Sequential Data Fusion of GNSS Measurements with Map-Based Vision Systems

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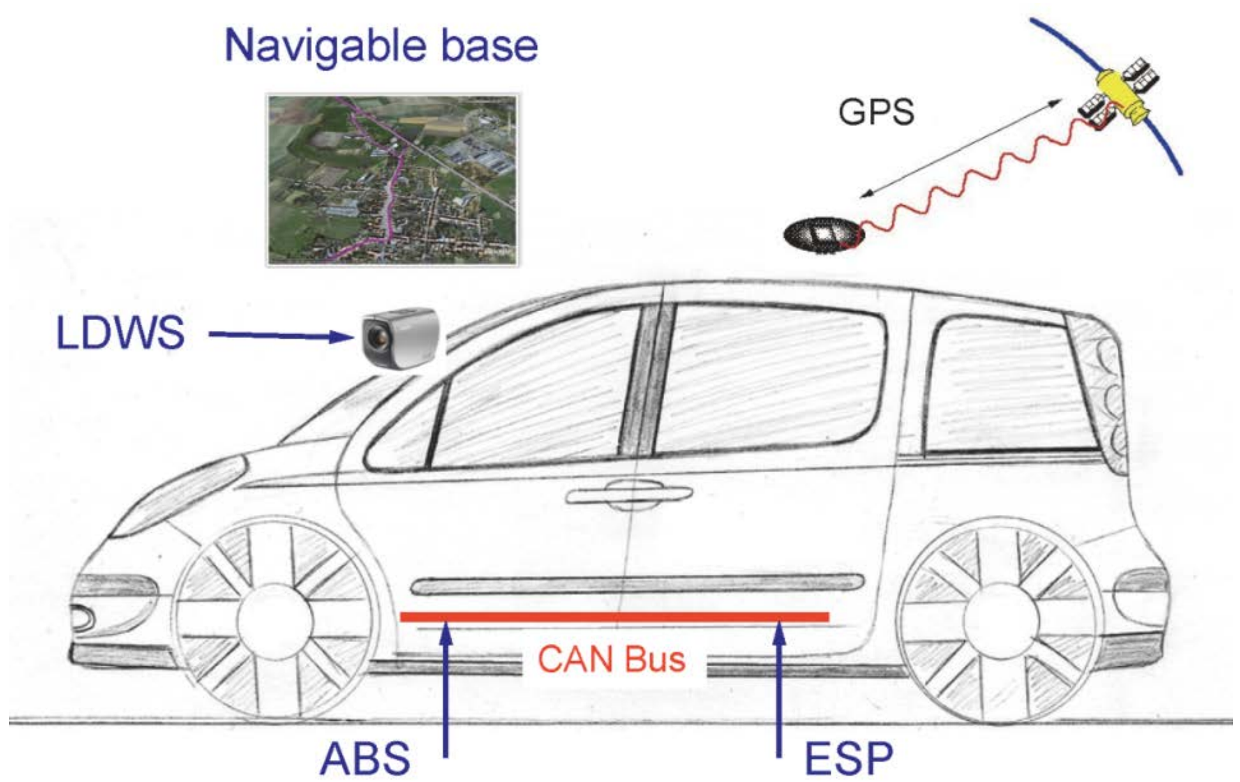
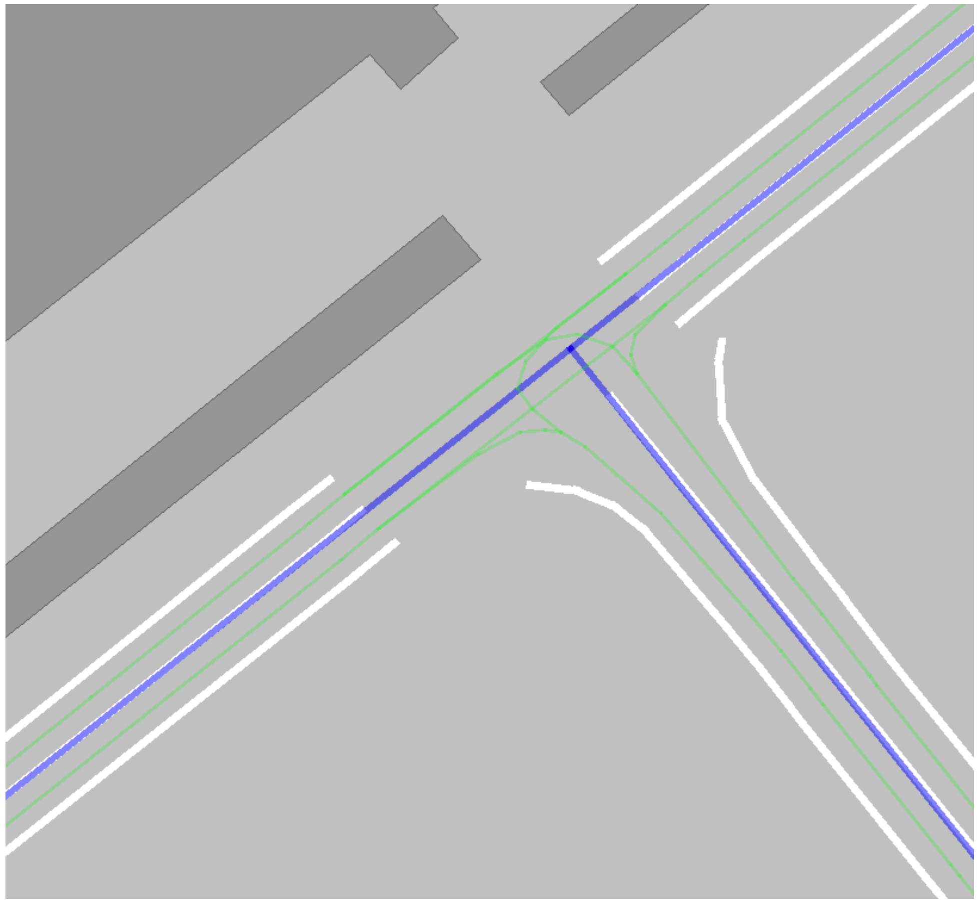
Objective and information sources

