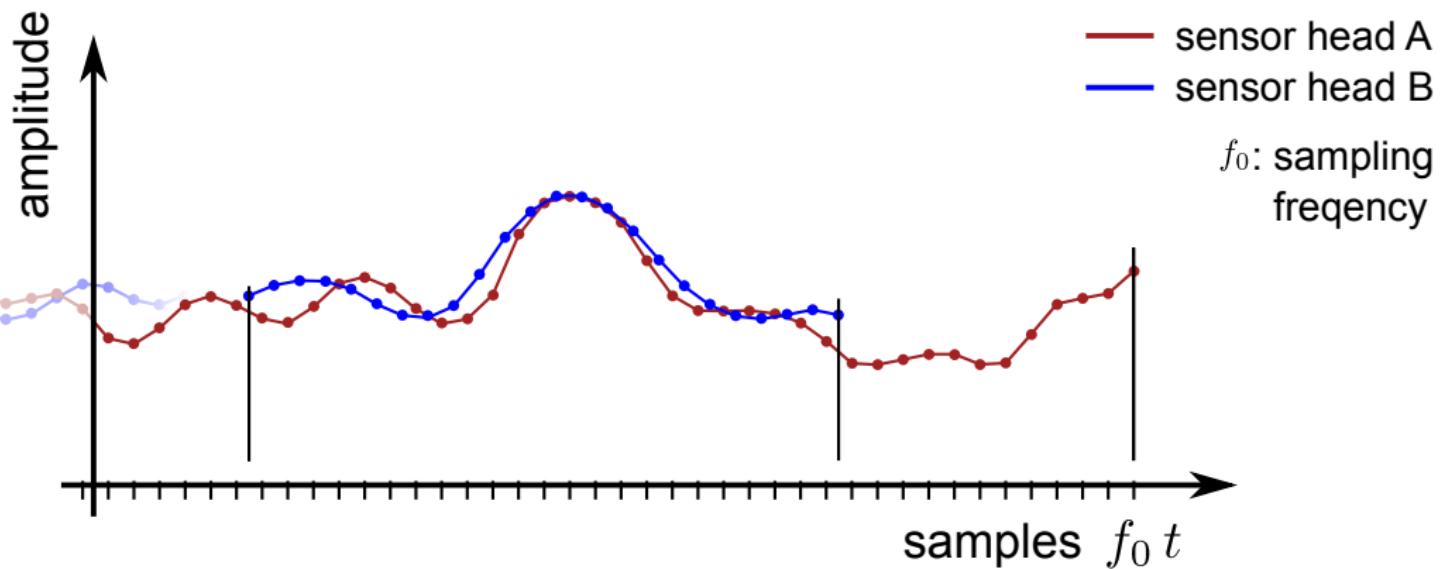
Velocity Estimation



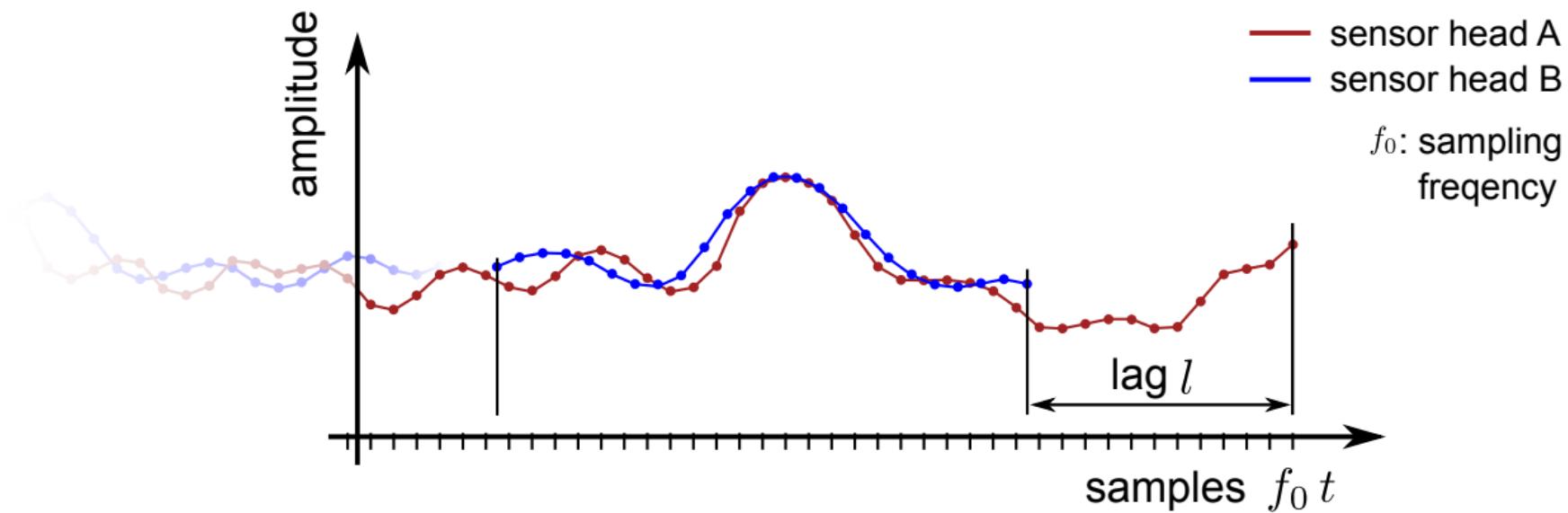
Velocity Estimation



Velocity Estimation

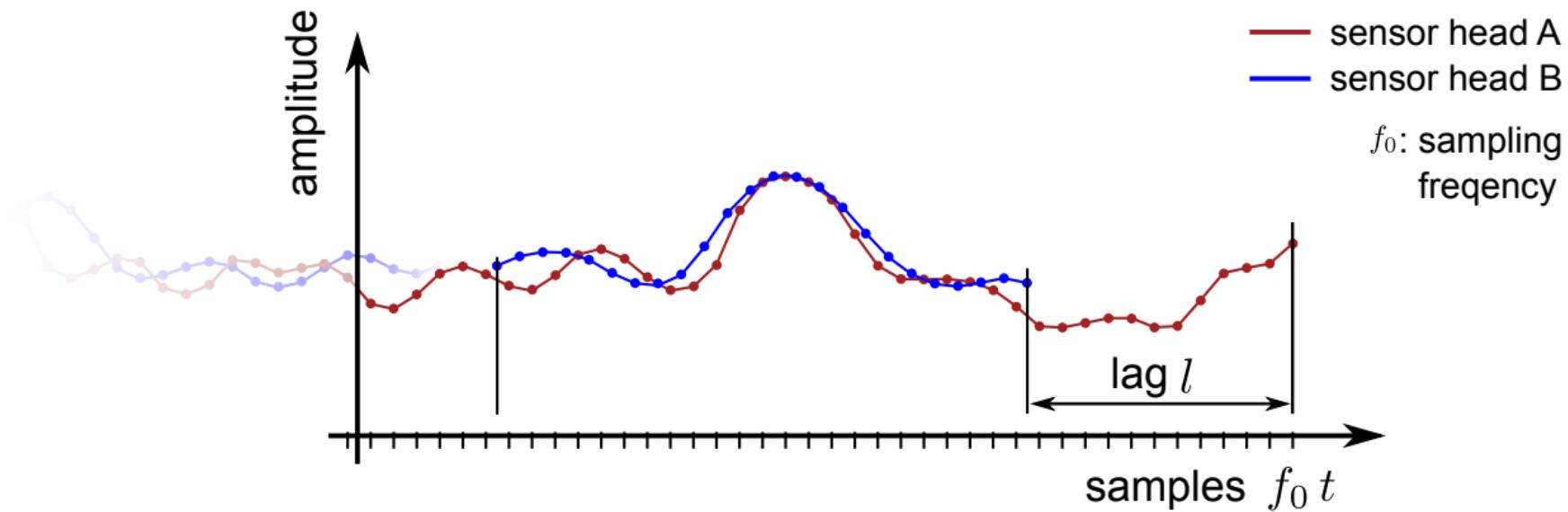


Velocity Estimation



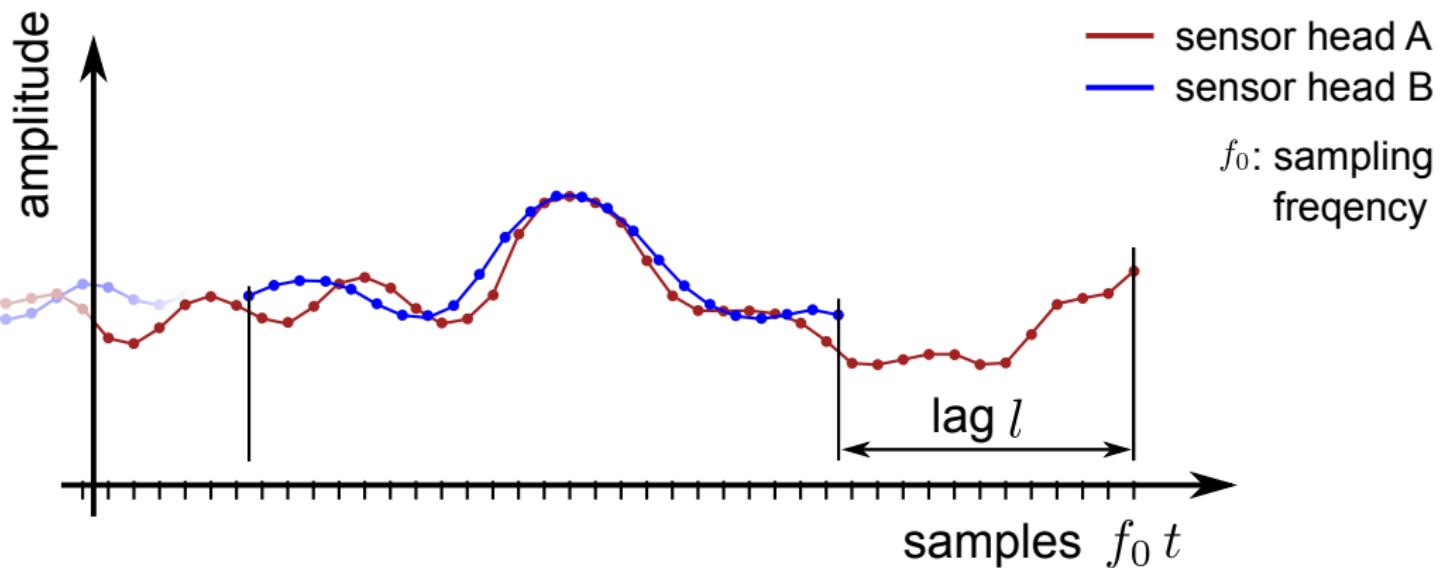
