



Localization Integrity for Intelligent Vehicles: How and for what?

Philippe Bonnifait

Professor at the
Université de Technologie de Compiègne, Alliance Sorbonne Université
Heudiasyc UMR 7253 CNRS, France

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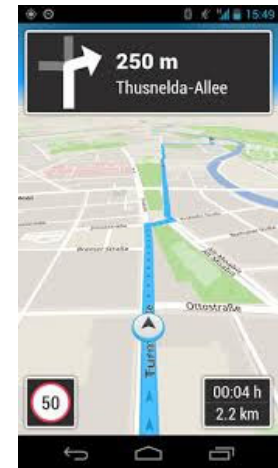


Localization for what?

A localization system enables a vehicle to reach a destination, usually far away.

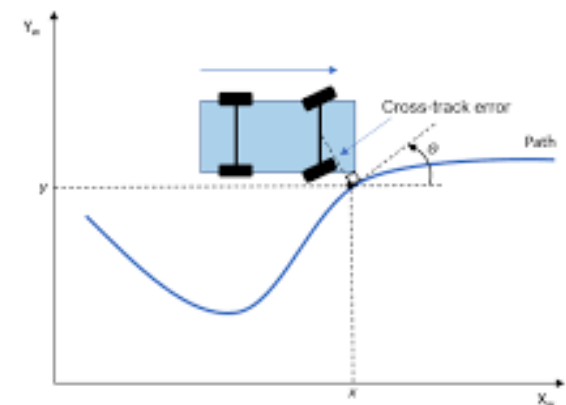
GPS navigator:

- Turn by turn navigation
- Here, localization is used at the strategic and tactical level (for maneuvers)



We also know that with an accurate localization we can control a vehicle

- Path following, etc.



Localization for Autonomous Driving

In theory:

- A vehicle could navigate with only a perception system that would understand everything about its surroundings

In practice:

- We are far from this!

Something everyone knows:

- We navigate more efficiently on roads we have already traveled thanks to the geospatial knowledge of the environment

Localization and maps are a way to simplify navigation tasks

- Maps facilitate situation understanding
- Localization is a way to increase perception beyond the sensors' field of view, in hidden areas or in degraded conditions with cooperative systems

Localization Integrity

Localization has to be

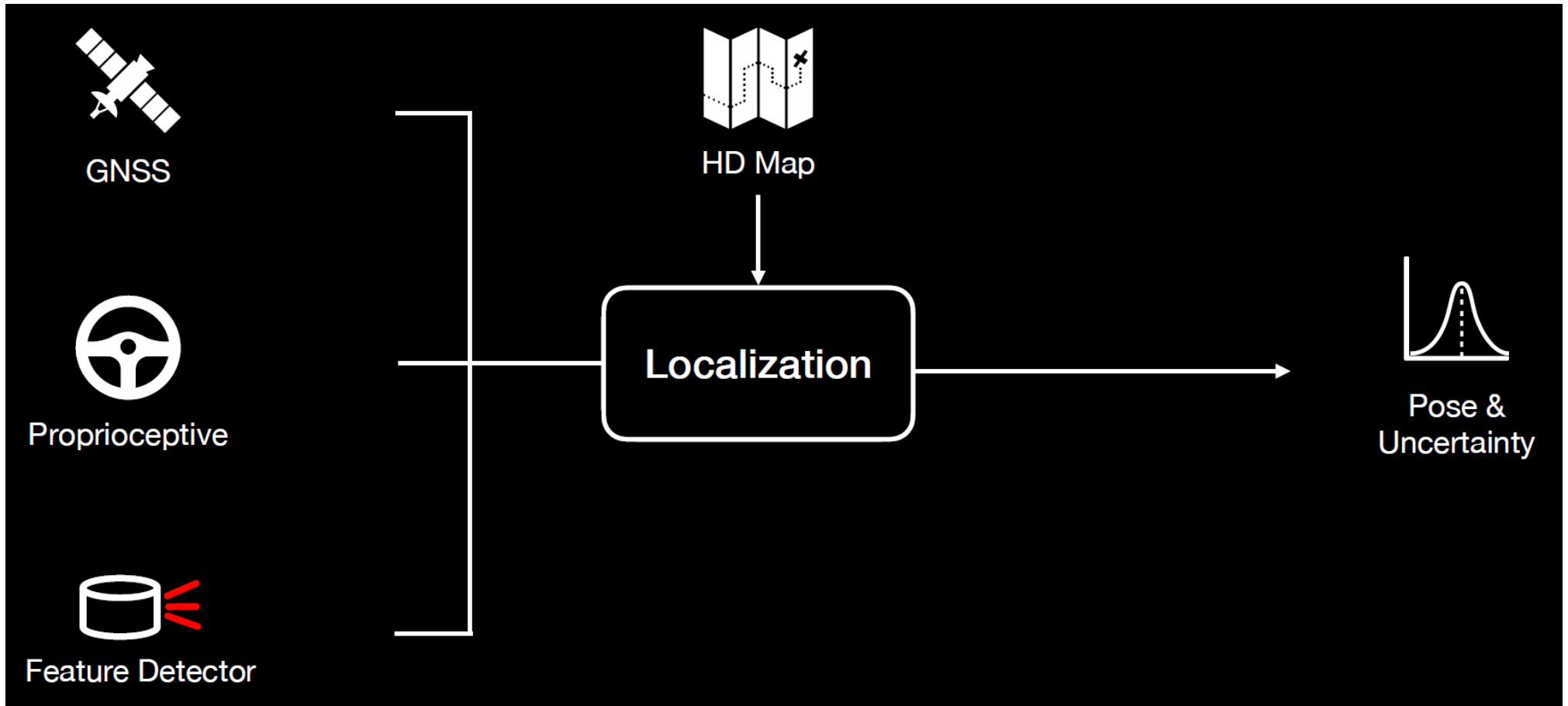
- Accurate enough for the tasks to be performed
- Available at a sufficiently high rate
- Non-misleading and Trustworthy
 - Integrity monitoring in real-time

This integrity monitoring depends on the use of the localization information and therefore on the navigation tasks to be performed.

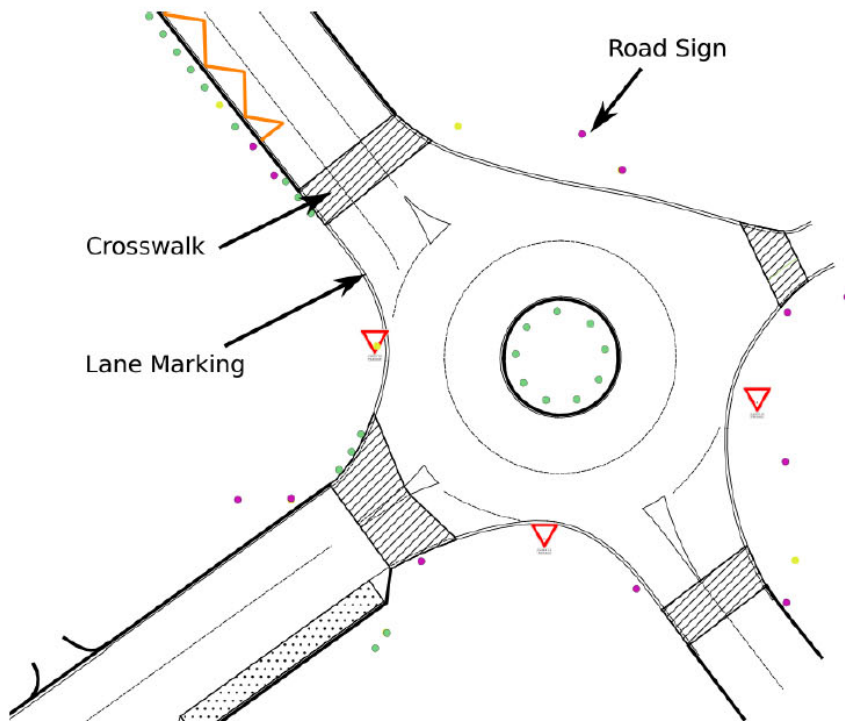
Outline

1. Typical architecture
2. Integrity concepts and estimation error bounds
3. Sequential data fusion for high-integrity localization
 - Application to multi-lane camera measurements
4. HD map validation and errors detection
5. Integrity for cooperative systems