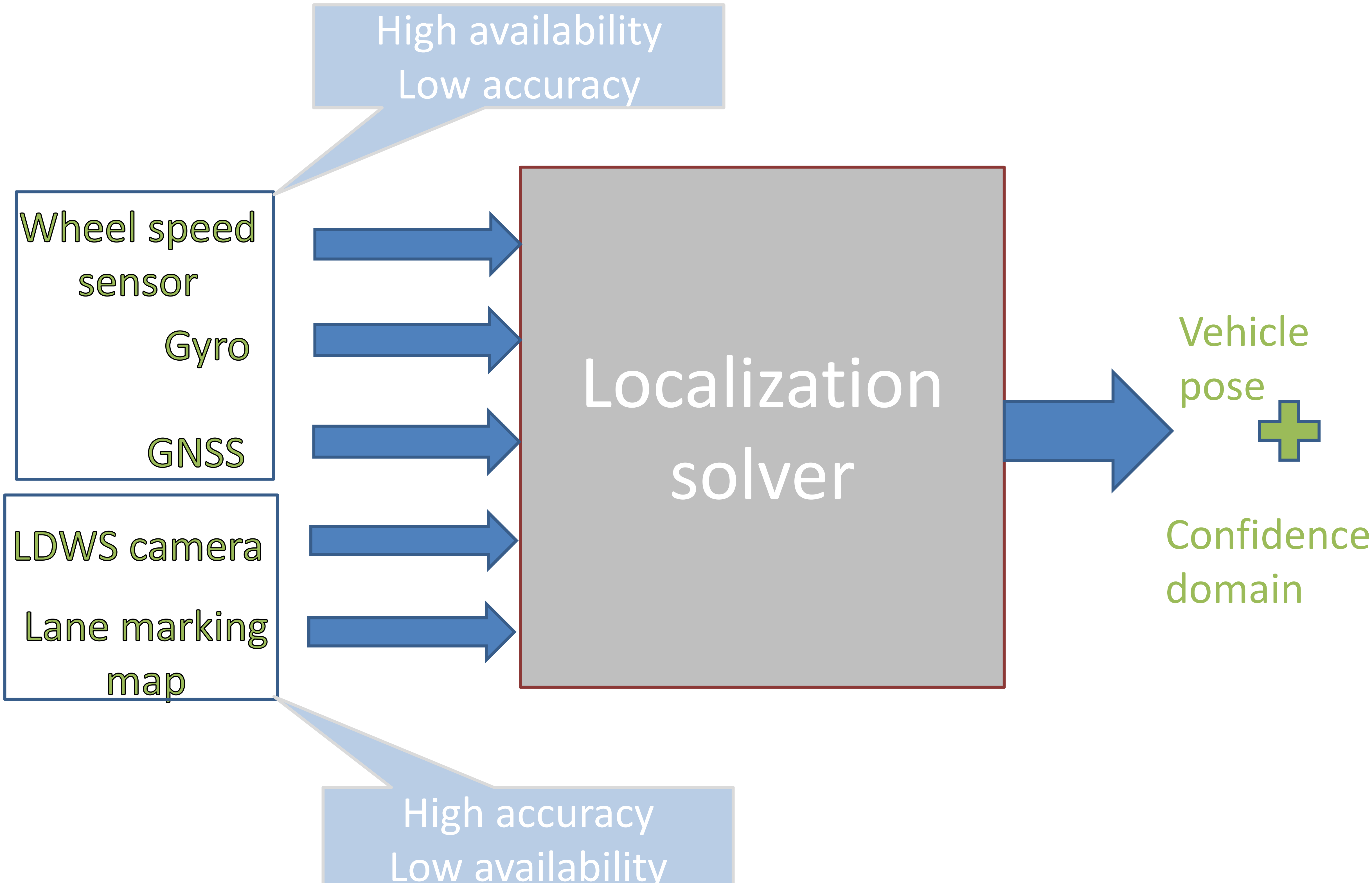
To achieve a localization system with high availability, high accuracy and high consistency with low cost standard automotive sensors to feedback autonomous navigation



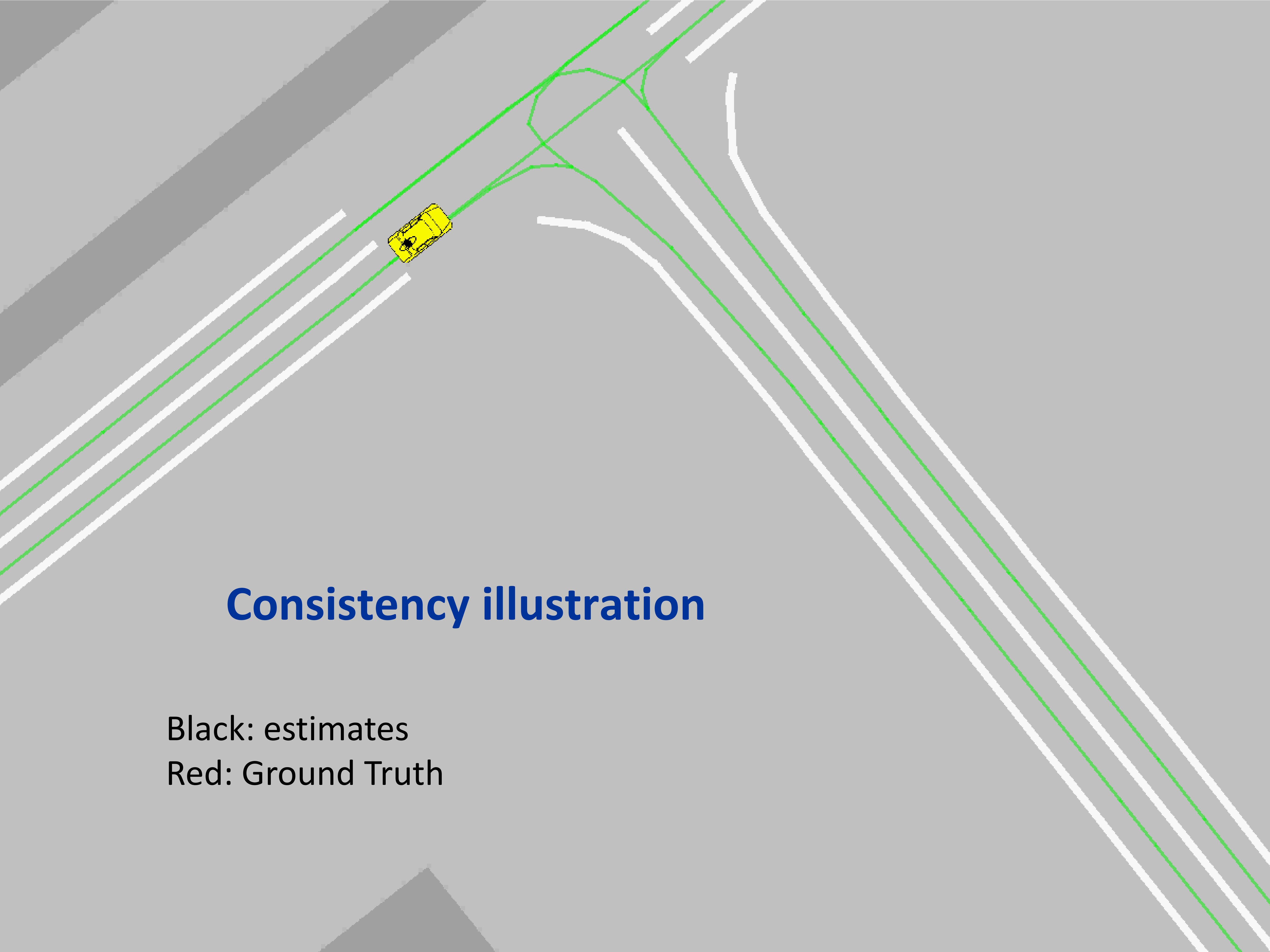


- Map-aided
- with a Lane Departure Warning System camera
- Lane markings accurately mapped