- l gives current velocity, found by maximizing cross-correlation

Velocity Estimation

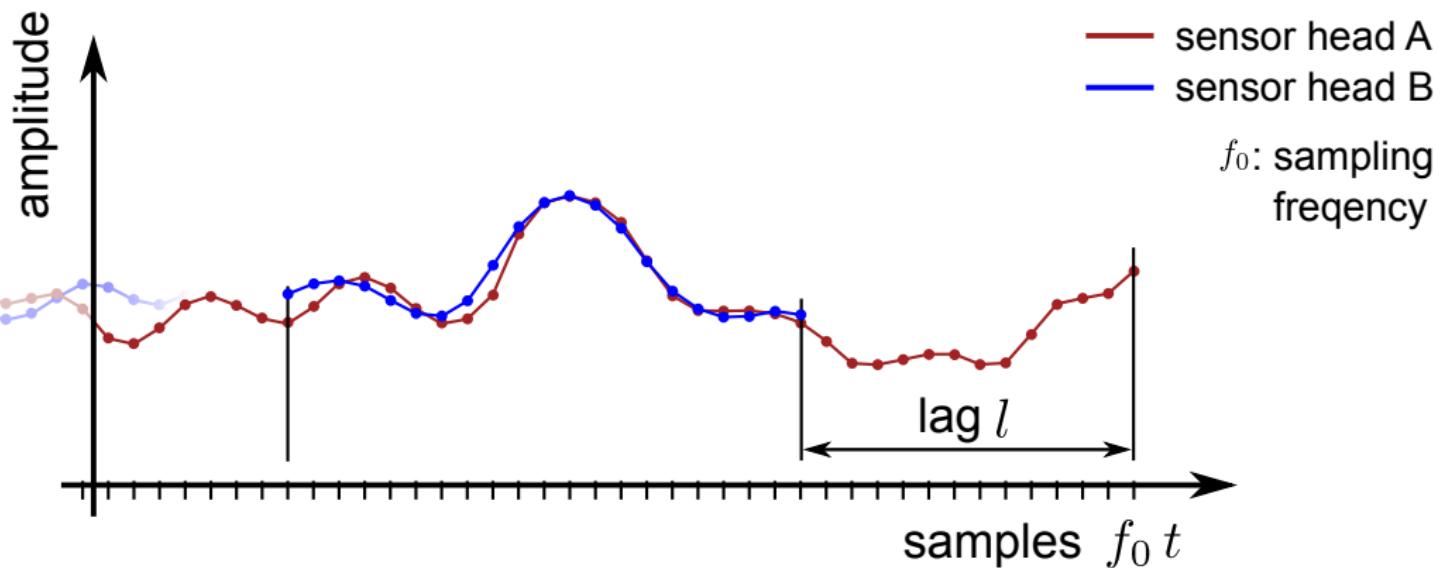


- l gives current velocity, found by maximizing cross-correlation
- good solution for constant velocity