Typical Architecture



Map-aided localization



The concept of integrity

The information delivered by a system is non-misleading if it is of higher (or equal) quality to what is expected to successfully perform the navigation task

Integrity is intended to serve as a **real-time decision-making**

— for the use or non-use of the system

A high integrity system is a system that provides miss-leading information with a very low rate

— The probability of hazardous situations (that would possibly put at risk human lives) is in general very small (e. g. 10^{-6})

Integrity Failure Risk

Integrity Failure

- The system does not raise an alert while the error is above the allowed Alert Limit (AL)

Integrity Failure Risk

$$\Pr(e > AL \text{ without Alert}) = IR$$

- It is hard to compute, especially if the AL thresholds change

Classical solution:

- to bound the estimation error with a Protection Level (PL)

Integrity in terms of error bounds

A Protection Level (PL) is a statistical bound of the error

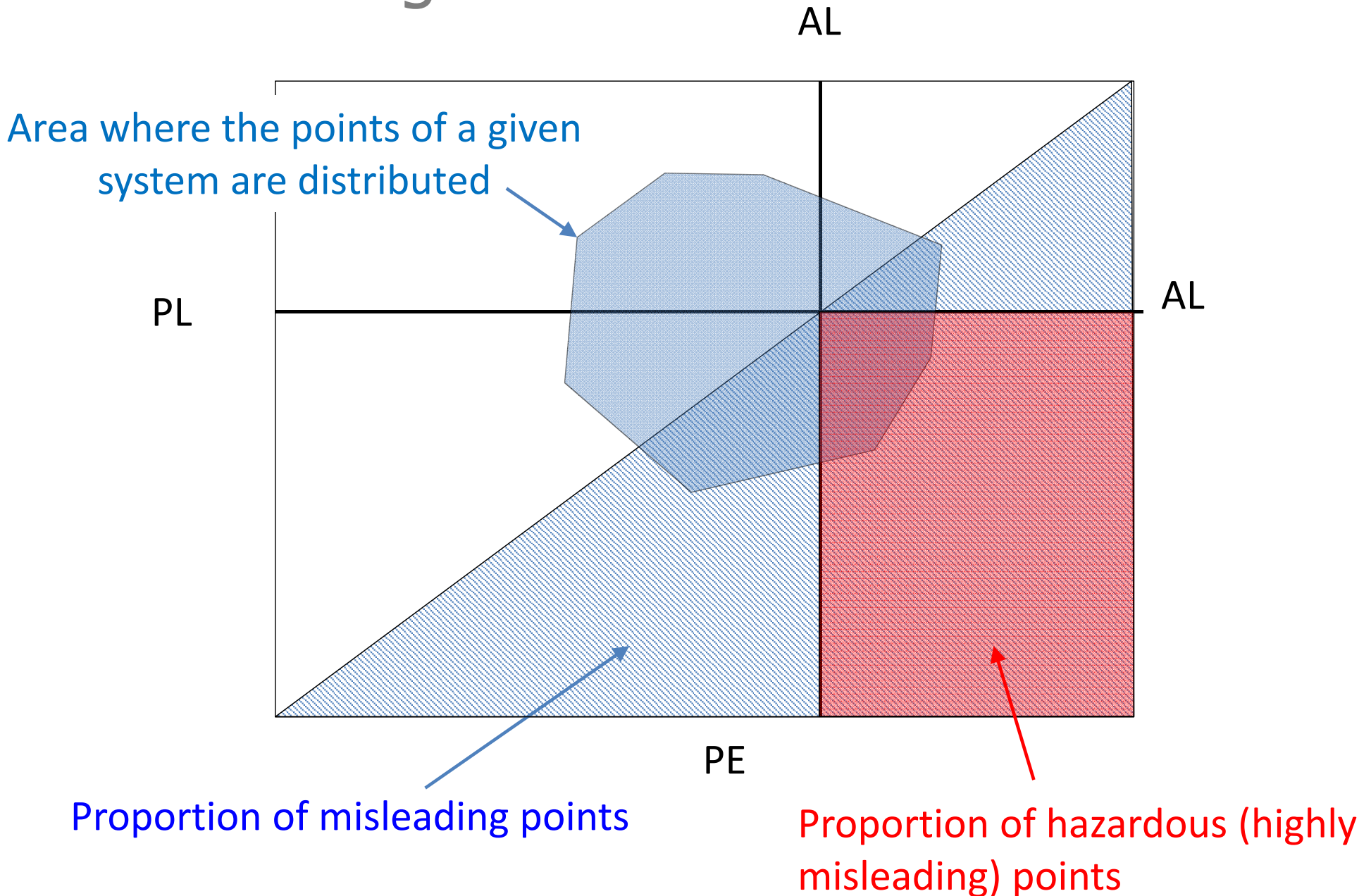
A Target Integrity Risk (TIR) is defined by the application

— The TIR is used to tune the parameters of the models and the filters to compute the PL in real-time

A system is considered as satisfying the integrity requirement at a given TIR , if

$$\Pr(e > PL(TIR)) \leq TIR$$

Stanford Diagram



Common practice

The proportion of points in the read area is difficult to compute, but:

If

One designs an integrity monitoring system that respects the integrity risk for a given TIR

Then

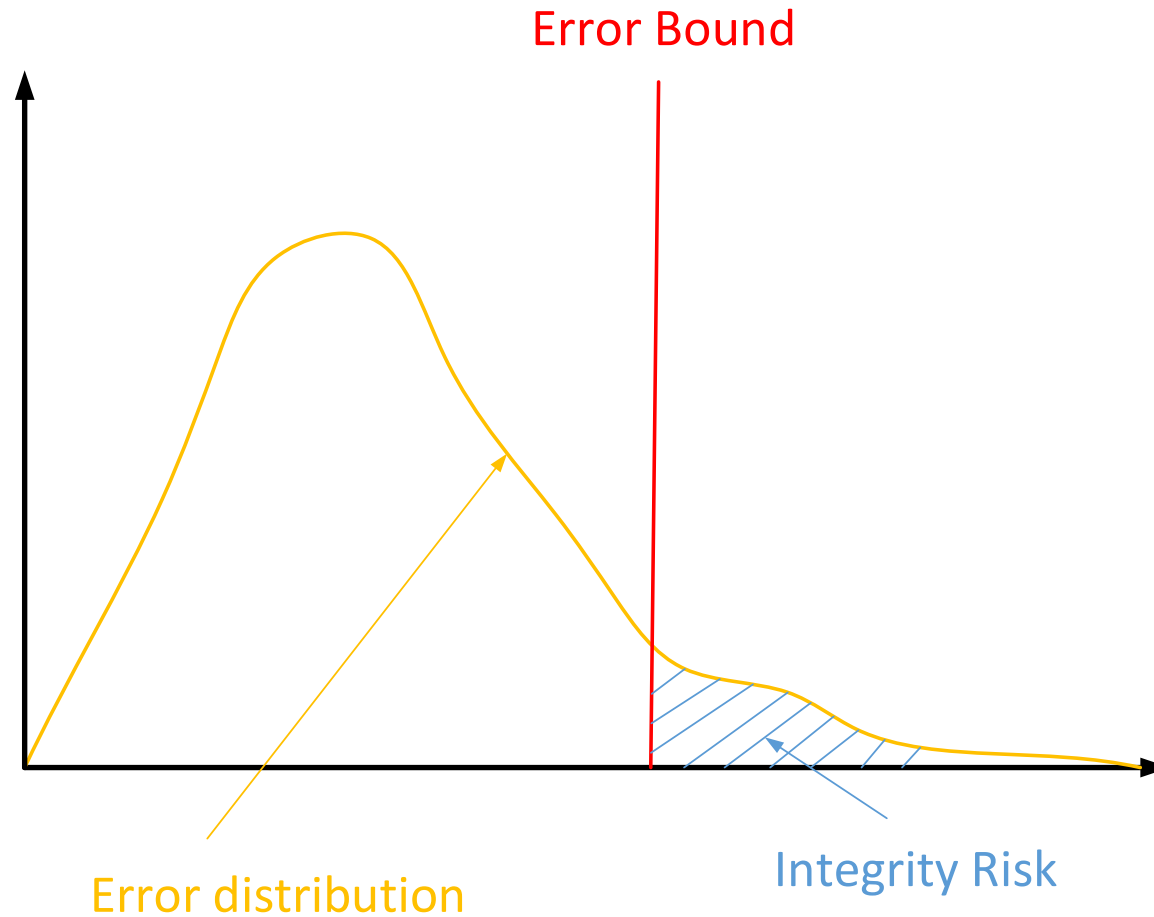
The system verifies the required risk of integrity failure