Data fusion problem

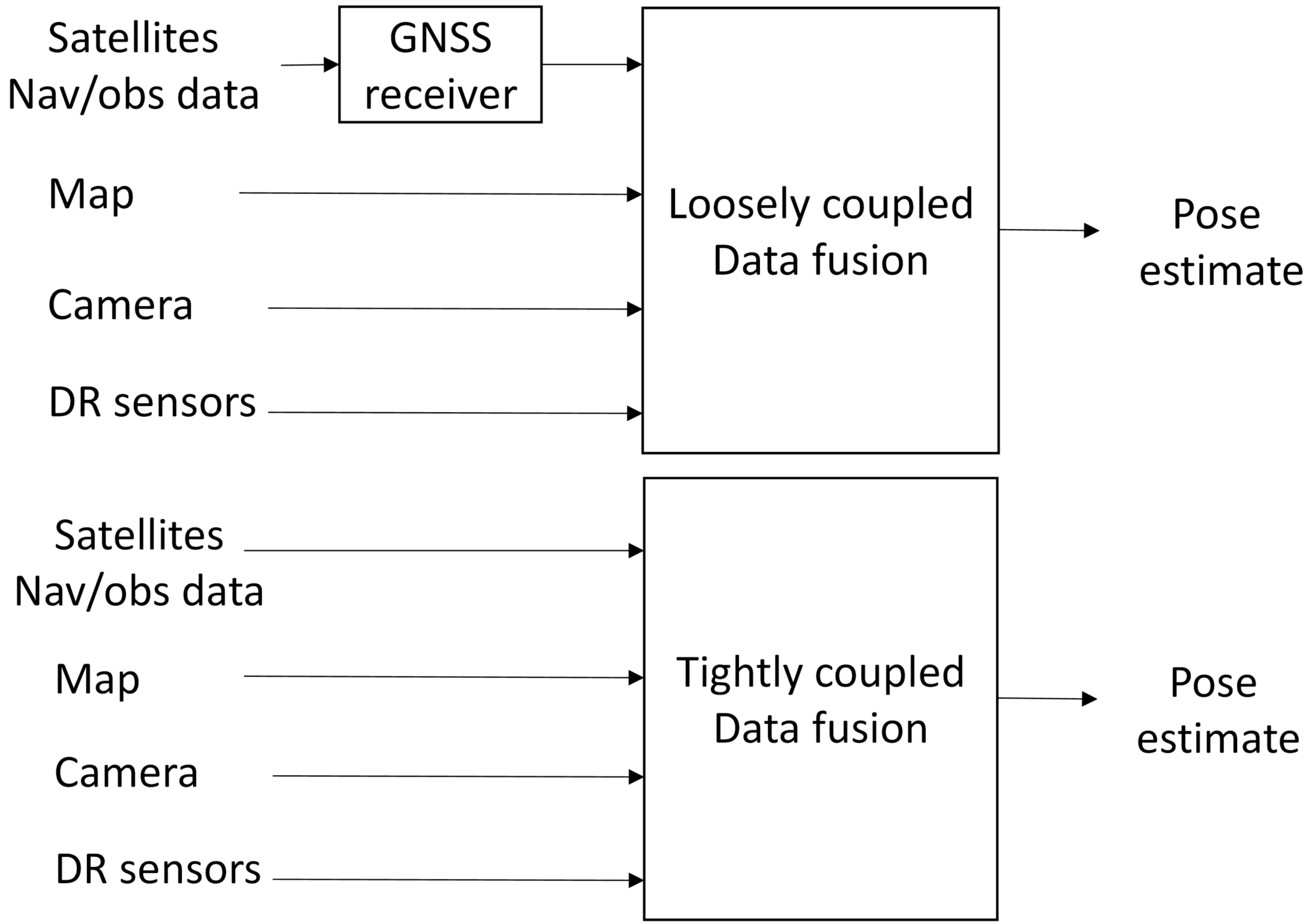


Consistency illustration



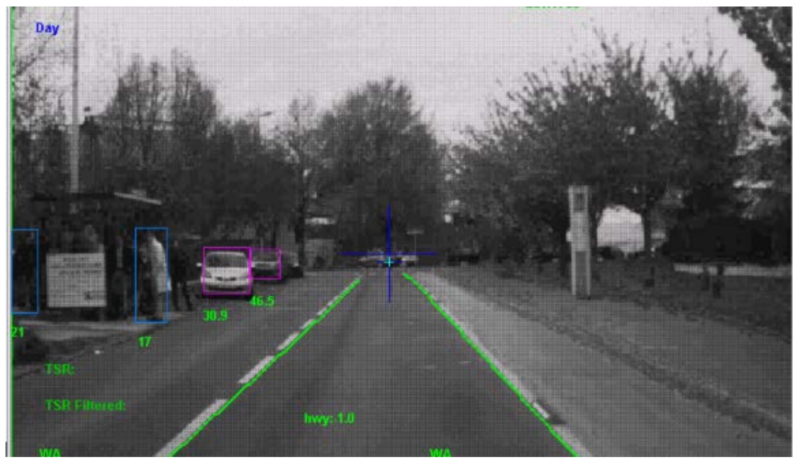
Black: estimates
Red: Ground Truth

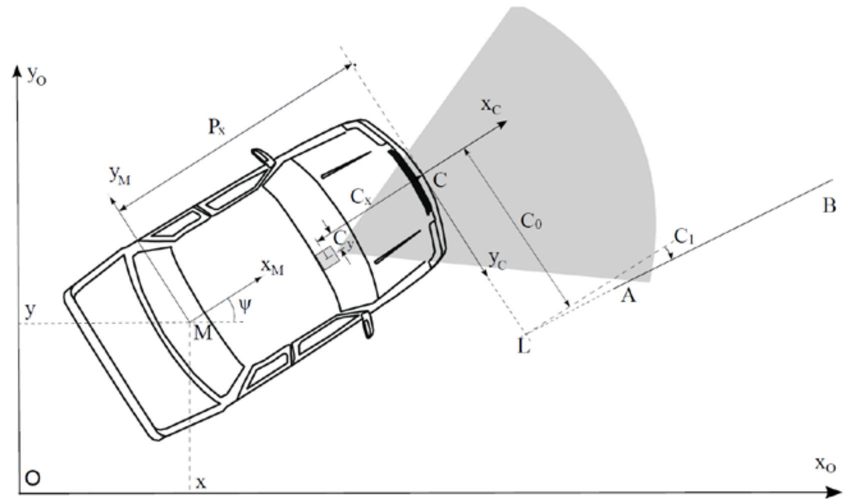
Strategies for the fusion of GNSS data



Camera observation model

Local measurements





Global map

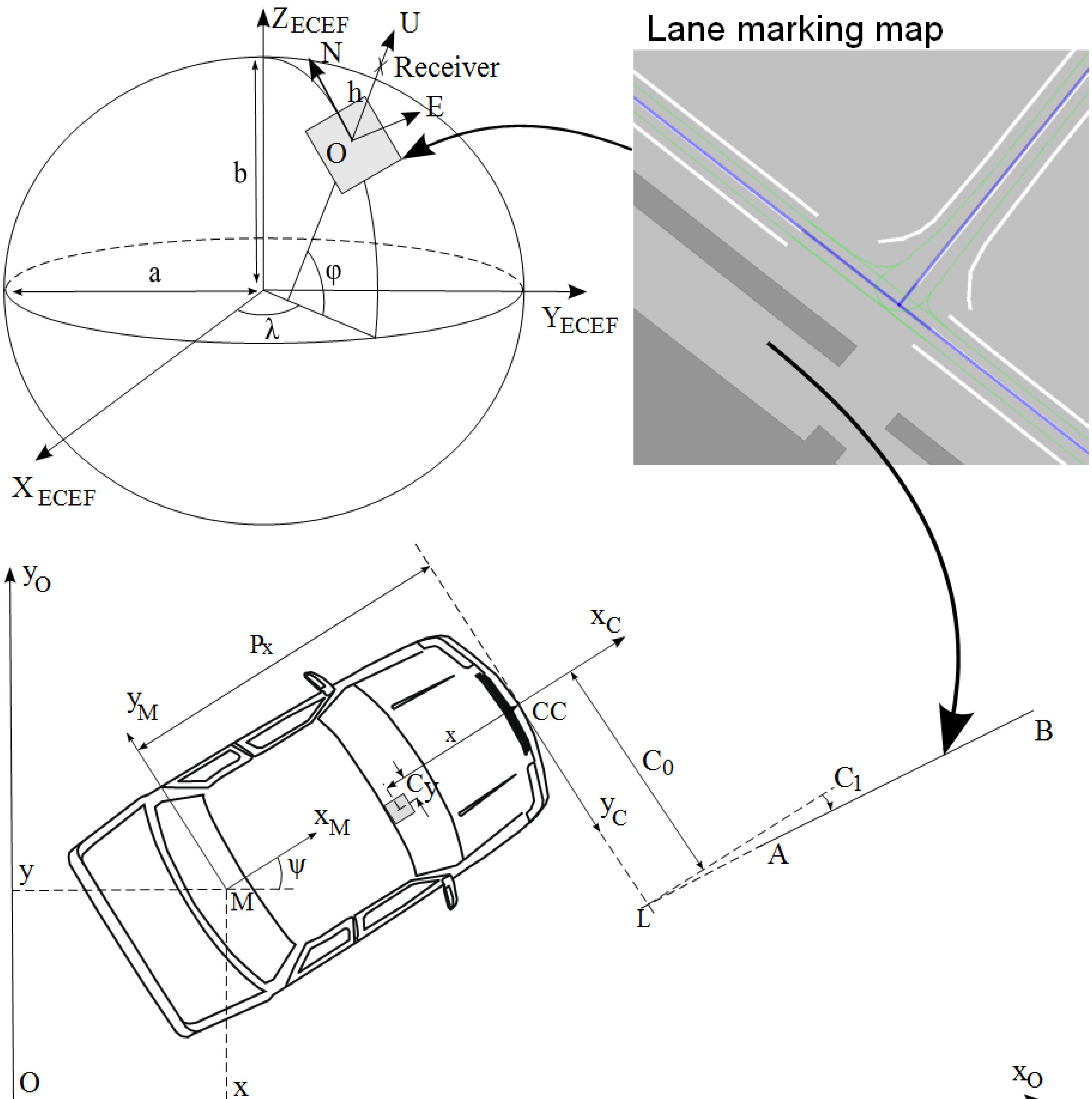
Map matching and
data association

$$C_0 = \frac{(P_x \cdot \sin\psi + y - y_A)\, x_{AB} - (P_x \cdot \cos\psi + x - x_A)\, y_{AB}}{x_{AB} \cdot \cos\psi + y_{AB} \cdot \sin\psi}$$