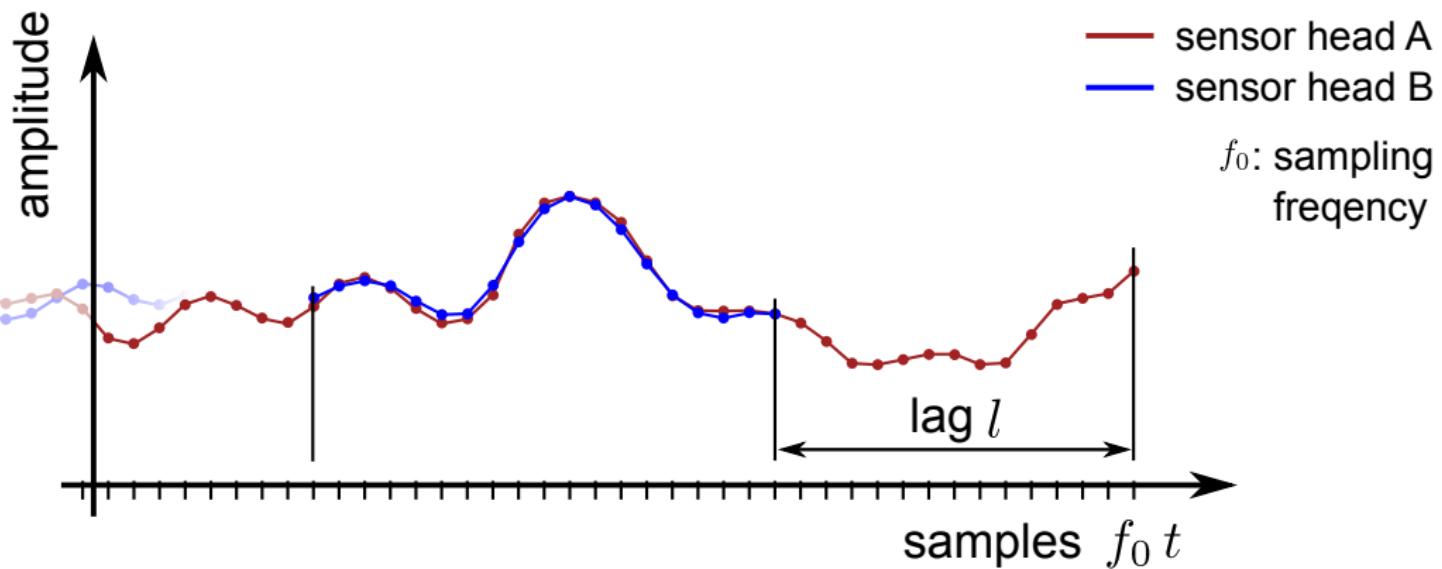
Acceleration Estimation



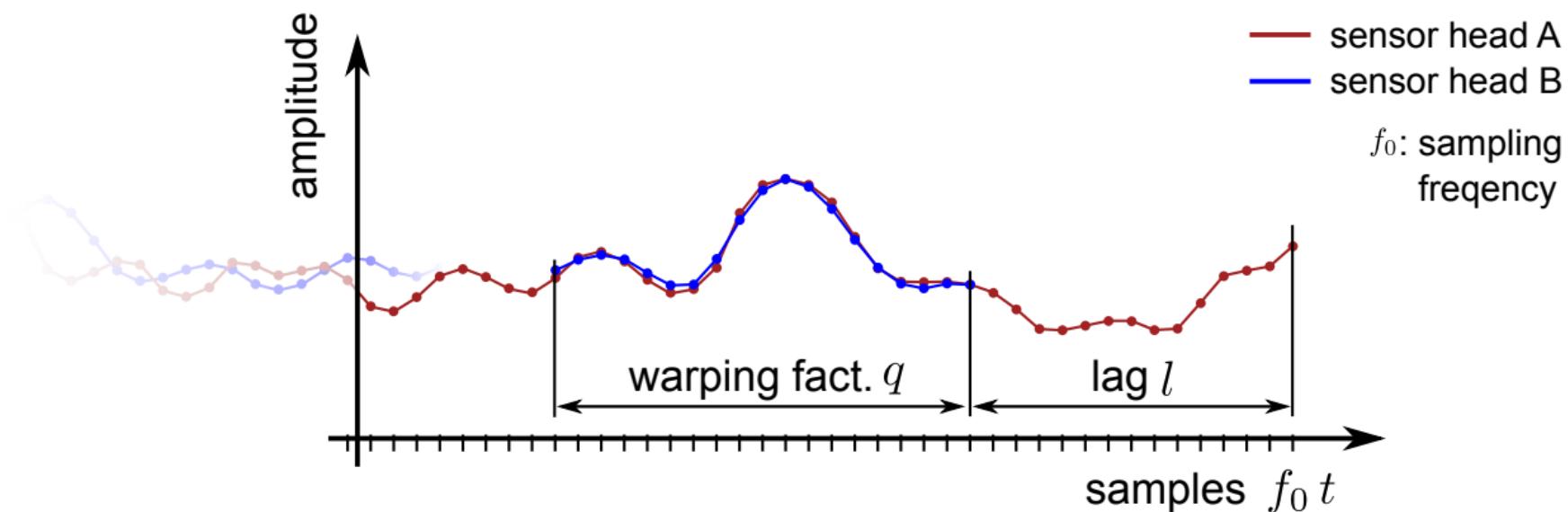
Acceleration Estimation



Acceleration Estimation

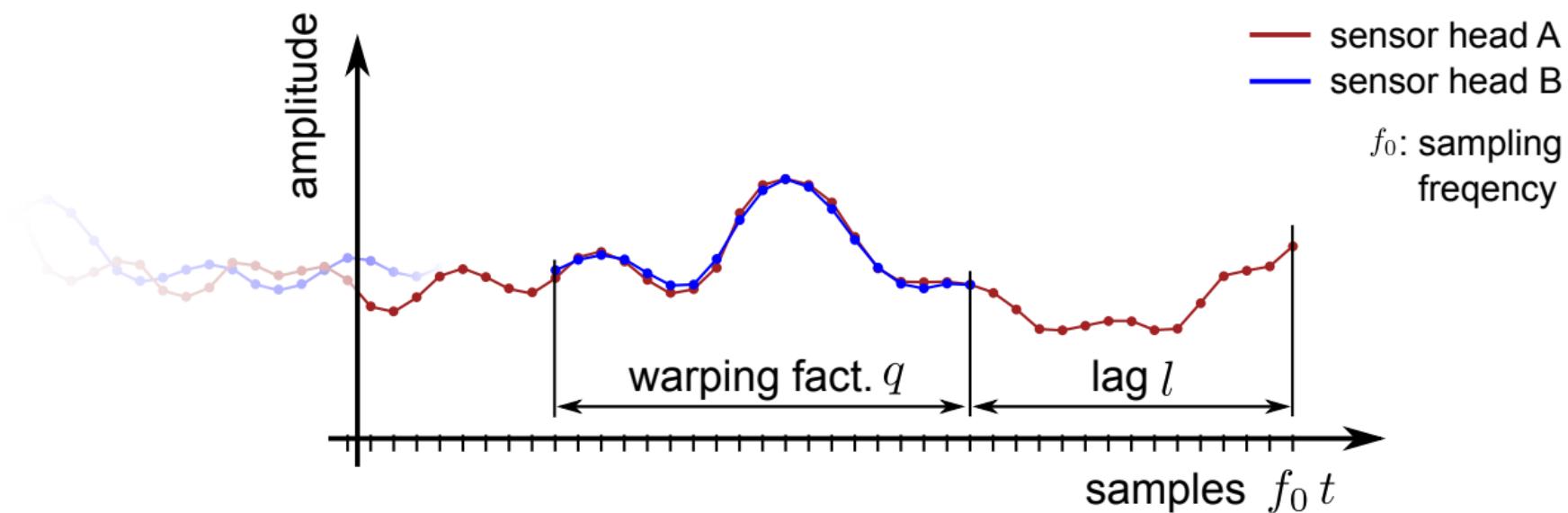


Acceleration Estimation



- q gives current acceleration, found by maximizing cross-correlation

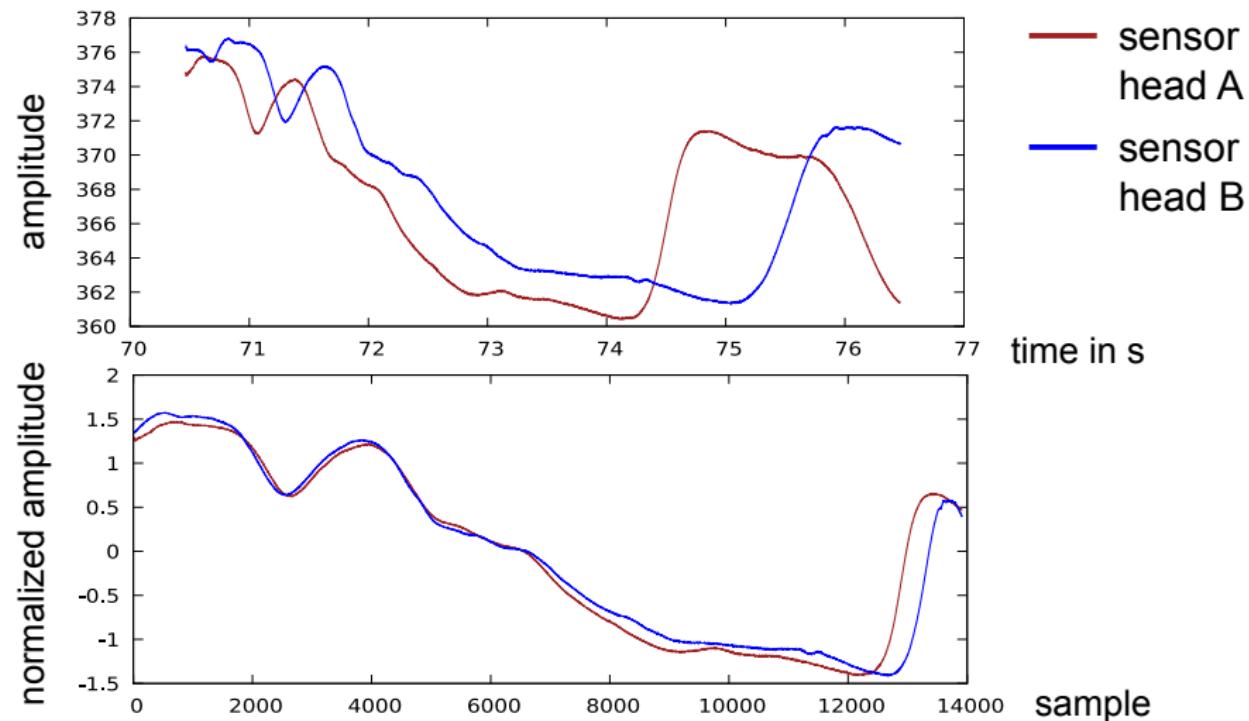
Acceleration Estimation



- q gives current acceleration, found by maximizing cross-correlation
- finite state machine to handle standstill

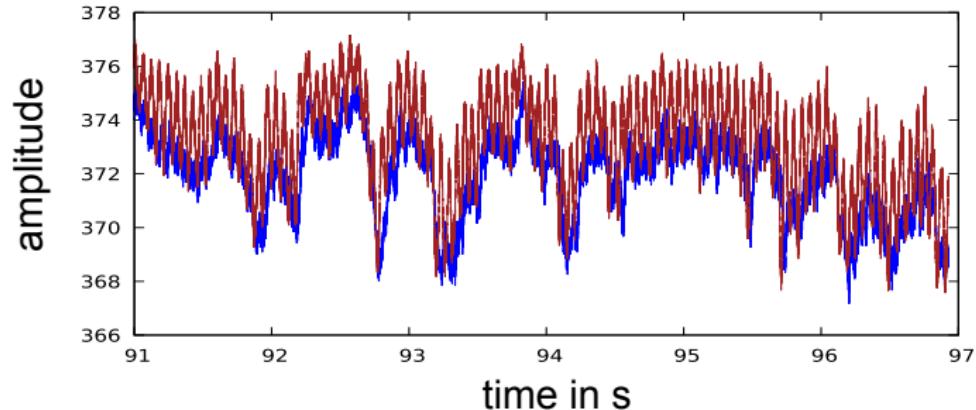
Velocity and Acceleration Estimation

- sample of measured ferromagnetic signals
- signals after normalization, shifting and warping