As the proportion of hazardous points (red area) is lower than that of misleading points (blue area)

Therefore, it is sufficient to design a system with a given TIR

— At the price of a loss of availability

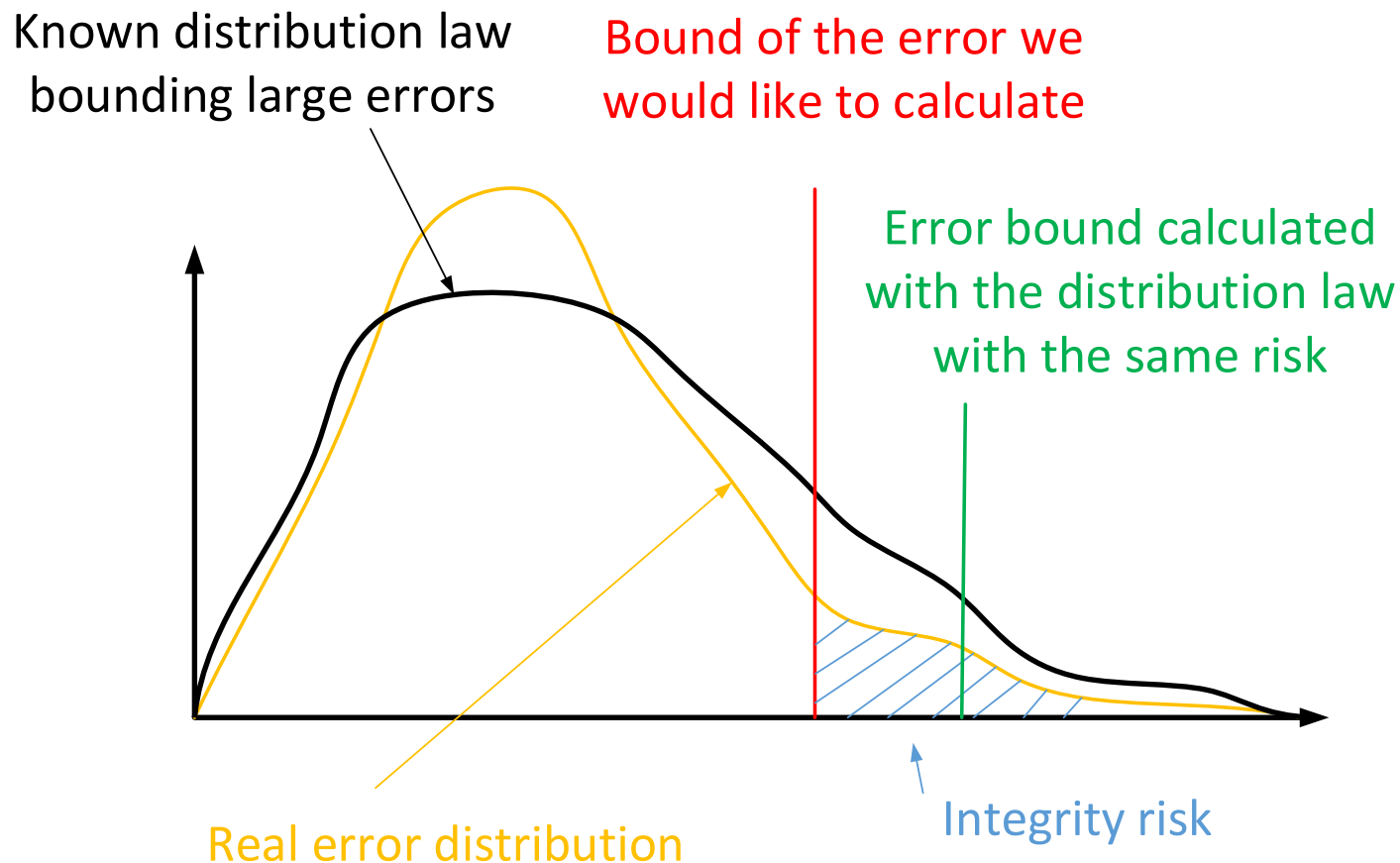
For a chosen TIR, how to find the error bound?



Classical Approach

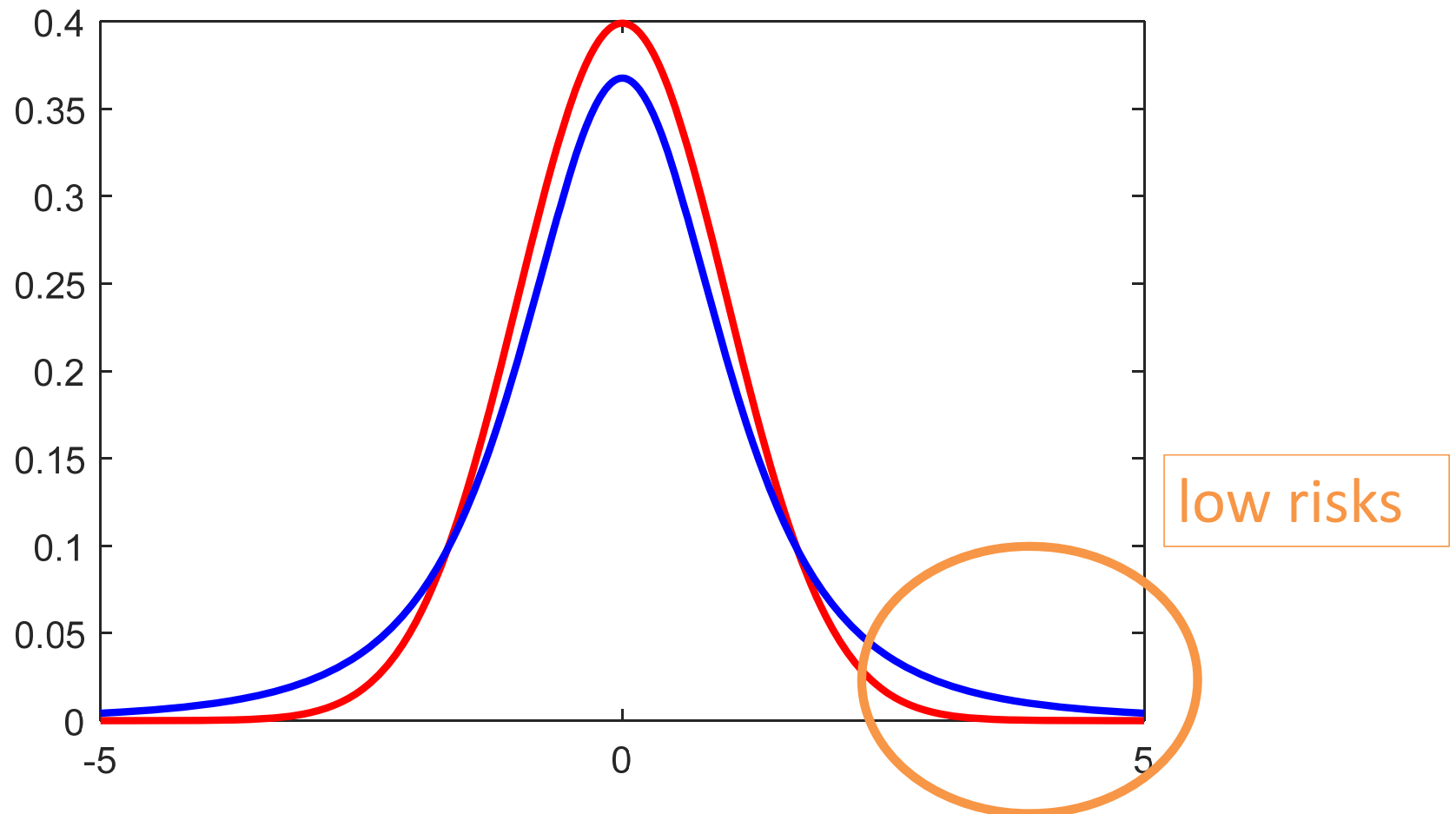
Heavy tail distribution

with an easy to manipulate mathematical expression that bounds the actual error, especially for small risks