Frames

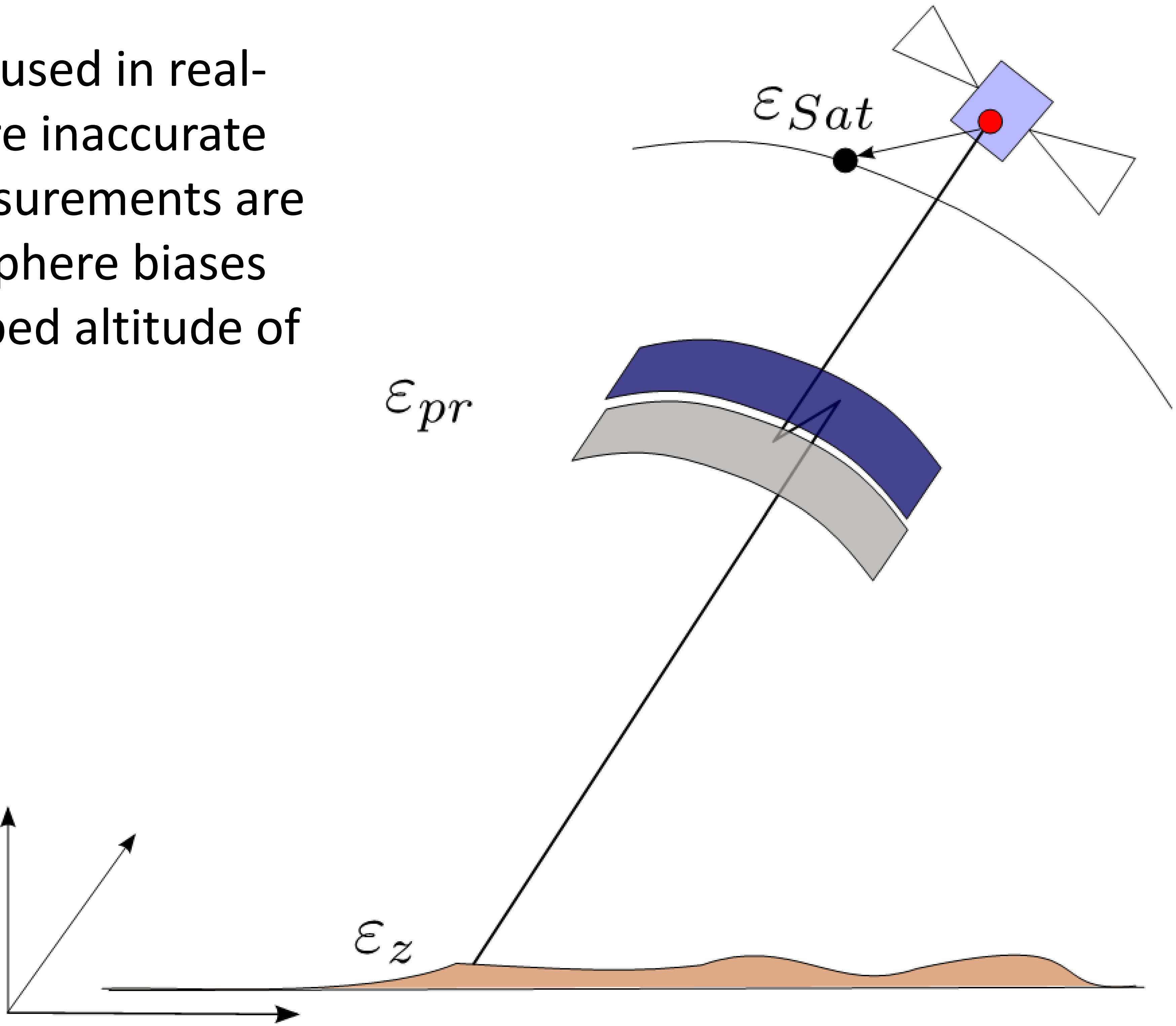
2D Pose vector

$$\mathbf{q} = (x, y, \psi)^T$$

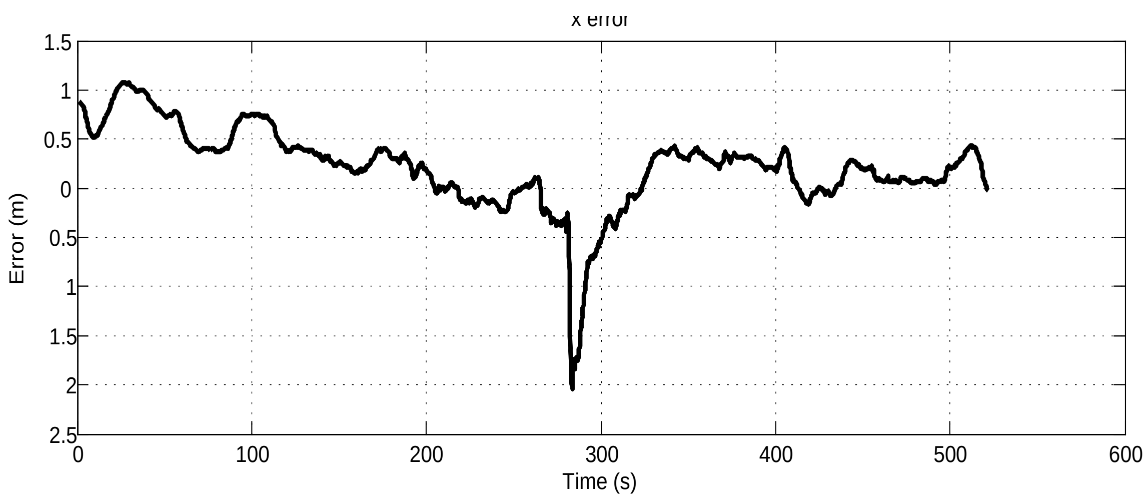


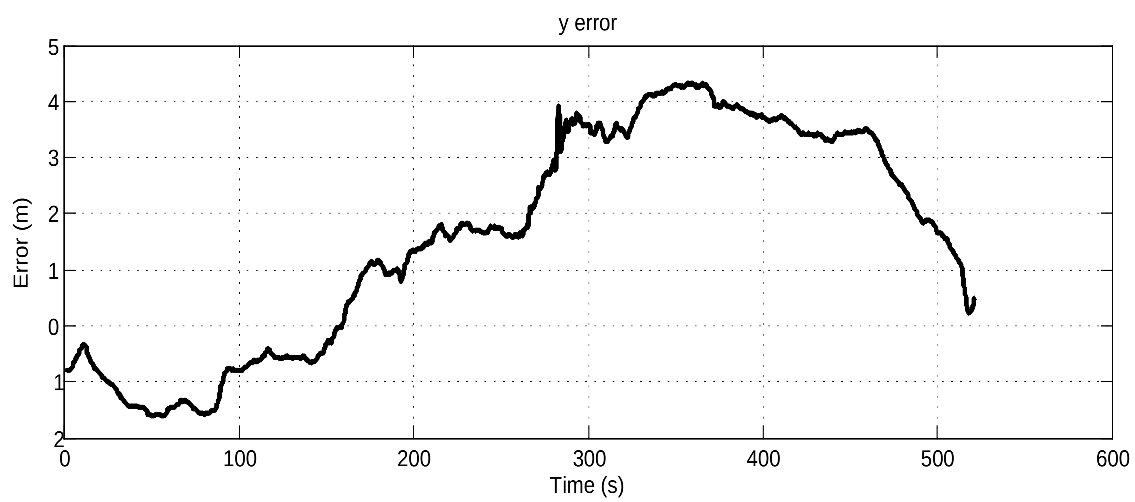
Range-error sources

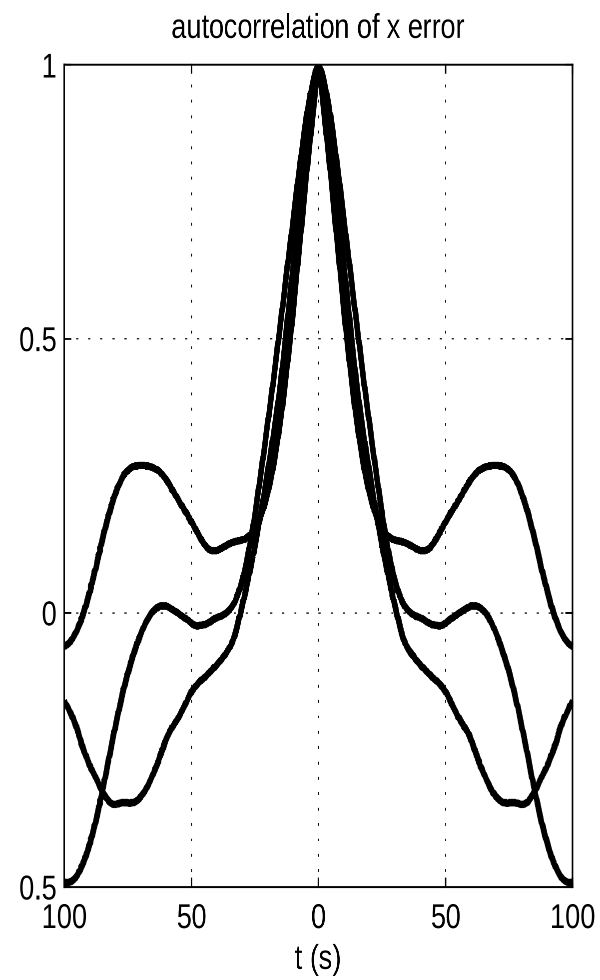
1. Satellite positions used in real-time ephemeris are inaccurate
2. Pseudorange measurements are affected by atmosphere biases
3. Errors in the mapped altitude of the road

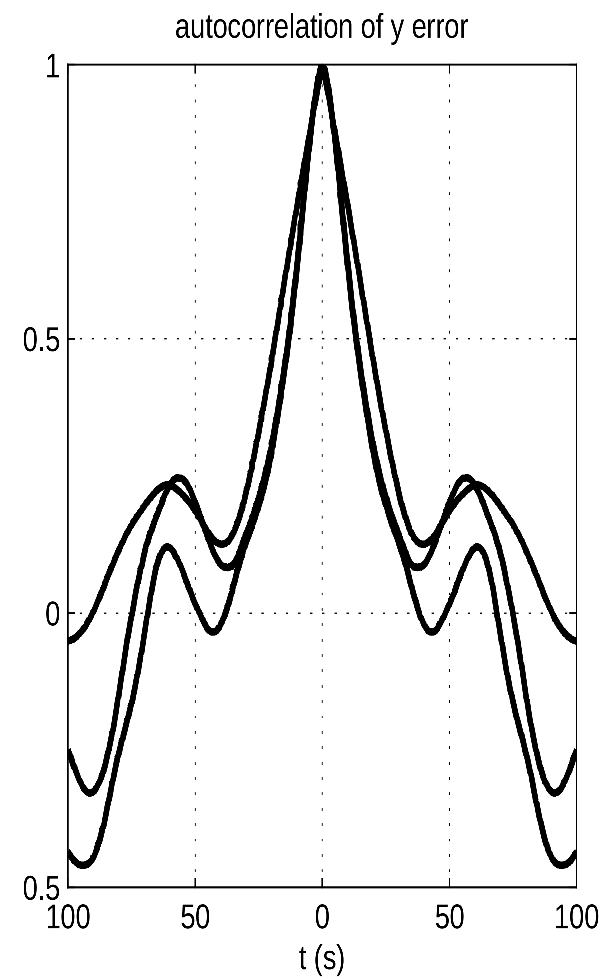


GNSS positioning errors are not white









Shaping filter

Pseudorange observation model

$$\rho^i = \sqrt{(x_a - x^i)^2 + (y_a - z^i)^2 + (z_a - z^i)^2} + c \cdot dt_u + \varepsilon^i + \beta^i$$

Receiver antenna

Satellite position

Receiver clock offset

White noise

Colored Range error

First-order autoregressive process driven by zero-mean white noise