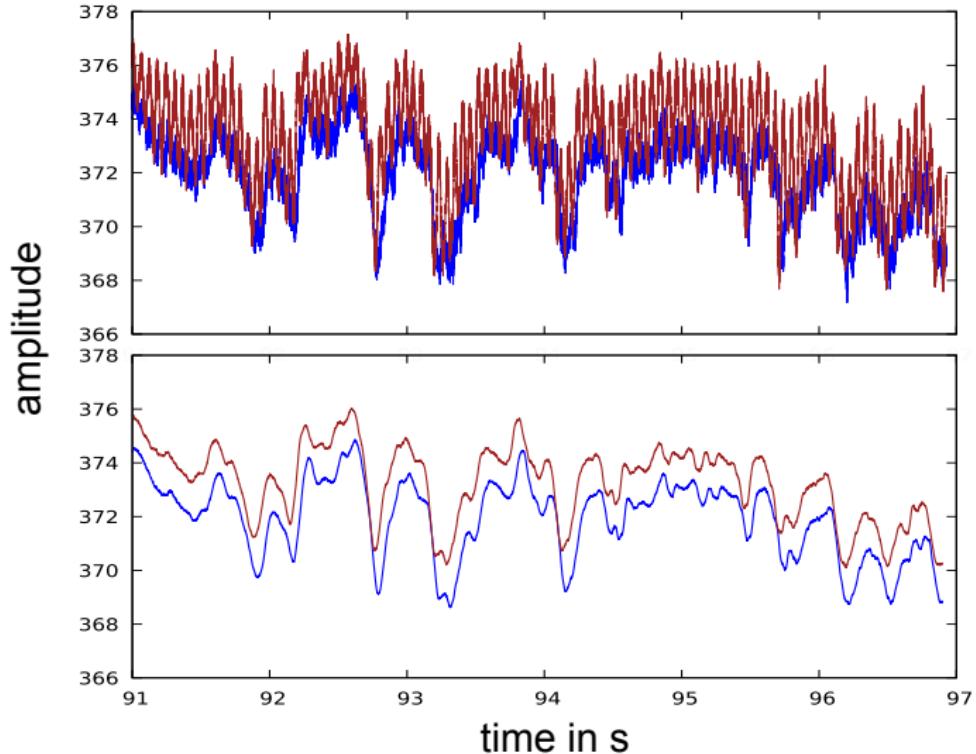
Noise reduction

- raw sensor data with noise
e.g. quantization, electrical components with 16.7 Hz



Noise reduction

- raw sensor data with noise
e.g. quantization, electrical components with 16.7 Hz
- significant reduction using a lowpass filter (moving average)

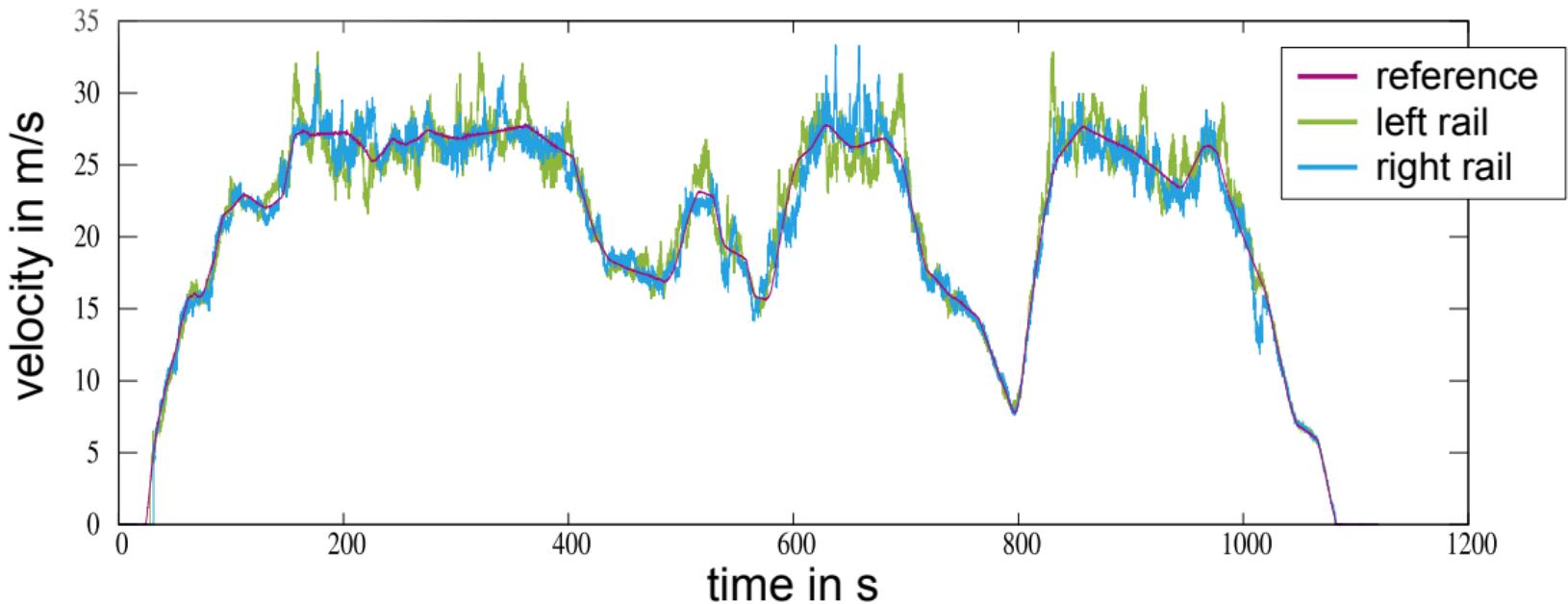


Evaluation Setup

- mounted on railway vehicle
 - two sensors over both rails
 - distance to rail = 100 mm
 - $d = 553$ mm
 - sampling frequency $f_0 = 30$ kHz
- reference sensor:
GNSS+INS+Odometer
- 130 km in operating traffic
- velocity up to 100 km/h



Evaluation of Velocity Estimation

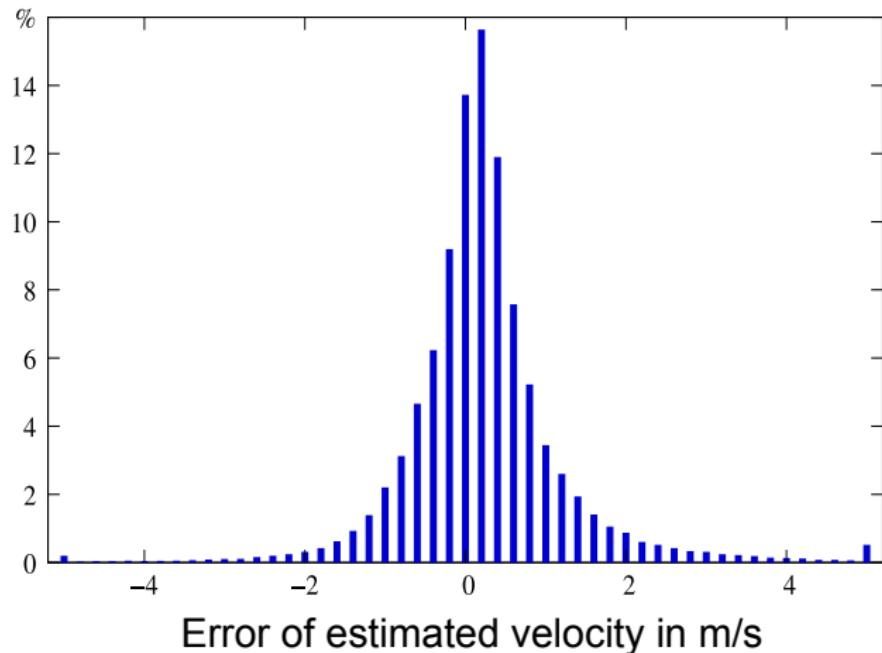


- above 0.1 m/s almost always a velocity was esitimated

Evaluation of Velocity Estimation

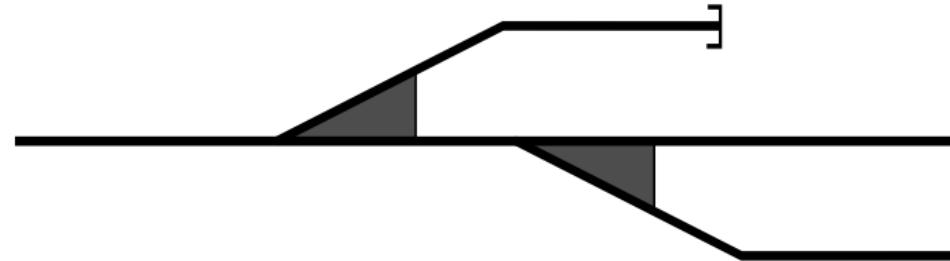
summary of errors over 130 km:

- 0.2 %: poor signal quality
- 1.0 %: no sufficient movement
- 98.8 %: accurate estimation
 - 80 %: error < 1 m/s
 - 93 %: error < 2 m/s
 - 97 %: error < 3 m/s



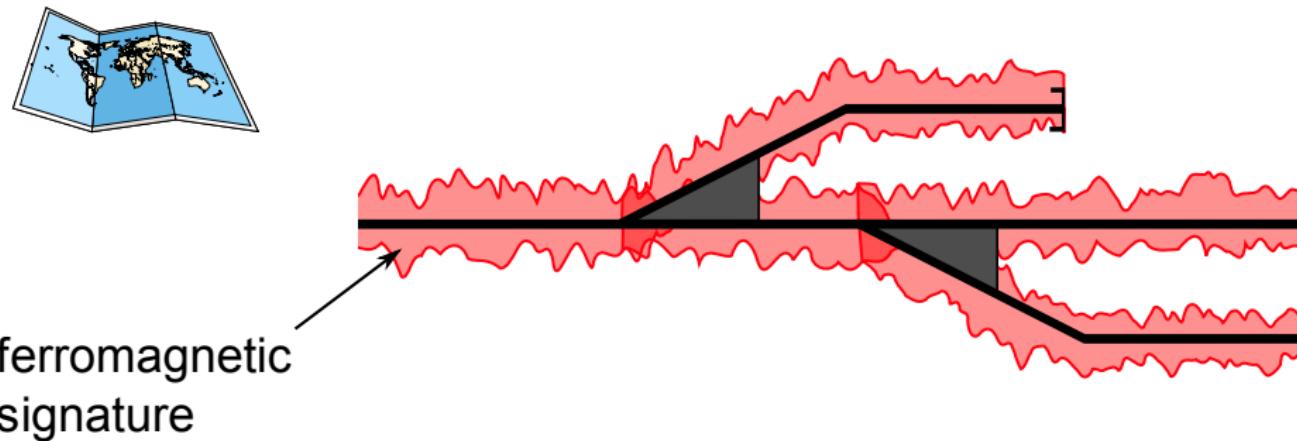
Ferromagnetic Map

- Localization using ferromagnetic signatures is based on a map



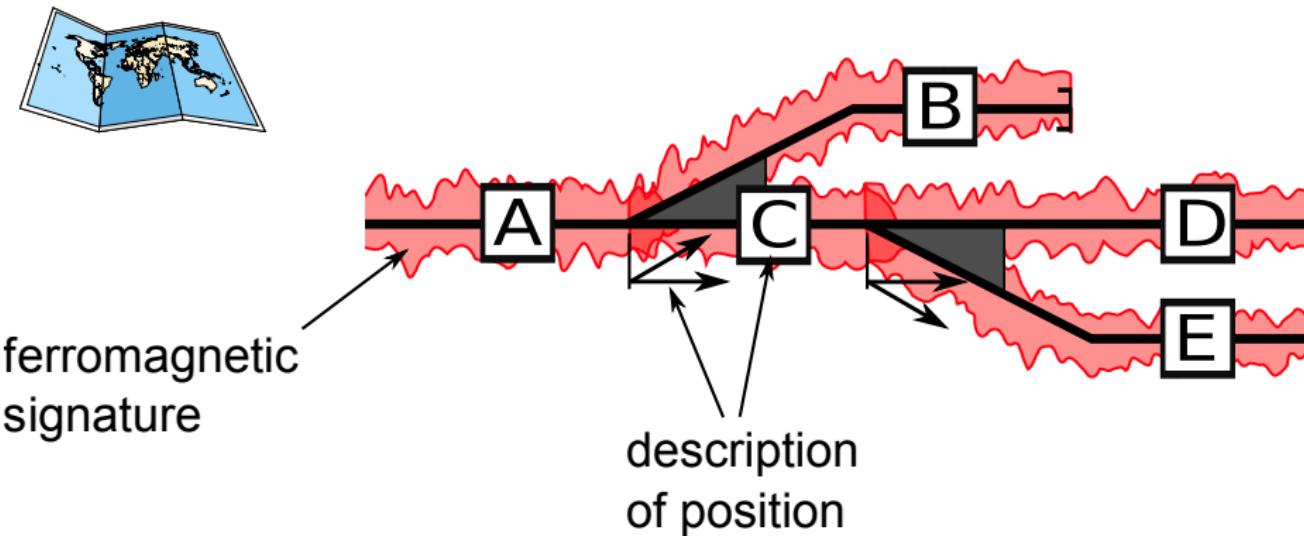
Ferromagnetic Map

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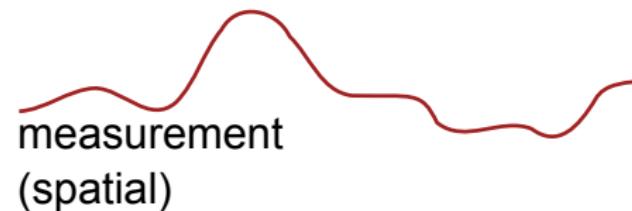
Ferromagnetic Map

- Localization using ferromagnetic signatures is based on a map



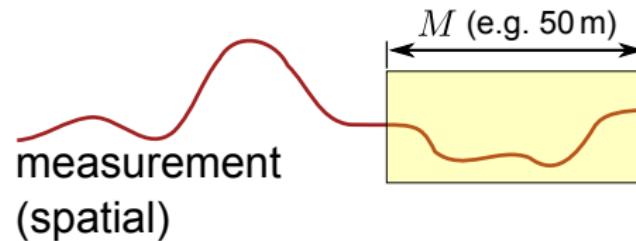
Localization

- convert measured signals from time domain into spatial domain



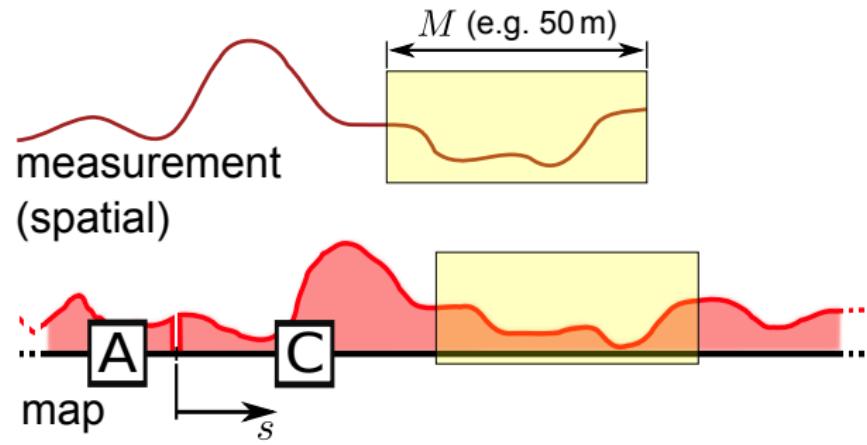
Localization

- convert measured signals from time domain into spatial domain
- take most recent values of the signal as template