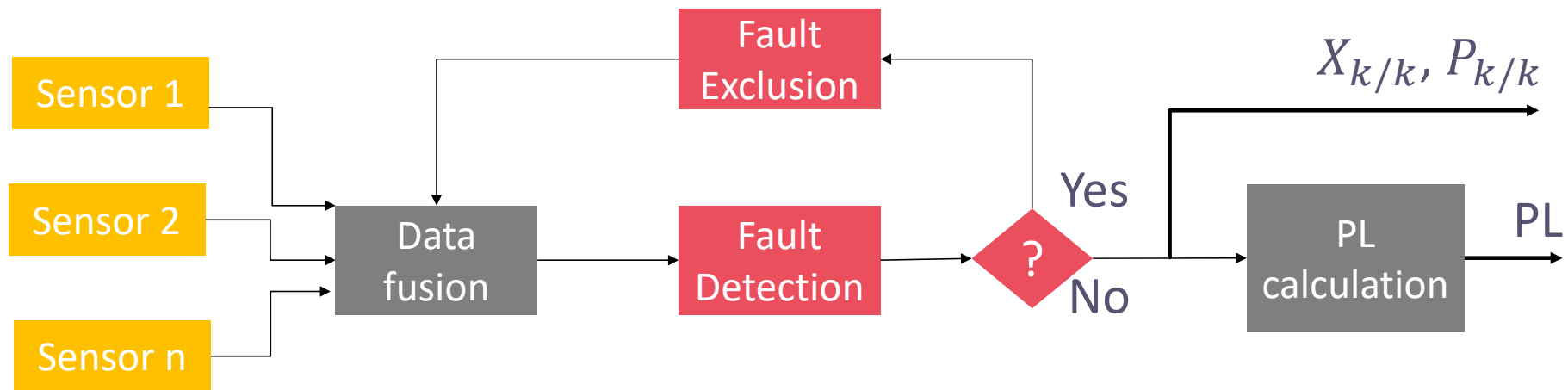


Student's t distribution

More conservative than a Gaussian for error bounding at low risks



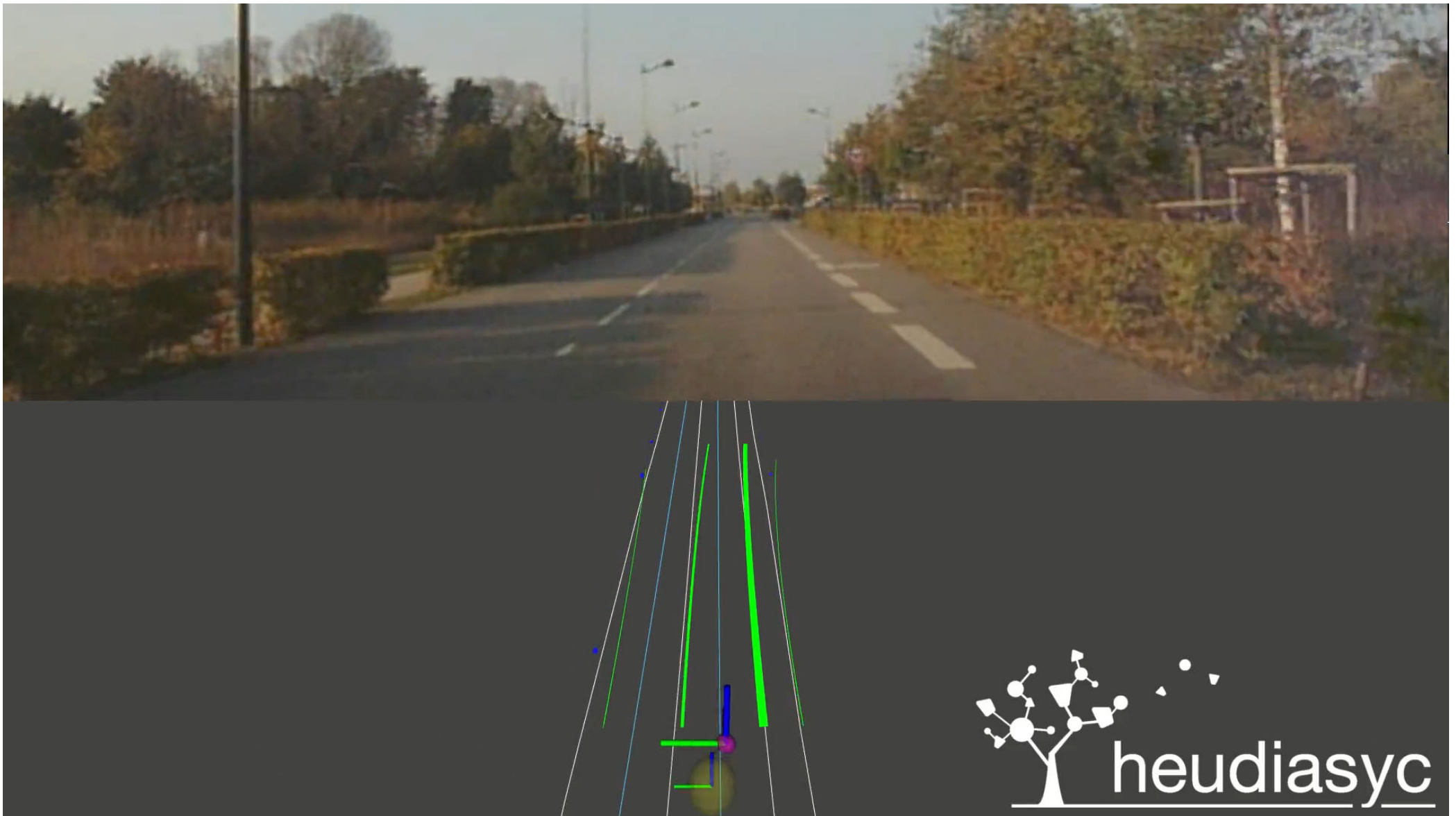
Robust multi-sensor data fusion with FDE and PL computation