$$\begin{cases} \varepsilon^i_{k+1} = \lambda \varepsilon^i_k + w_\varepsilon \\ \lambda = e^{-T/\tau_{pr}} \end{cases}$$

Doppler shift

Caused by the relative motion of the satellite with respect to the receiver antenna

Line Of Sight

$$\dot{\rho}^i = \left(\mathbf{v}_r - \mathbf{v}_s^i\right) \bullet u_{los}^i + c \cdot \dot{dt}_u + \dot{\varepsilon}^i + \beta_d^i$$

Receiver speed

Receiver clock drift

White noise

Satellite speed

$$\dot{\varepsilon}^i = -\varepsilon^i / \tau + \beta^{\varepsilon i}$$

Shaping Model of the error

Filter implementation

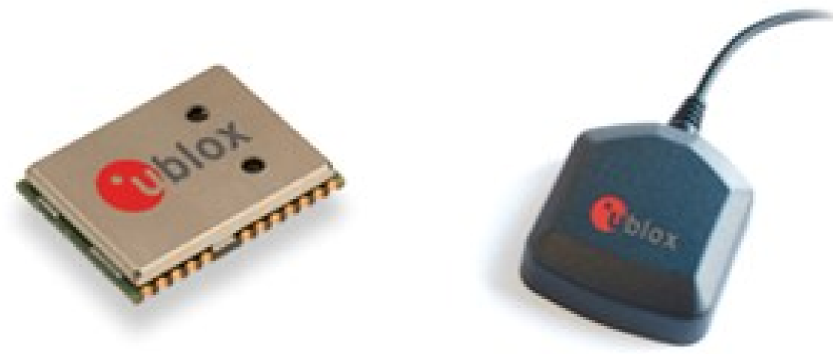
- ✓ The altitude of the GNSS antenna is extracted from the map
- ✓ We use Wieser's model to estimate the variance of the pseudorange error
- ✓ CAN-bus gateway was used to access the wheel speed sensors and the yaw rate gyro
- ✓ State vector:

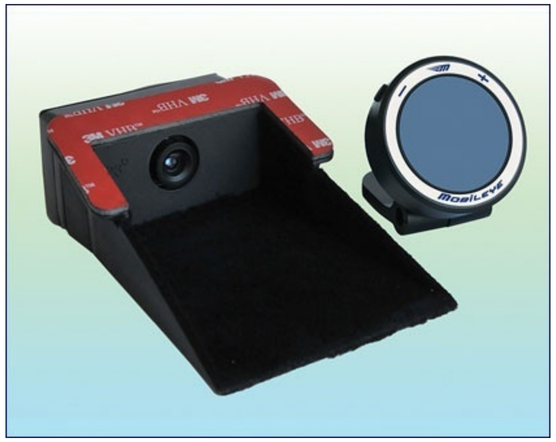
$$\mathbf{x} = \left[x, y, \psi, \underbrace{\varepsilon_\omega}_{\text{Gyro bias}}, d, \dot{d}, \underbrace{\varepsilon^1, \quad \cdots \quad, \varepsilon^n}_{\text{Satellites errors}}\right]^T$$

- ✓ Outlier rejection (e.g. multipath)
  - ✓ Test the Dopplers and then the pseudoranges at every estimation stage.
- ✓ The estimation process has correlated noises ➔ EKF with correlated noise

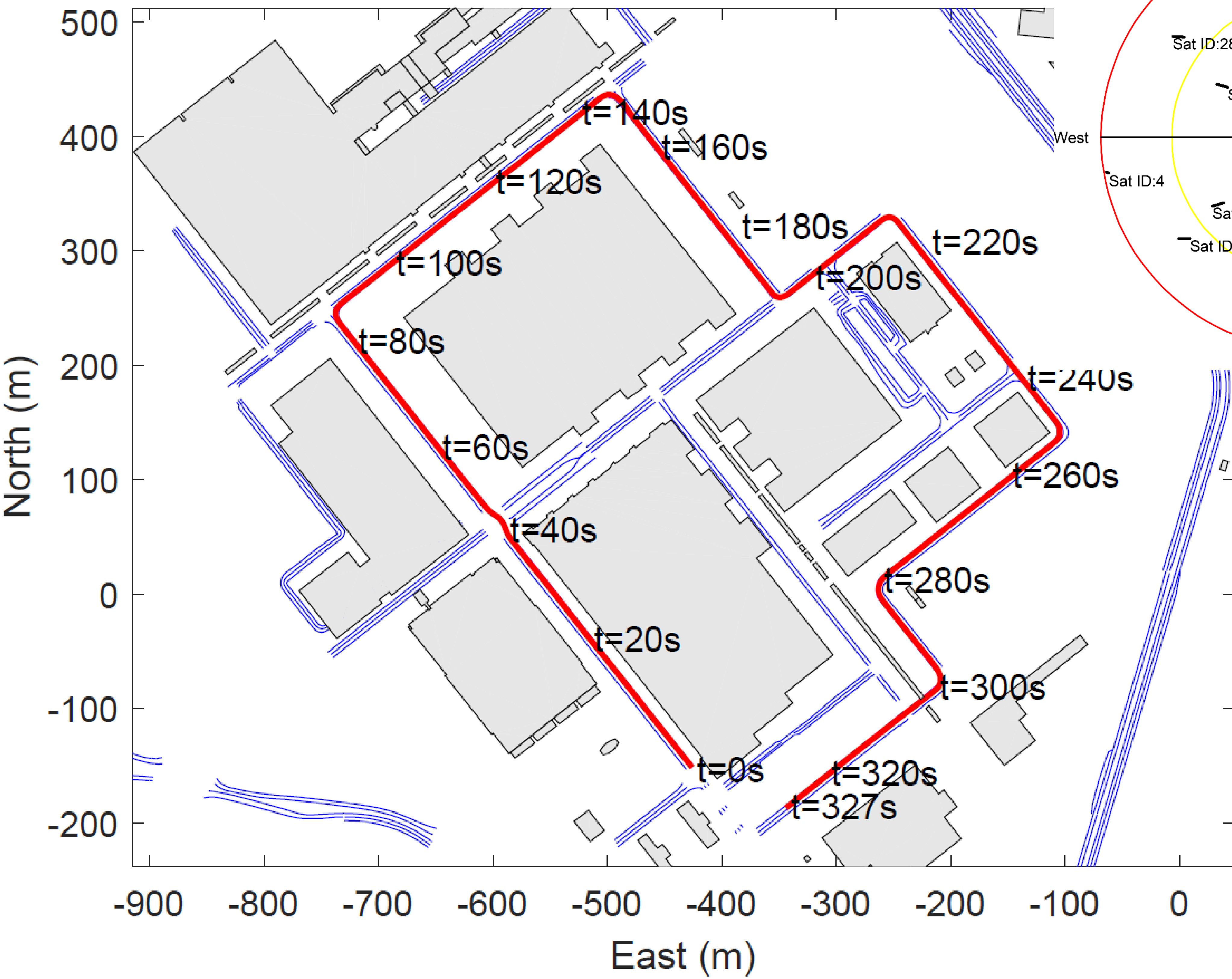
Experimental setup

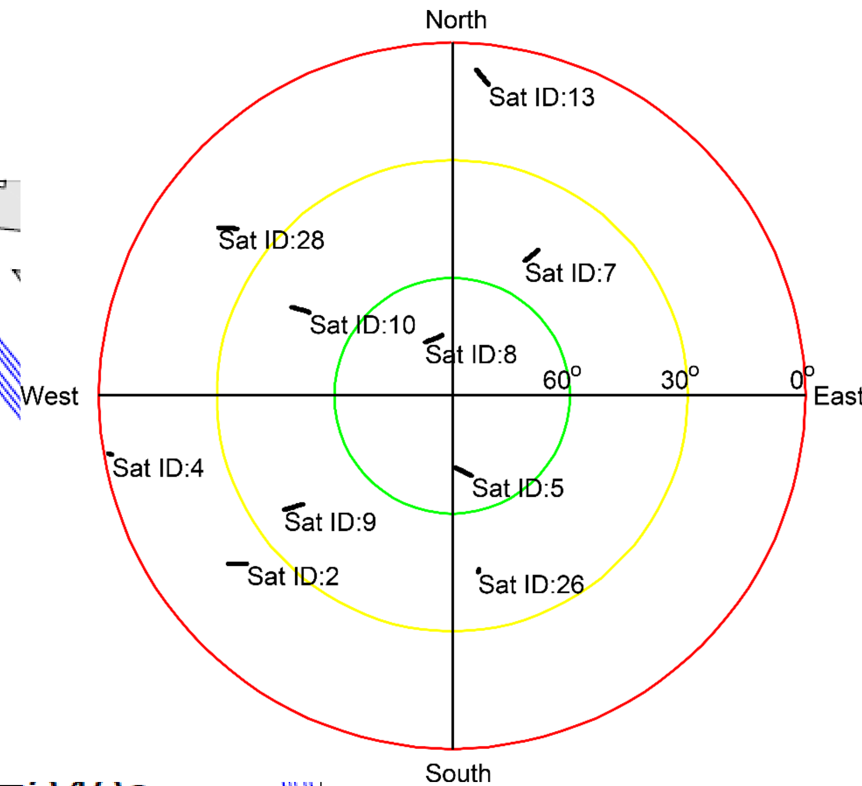
- Experimental vehicle: Renault Fluence ZE
- GPS: U-Blox 6T receiver
- Camera: MobilEye
- Ground truth: IMU Oxford RT3000
- 3 tests carried out in urban conditions
  - Speed : 10m/s
  - 3 Km long