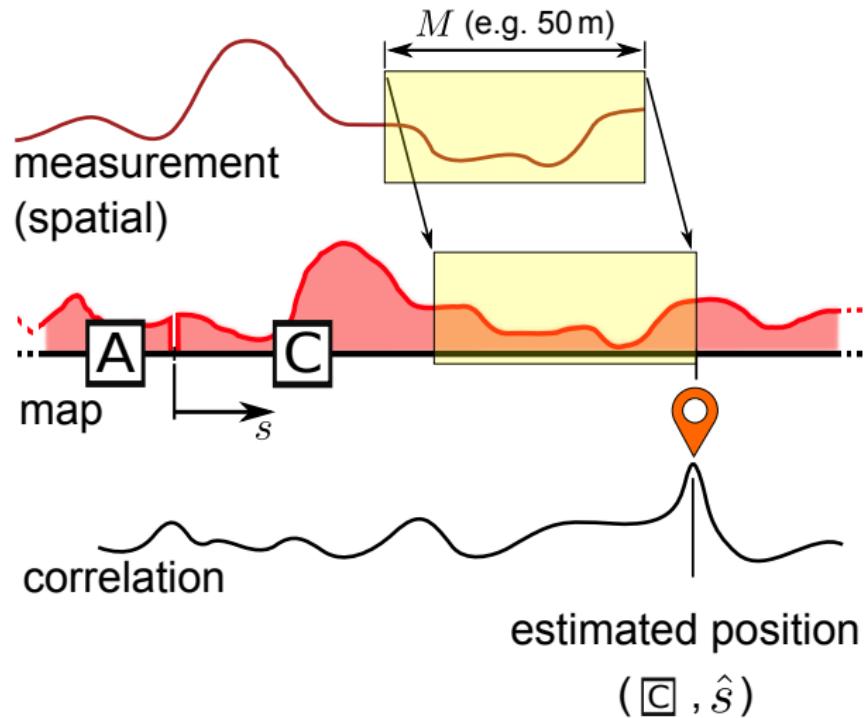
Localization

- convert measured signals from time domain into spatial domain
- take most recent values of the signal as template
- search for template in map



Localization

- convert measured signals from time domain into spatial domain
- take most recent values of the signal as template
- search for template in map
- take the position with the highest similarity

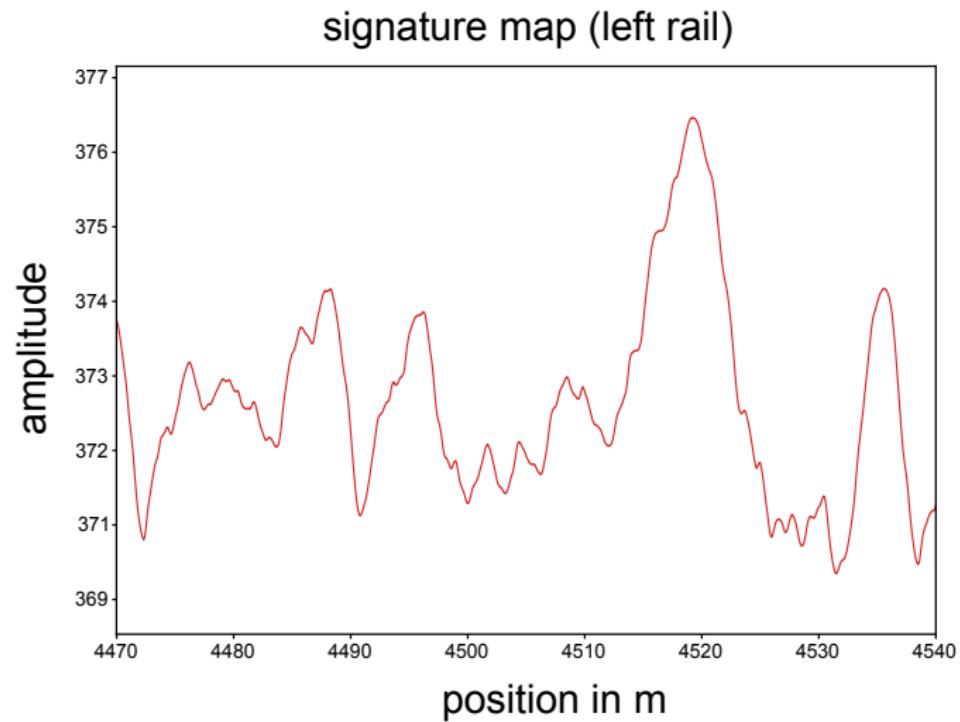


Evaluation of Position Estimation

- evaluation on section of 12 km that was passed four times

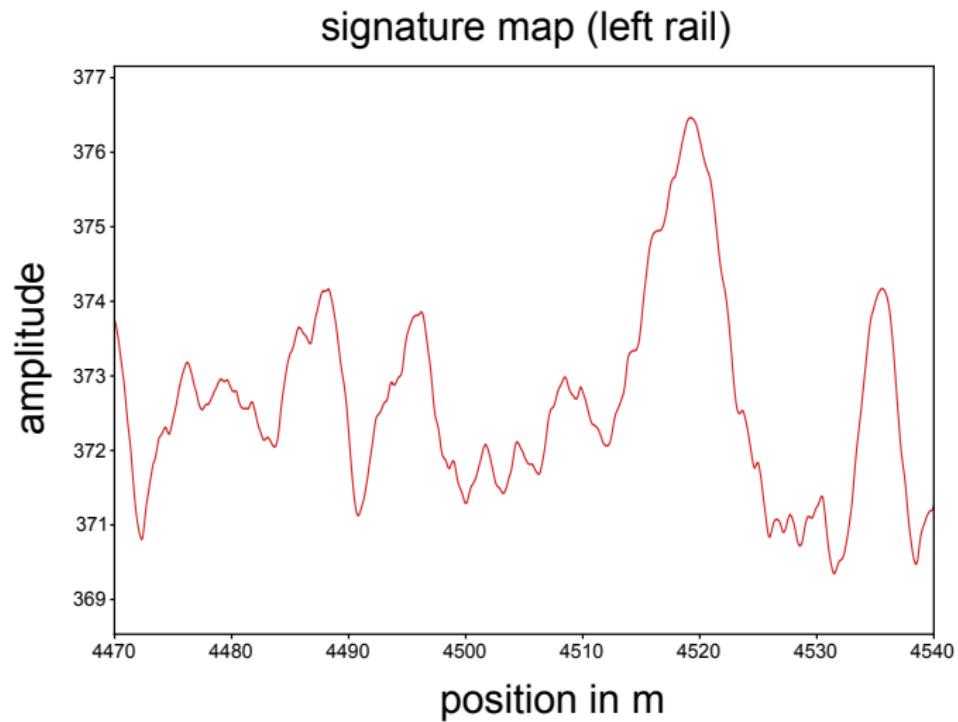
Evaluation of Position Estimation

- evaluation on section of 12 km that was passed four times
- one drive used for mapping (sampled at 10 cm)



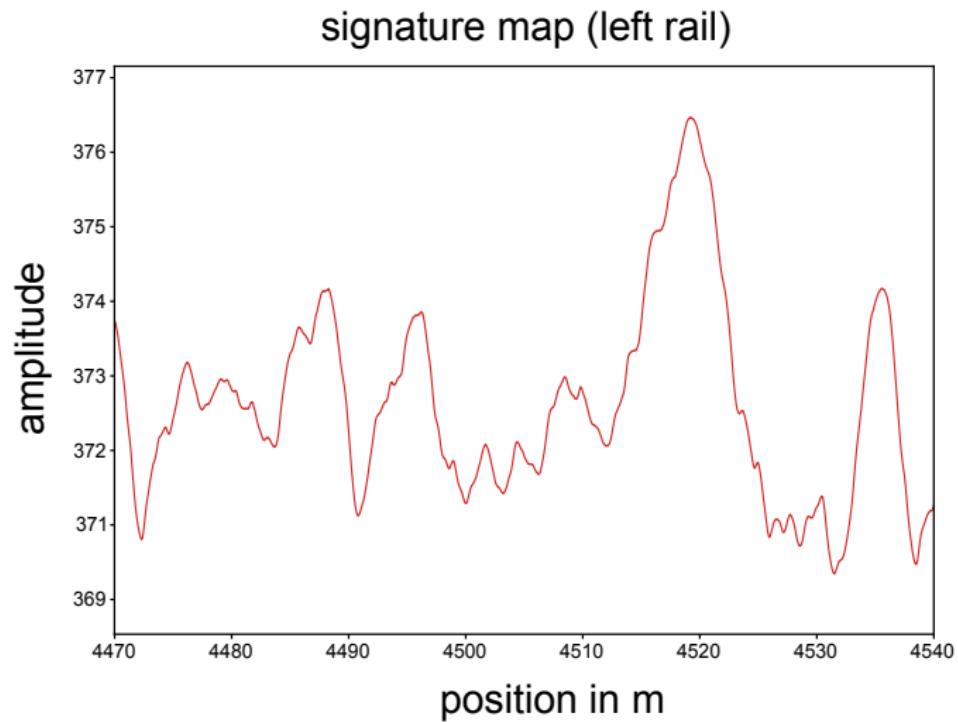
Evaluation of Position Estimation

- evaluation on section of 12 km that was passed four times
- one drive used for mapping (sampled at 10 cm)
- remaining three drives used for localization
(template length $M = 50$ m)