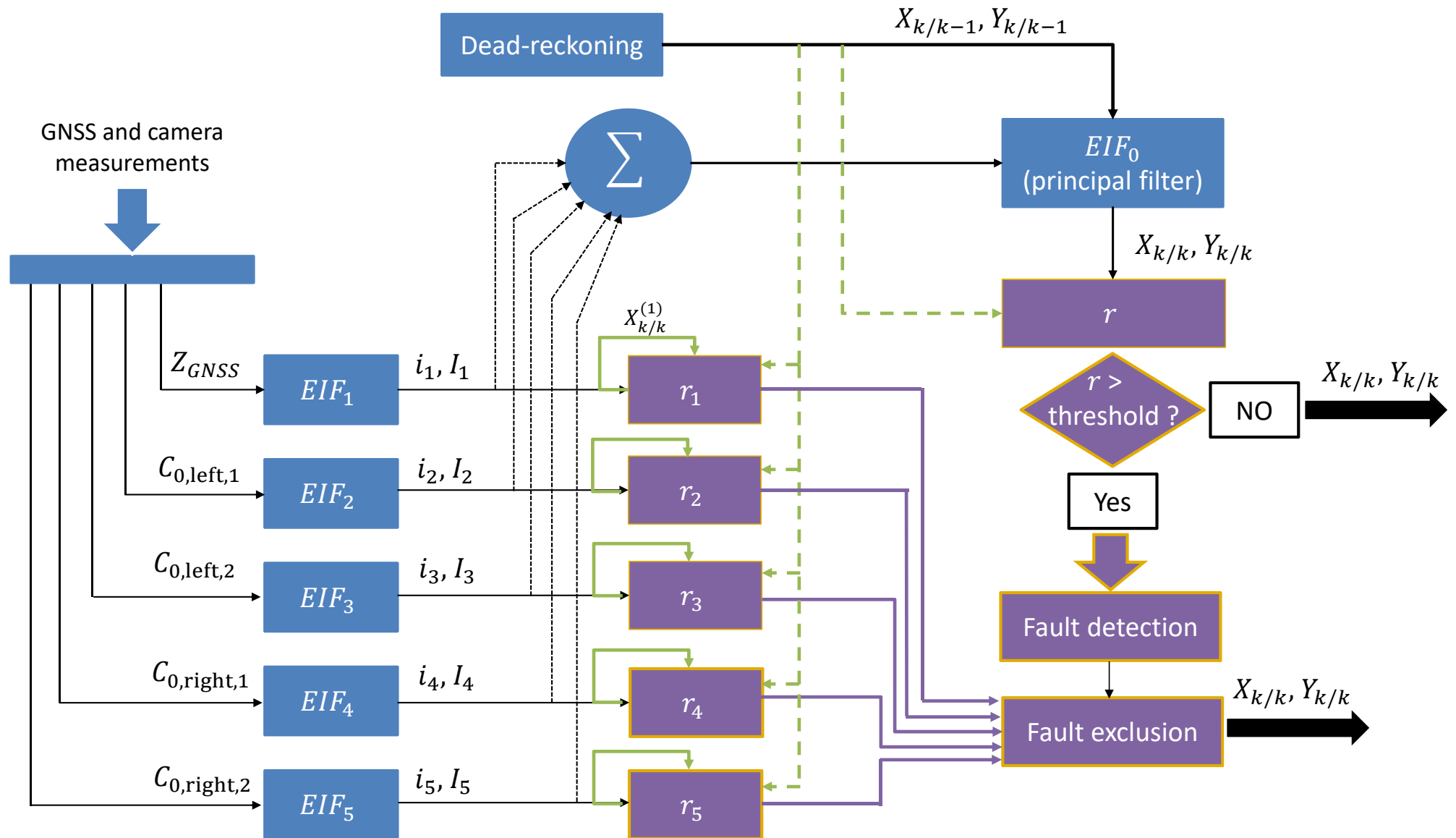
Faults are due to:

- GNSS NLOS
- Data association errors with the HD map
- Errors in georeferenced features

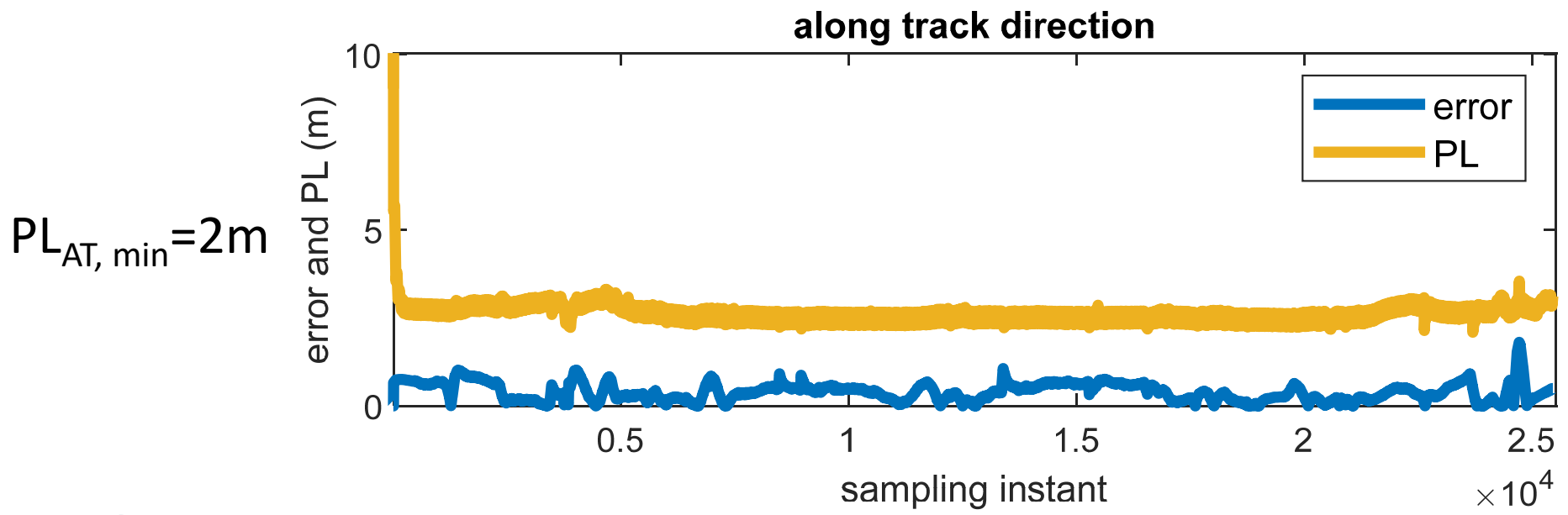
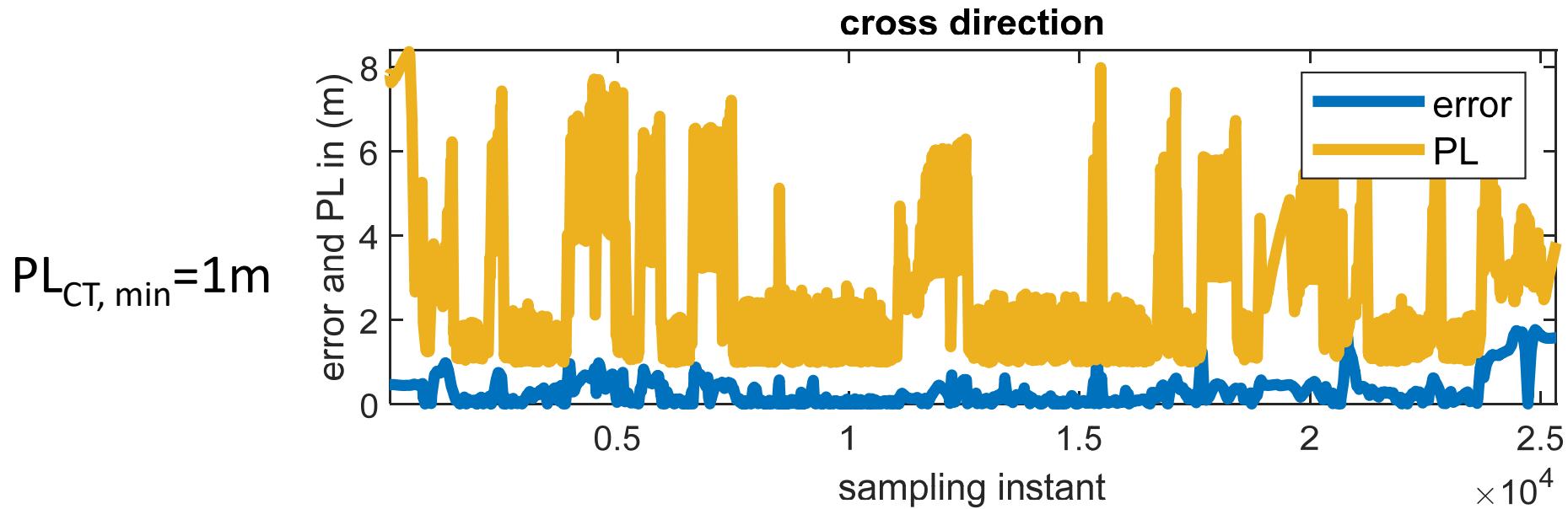
Localization with multi-lane camera measurements