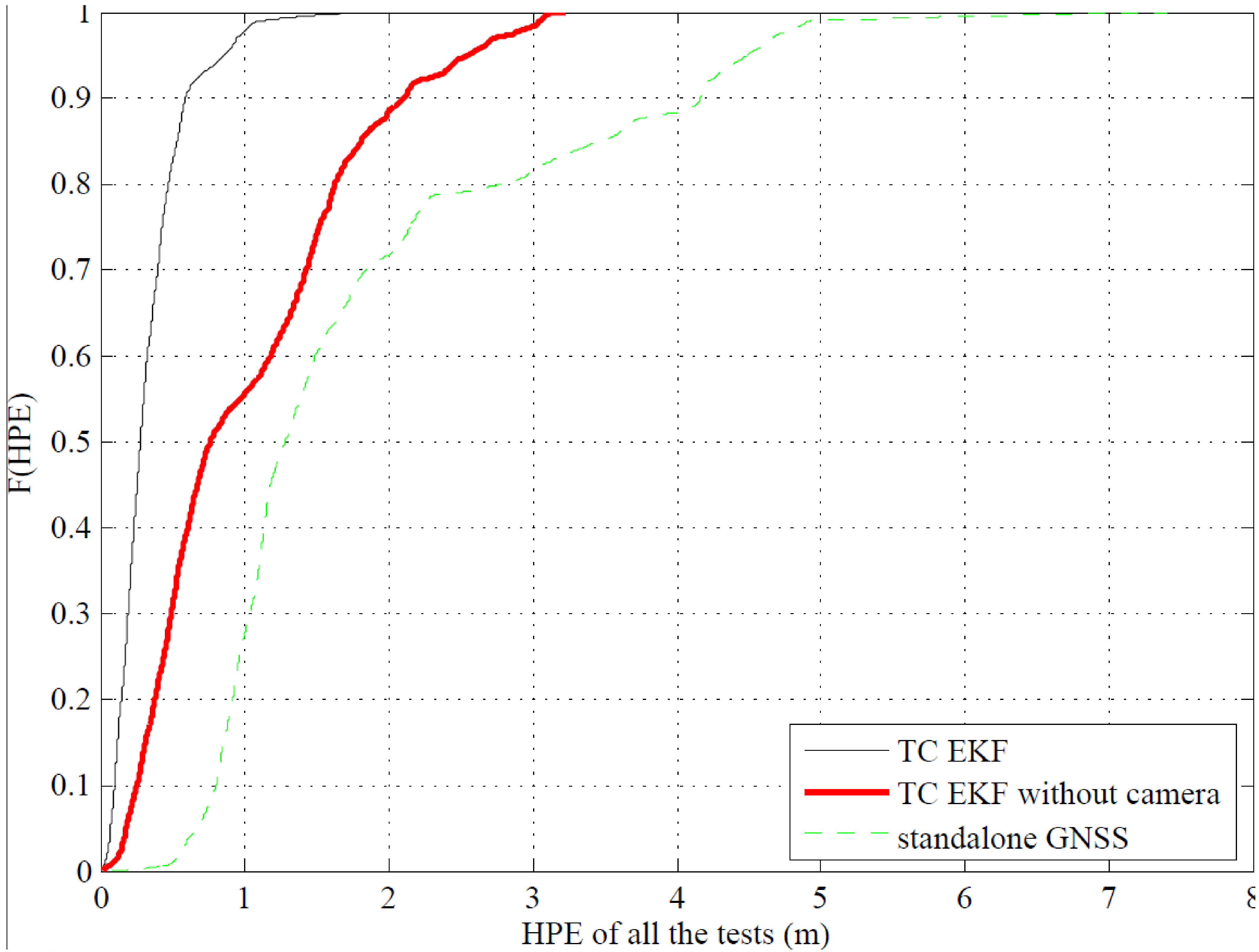


Test area

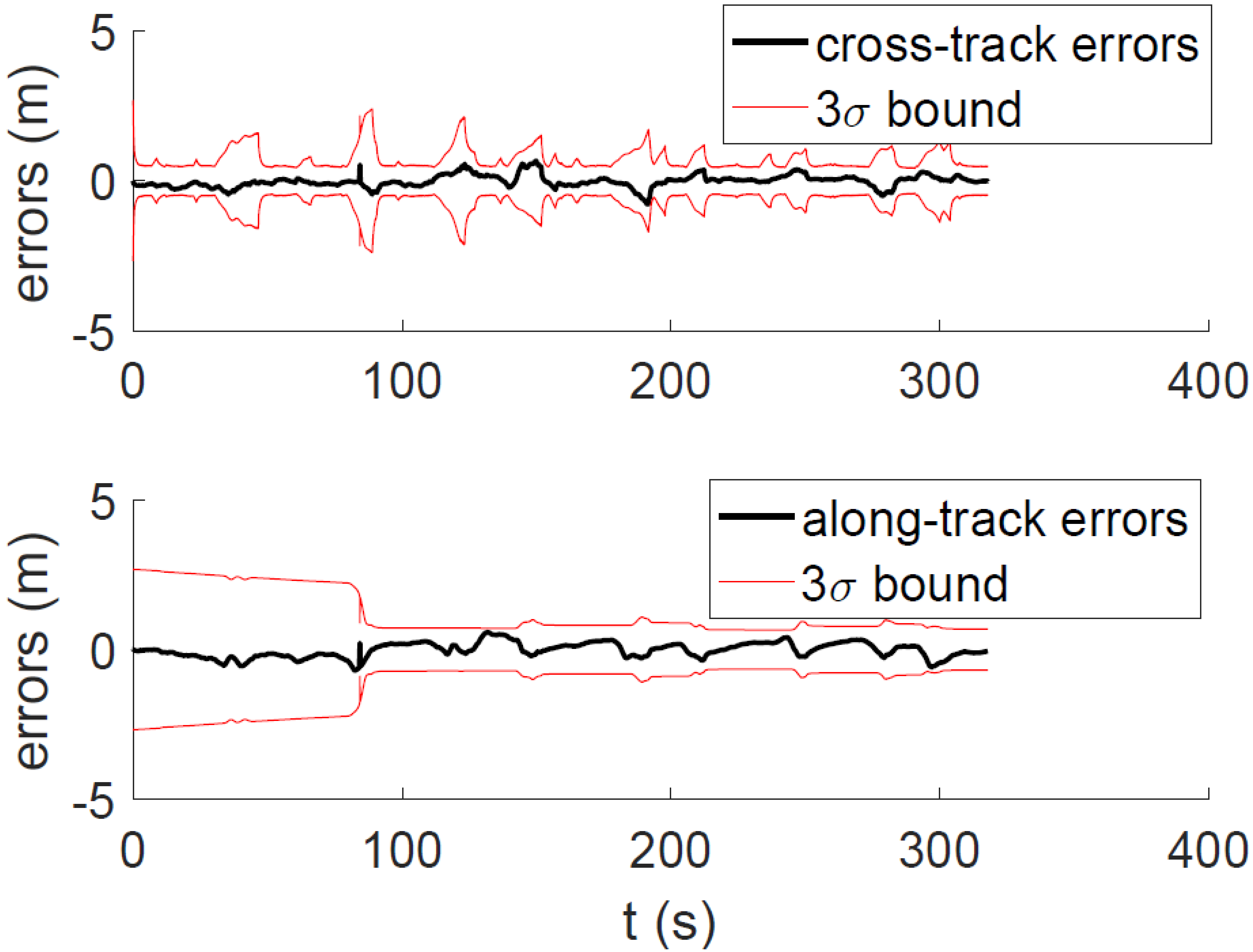

t=0s
t=20s
t=40s
t=60s
t=80s
t=100s
t=120s
t=140s
t=160s
t=180s
t=200s
t=220s
t=240s
t=260s
t=280s
t=300s
t=320s
t=327s
North (m)
East (m)


North
South
West
East
Sat ID:13
Sat ID:28
Sat ID:7
Sat ID:10
Sat ID:8
Sat ID:4
Sat ID:5
Sat ID:9
Sat ID:2
Sat ID:26
60°
30°
0°