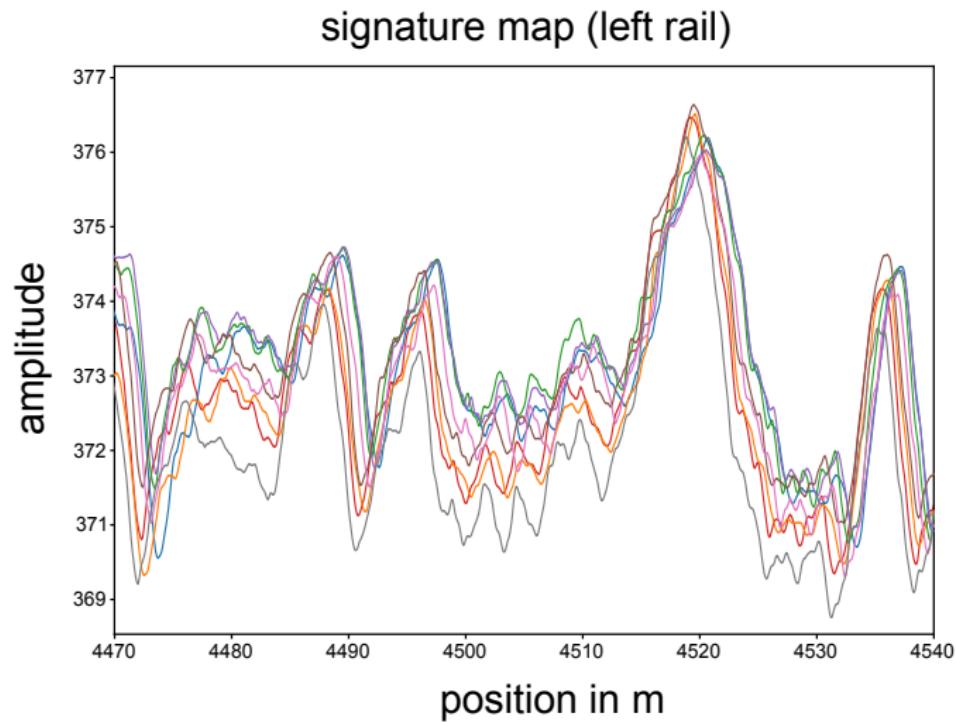
Evaluation of Position Estimation

- evaluation on section of 12 km that was passed four times
- one drive used for mapping (sampled at 10 cm)
- remaining three drives used for localization
(template length $M = 50$ m)
- separately for left and right rail



Evaluation of Position Estimation

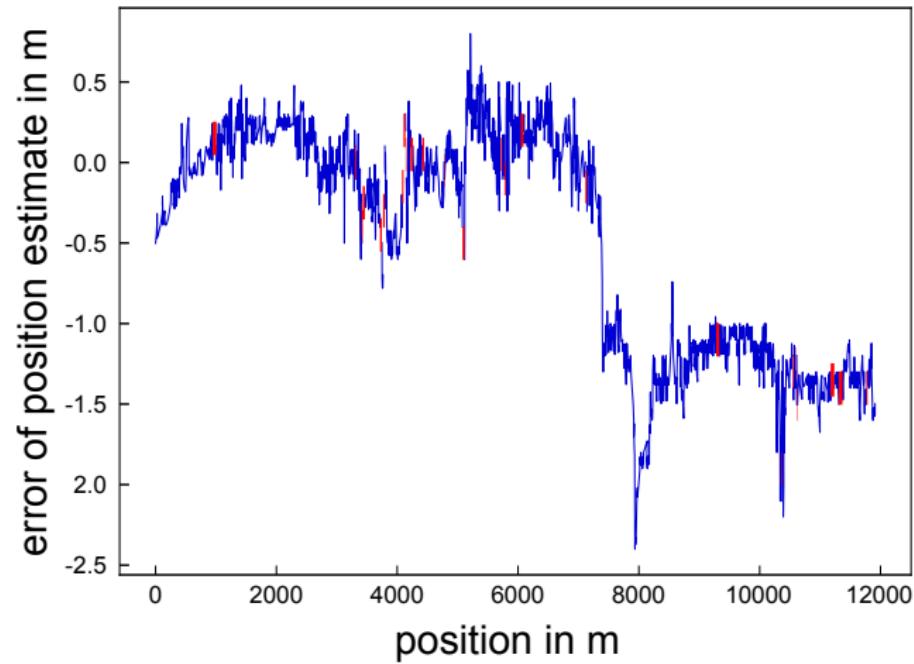
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Evaluation of Position Estimation

For each localization drive:

- localization error estimated at 2500 equally distributed points



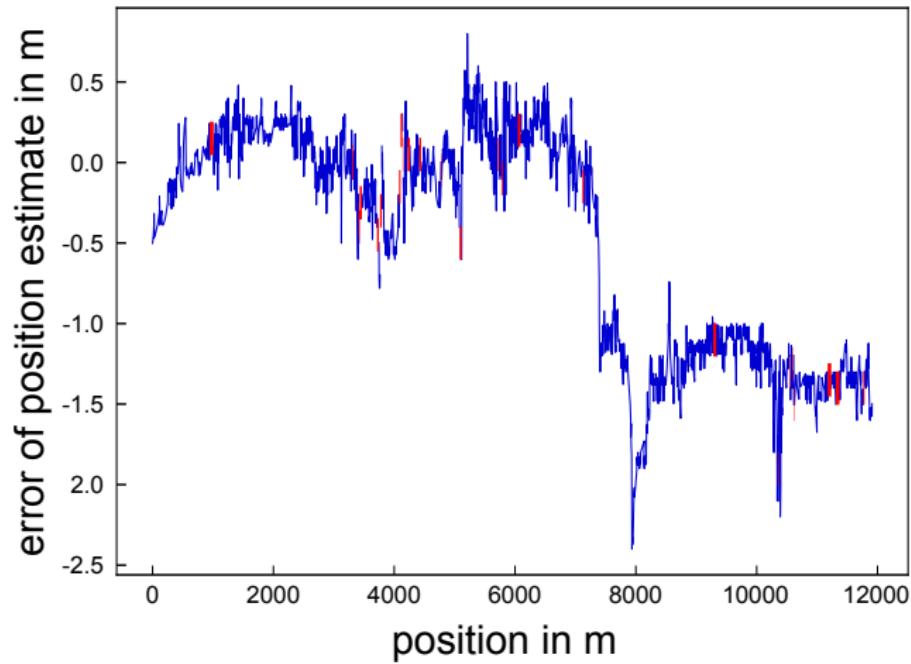
Evaluation of Position Estimation

For each localization drive:

- localization error estimated at 2500 equally distributed points

Two types of error:

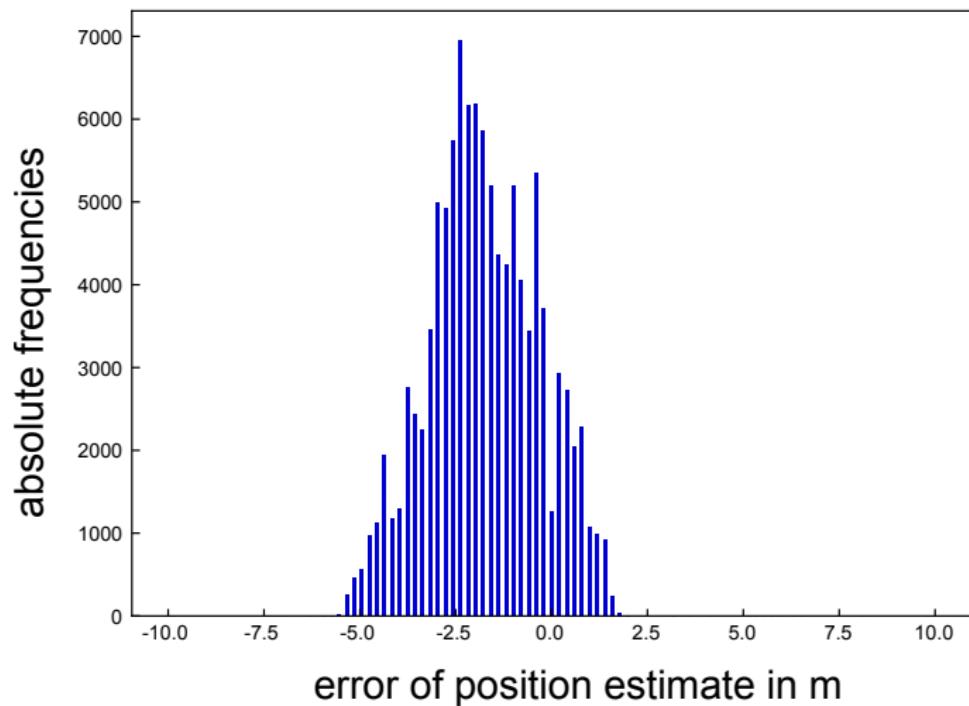
- small (< 10 m): synchronization with reference, imprecise mapping
- large: pattern mismatch, can be detected