State Estimation Filter

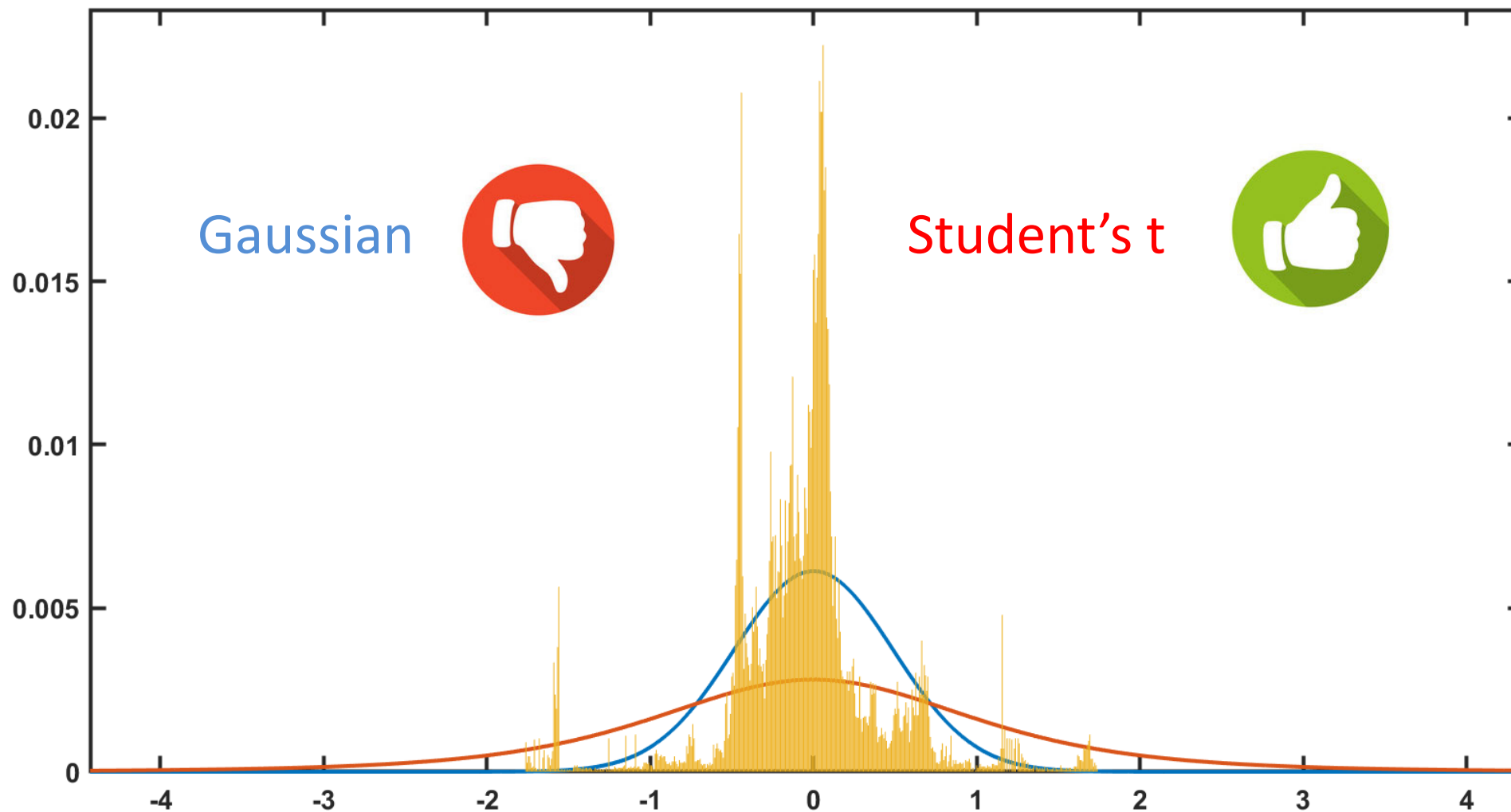


Errors and PLs in the AT and CT directions



TIR= 10^{-3} , Empirical IR = 0

Cross-Track Error distribution



Map Error Detection

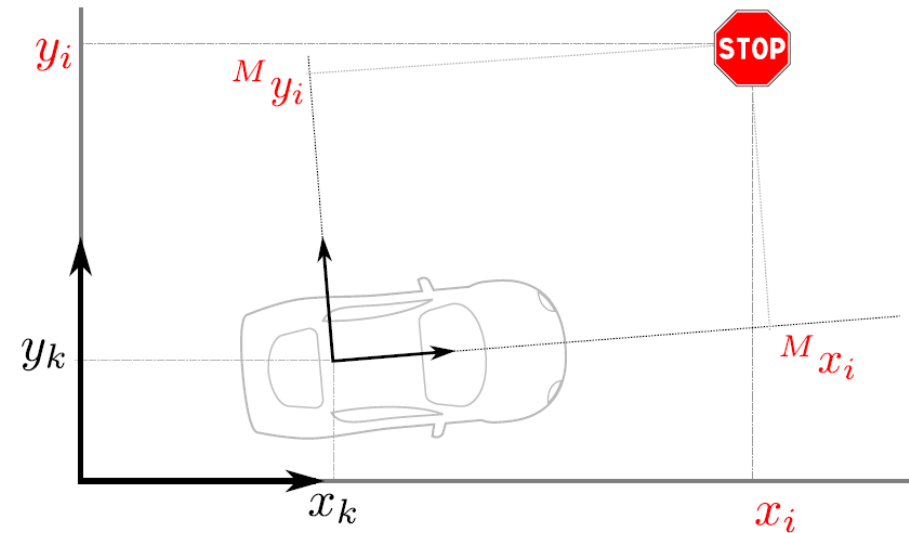
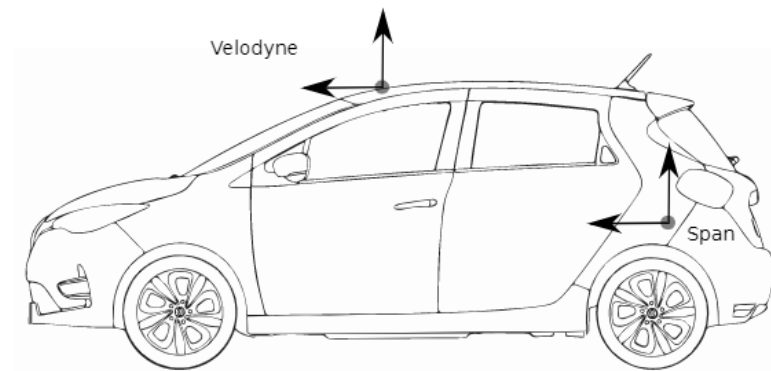
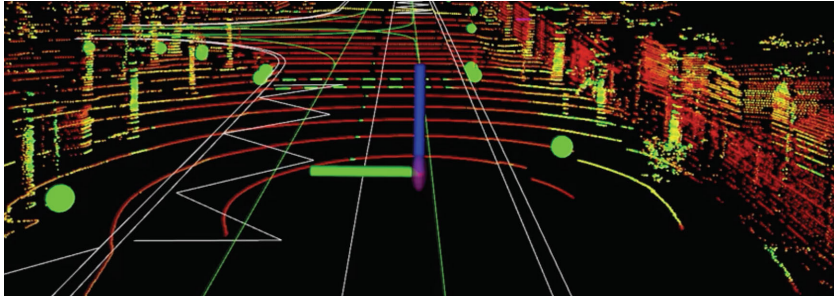
Map features can change