Cumulative distribution functions of errors

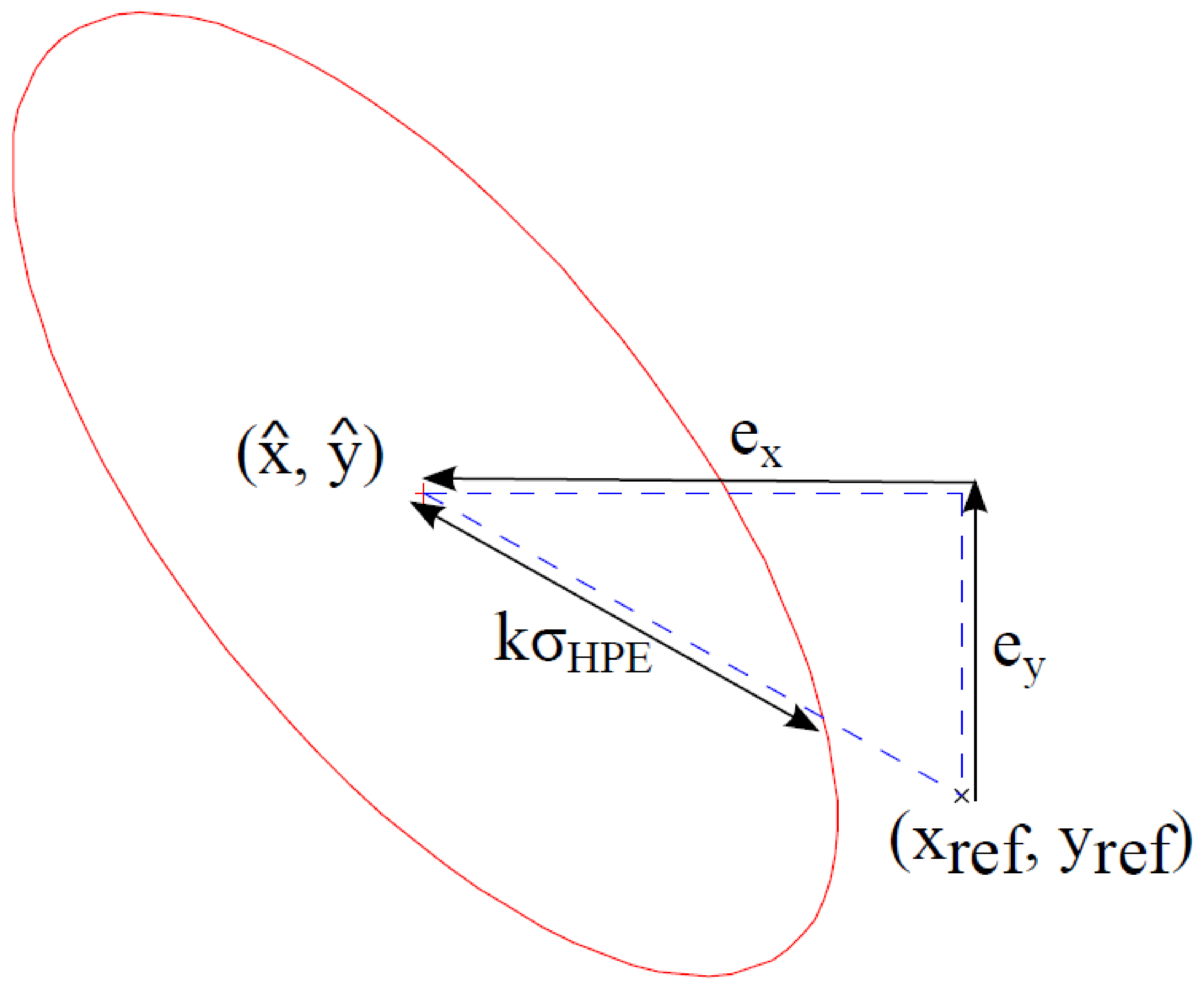


Errors + confidence bounds

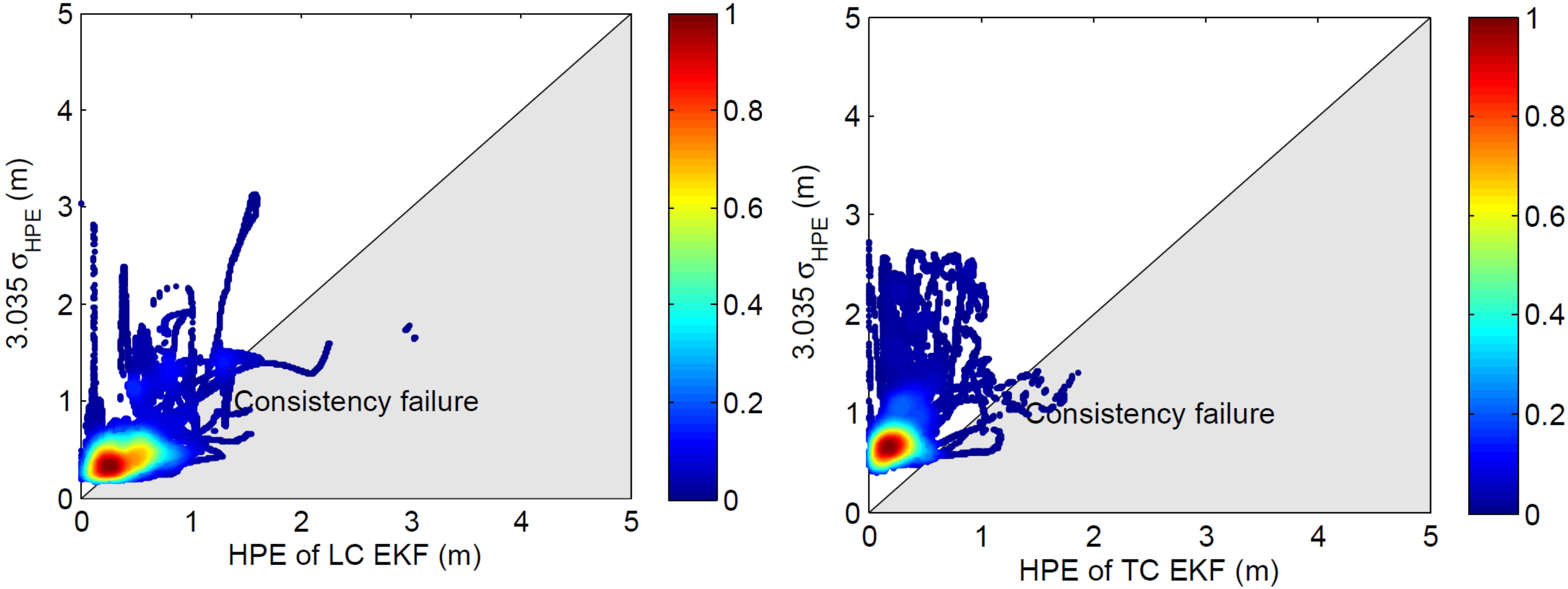


Consistency

- Bayesian state filtering is often overconfident
- To examine the consistency of the horizontal positioning error, one usually looks at the percentage of samples exceeding a determined threshold
- Standard deviation along the horizontal positioning error vector



Consistency plots (simplified Stanford diagrams)



TC EKF is clearly more consistent, as the density of the points is above the first bisector

TC EKF provides a better estimate of confidence

Conclusion

A method to merge raw GNSS measurements and lane marking measurements detected by a camera

Close-to-market sensors for autonomous vehicle navigation

The tightly coupled method is the better method when the vehicle is traveling in complex GNSS environments with satellite outages and multipath because:

- The filter is able to function with very few satellites
- It is better at excluding raw satellite measurements contaminated by multipath.

In good GNSS environments, the loosely coupled method may be adequate if the requirements in terms of accuracy and consistency are less stringent.

Thank you for your attention!

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