Evaluation of Position Estimation

histogram of errors of all experiments

- almost Gaussian
- mean of -2.2 m due to synchronization with reference
- $95\% < 10\text{ m}$



Conclusion



localization without any changes
to existing infrastructure

Conclusion



localization without any changes
to existing infrastructure



method allows highly available and accurate
velocity ($97\% < 3 \text{ m/s}$) and position ($95\% < 10 \text{ m}$)

Conclusion



localization without any changes
to existing infrastructure



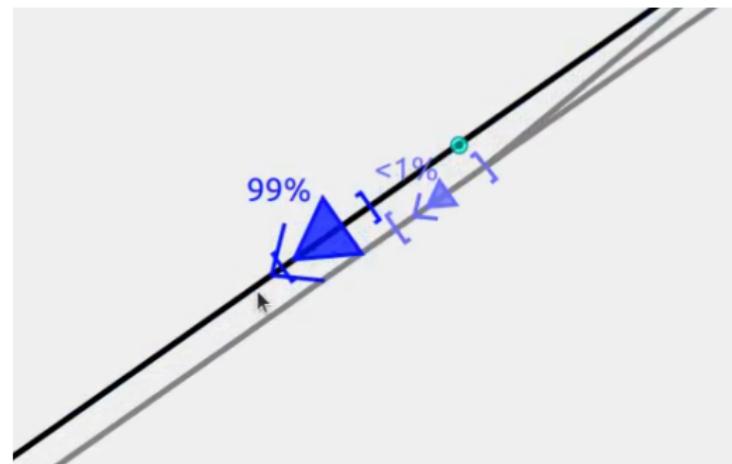
method allows highly available and accurate
velocity ($97\% < 3 \text{ m/s}$) and position ($95\% < 10 \text{ m}$)



high potential to improve existing systems

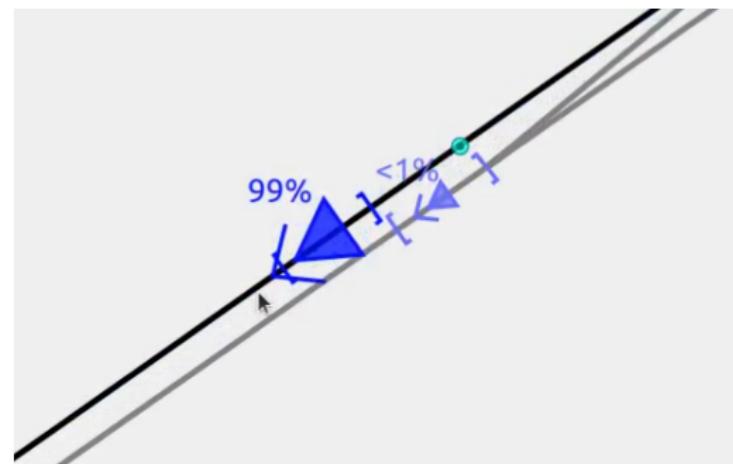
Work in progress

- combine velocity and position estimation



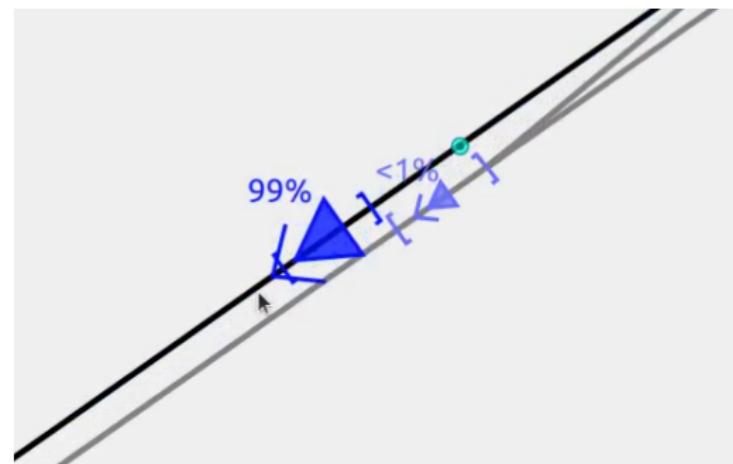
Work in progress

- combine velocity and position estimation
- combine both rails



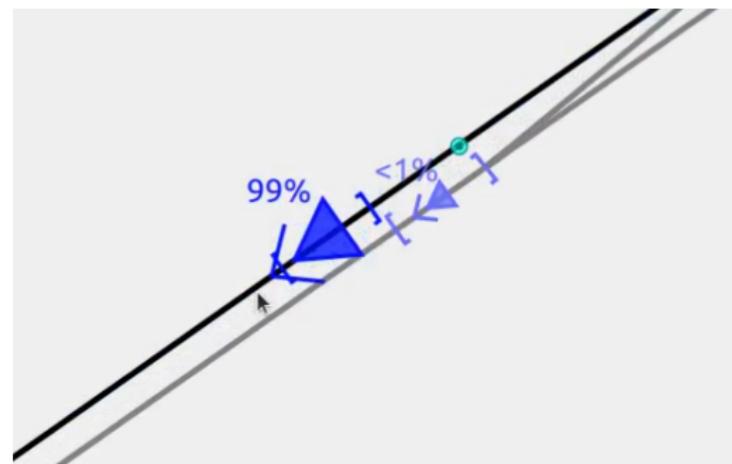
Work in progress

- combine velocity and position estimation
- combine both rails
- online processing

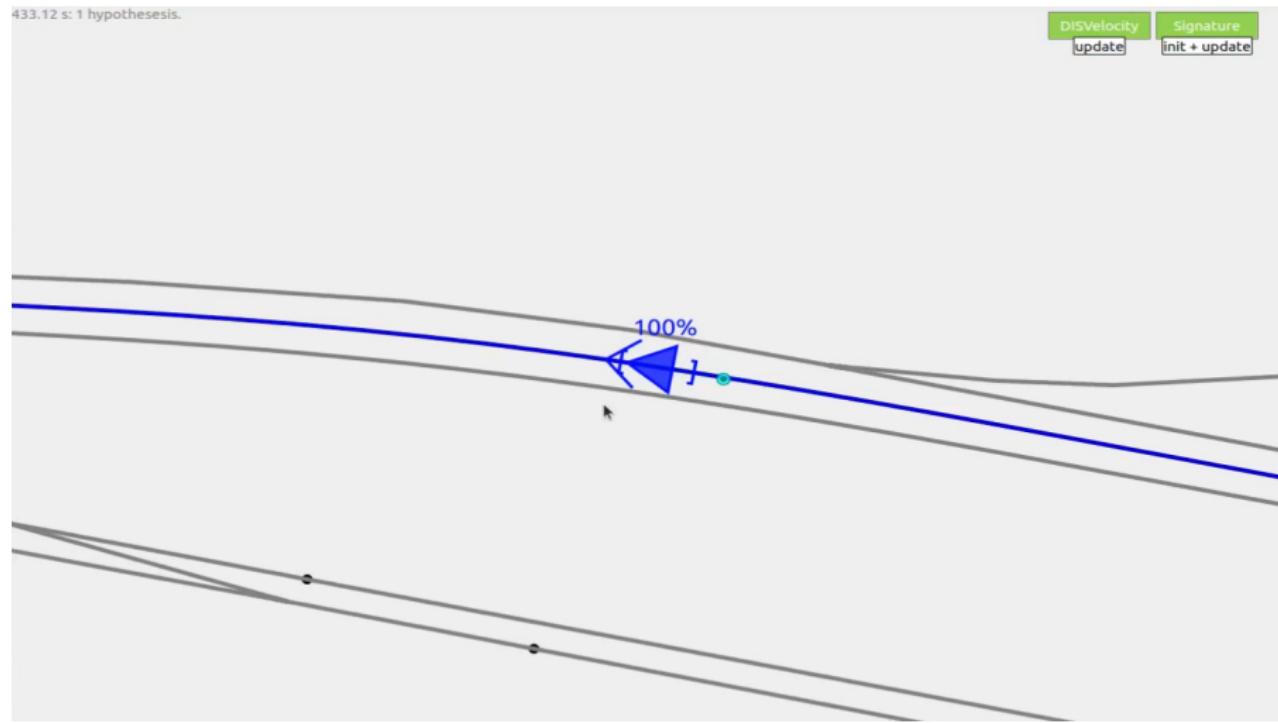


Work in progress

- combine velocity and position estimation
- combine both rails
- online processing
- long term stability of signatures



Demo



Thank you