- They can be modified and they can get damaged



HD Map Errors Detection using Multiple Drives

Lidar detection



$$\mathbf{z}_k^j = \begin{bmatrix} x_i \\ y_i \end{bmatrix} = h(\mathbf{x}_k)$$

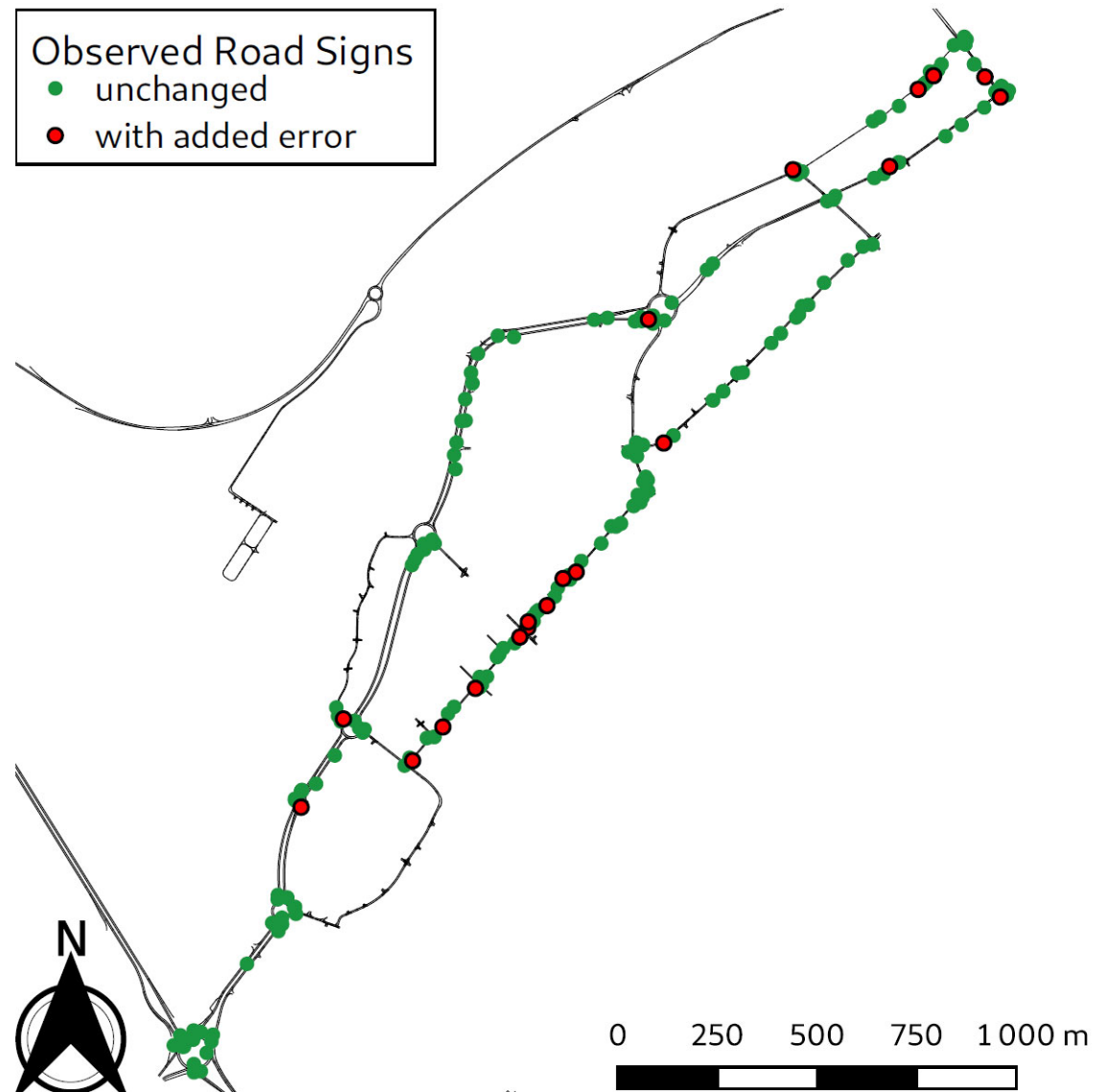
$$\mathbf{y}_{k|N}^j = \mathbf{z}_k^j - h(\hat{\mathbf{x}}_{k|N})$$

Kalman Smoothing Residuals

- Single drive
- Multiple drives

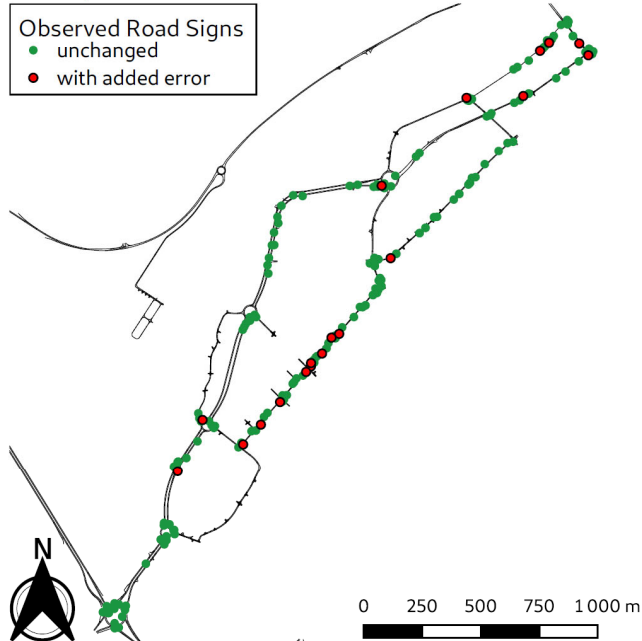
Experimental Results

207 traffic signs
20 with added error

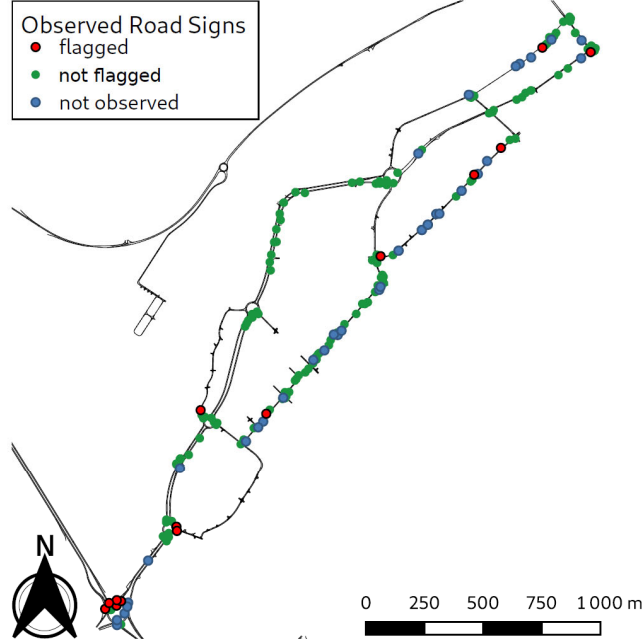


Map Error Detection

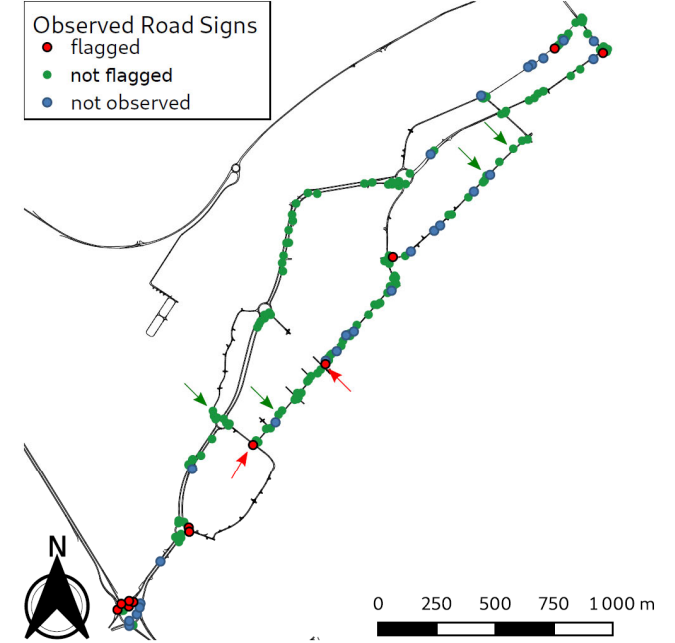
Map Errors



First



Second



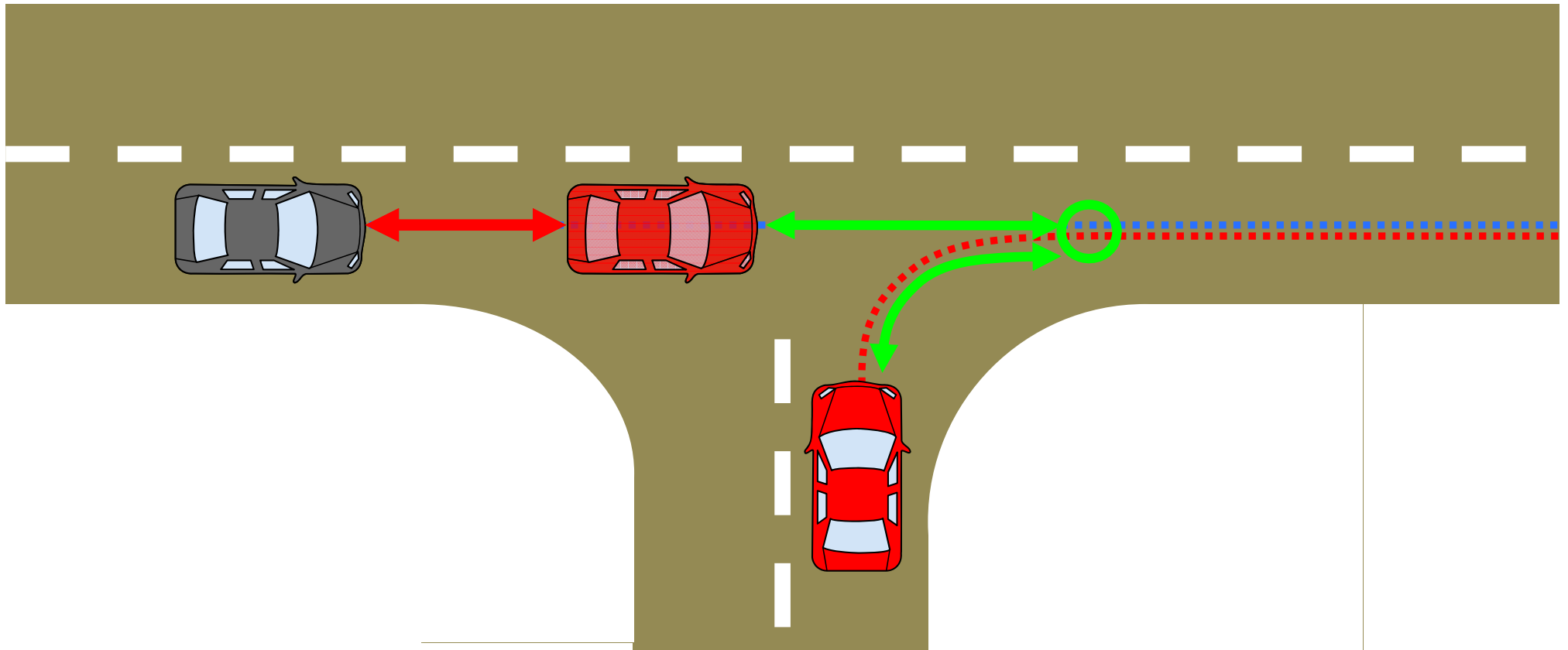
The method is able to

- Validate the correct signs that have been seen and matched
- Detect faulty ones, particularly with small errors down to 50 cm

Cooperative Systems for Intersection Crossing

Vehicles exchange their positions through wireless communication

This makes it possible to anticipate areas of interaction through the use of a map



Operating principle with integrity

Each communicating vehicle determines its absolute location and calculates Protection Levels

The pose, the speed, the PLs and the dimensions of the vehicles are communicated with a time stamp

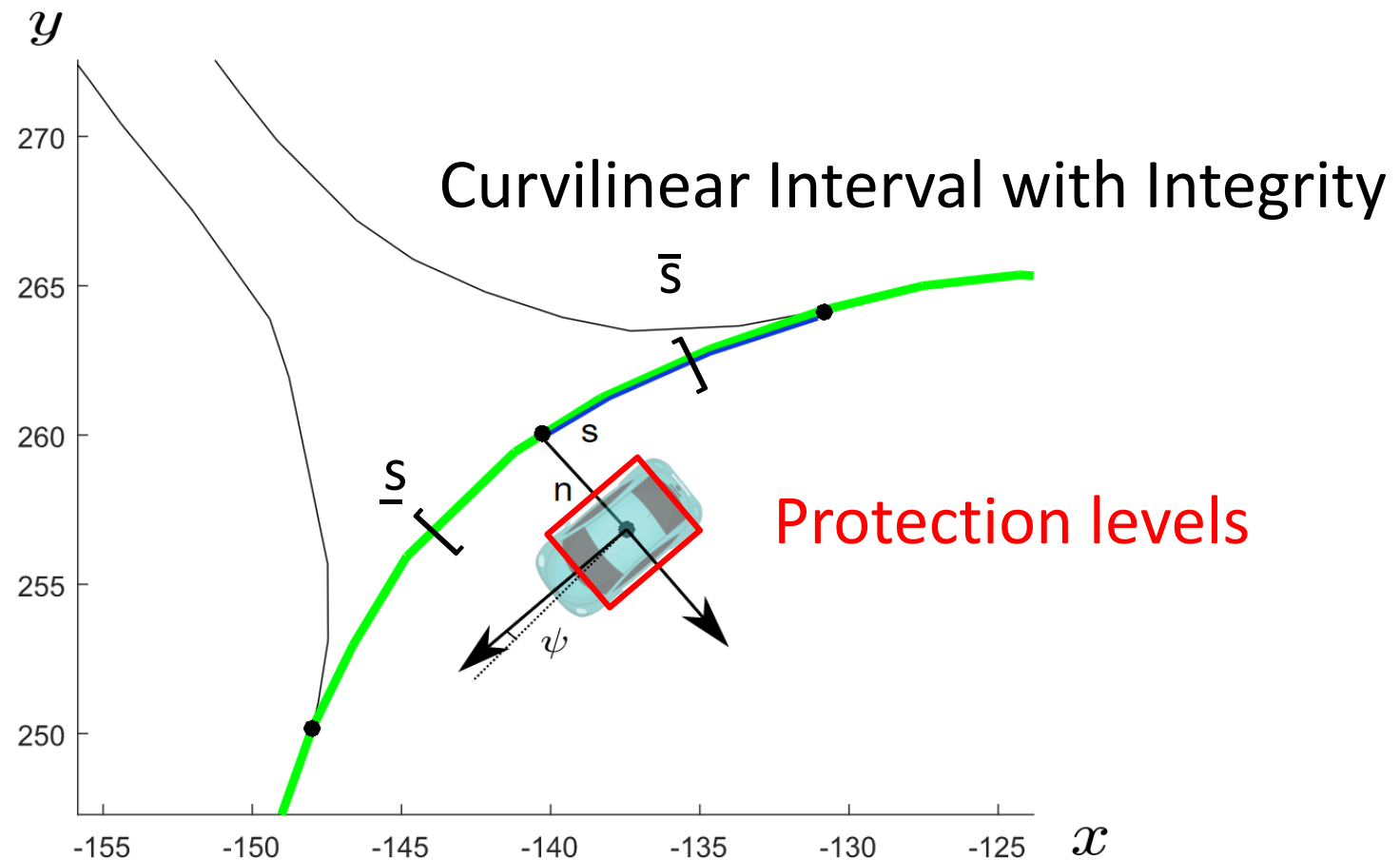
When a vehicle receives this information,

- it extrapolates the position according to the transmission delay
- it map-matches it on its HD map
- It computes intervals (occupancy + uncertainty bound)

It predicts the driving situation to determine the maneuver to execute

- stop and wait, engage, etc.

Curvilinear Coordinates along the center lane of the HD Map



Integrity for cooperative systems

Roundabouts crossing with cooperative systems



Conclusion

Integrity Method adapted to road vehicles

- Faulty measurements rejection (FDE)
- Error bound (PL) with a heavy tailed Student's t-distribution

HD Map integrity is an important issue

Integrity for collaborative navigation

Place of localization for autonomous navigation?

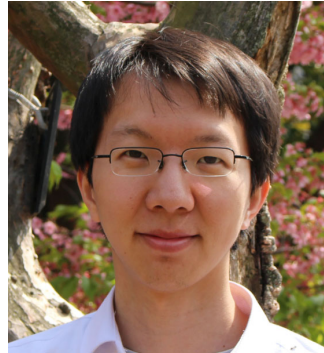
- if used for control, PLs must be very small.
 - Is it possible to reach this level of performance in the medium term?
- if used for decision making (lane level localization, cooperative systems, etc.), PLs of the order of magnitude of one meter will be computable in the medium term.

What level of performance?

What values for TIR and AL?

Thank you for your attention!

Associated publications



1. J Al Hage, P Xu, P Bonnifait, J Ibañez-Guzmán
Localization integrity for intelligent vehicles through fault detection and position error characterization
IEEE Transactions on Intelligent Transportation Systems 2021
2. A Welte, P Xu, P Bonnifait, C Zinoune
HD Map Errors Detection using Smoothing and Multiple Drives
IEEE IV 2021
3. S Masi, P Xu, P Bonnifait
Roundabout crossing with interval occupancy and virtual instances of road users
IEEE Transactions on Intelligent Transportation Systems 2022