High Integrity Localization of Intelligent Vehicles with Student's t filtering and Fault exclusion

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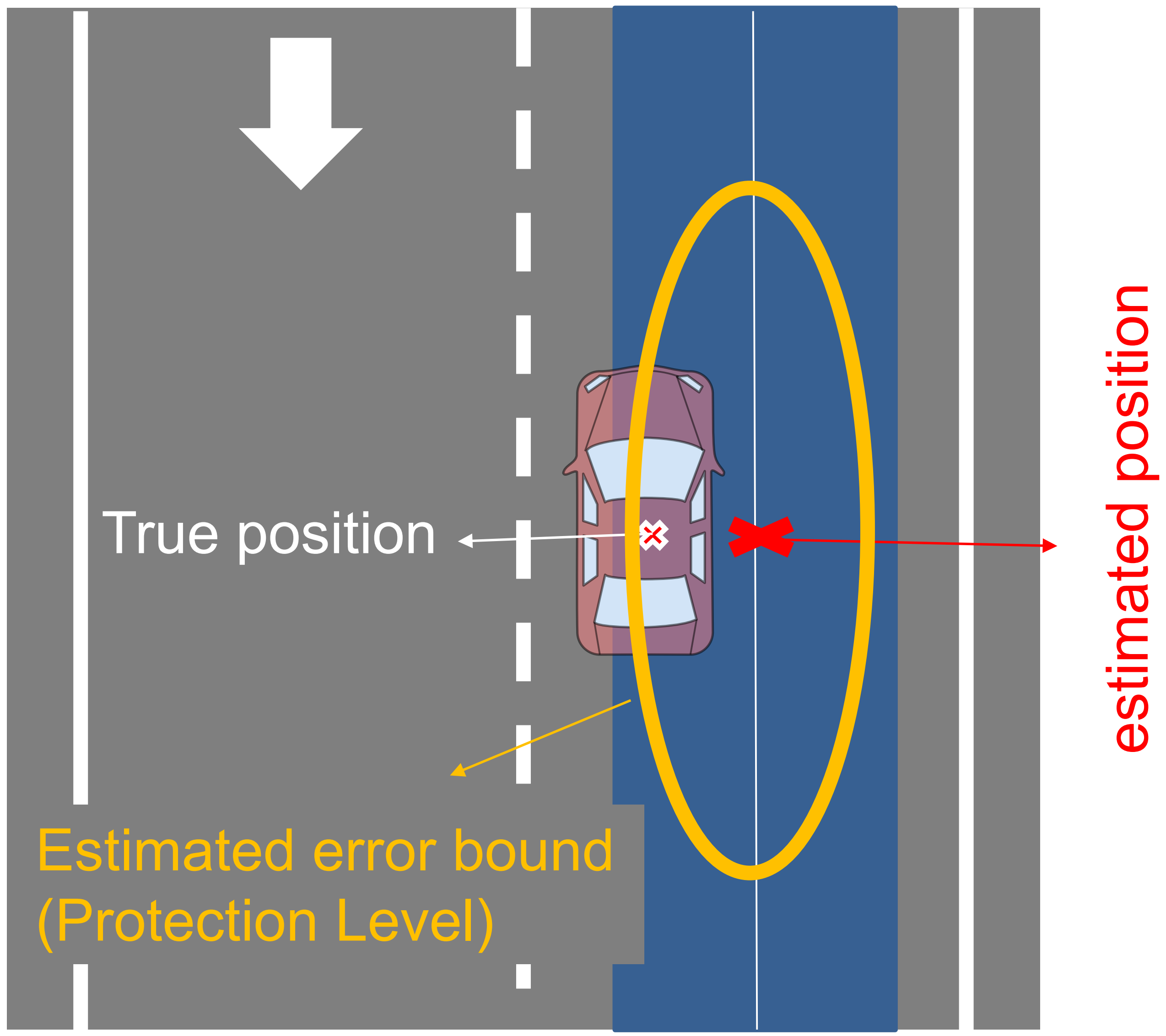
Localisation integrity

Information has to be

- Accurate enough for the task to be performed
- Available at a sufficiently high rate
- Non-misleading and trustworthy

Integrity involves combining and merging data from complementary, diversified and redundant sources

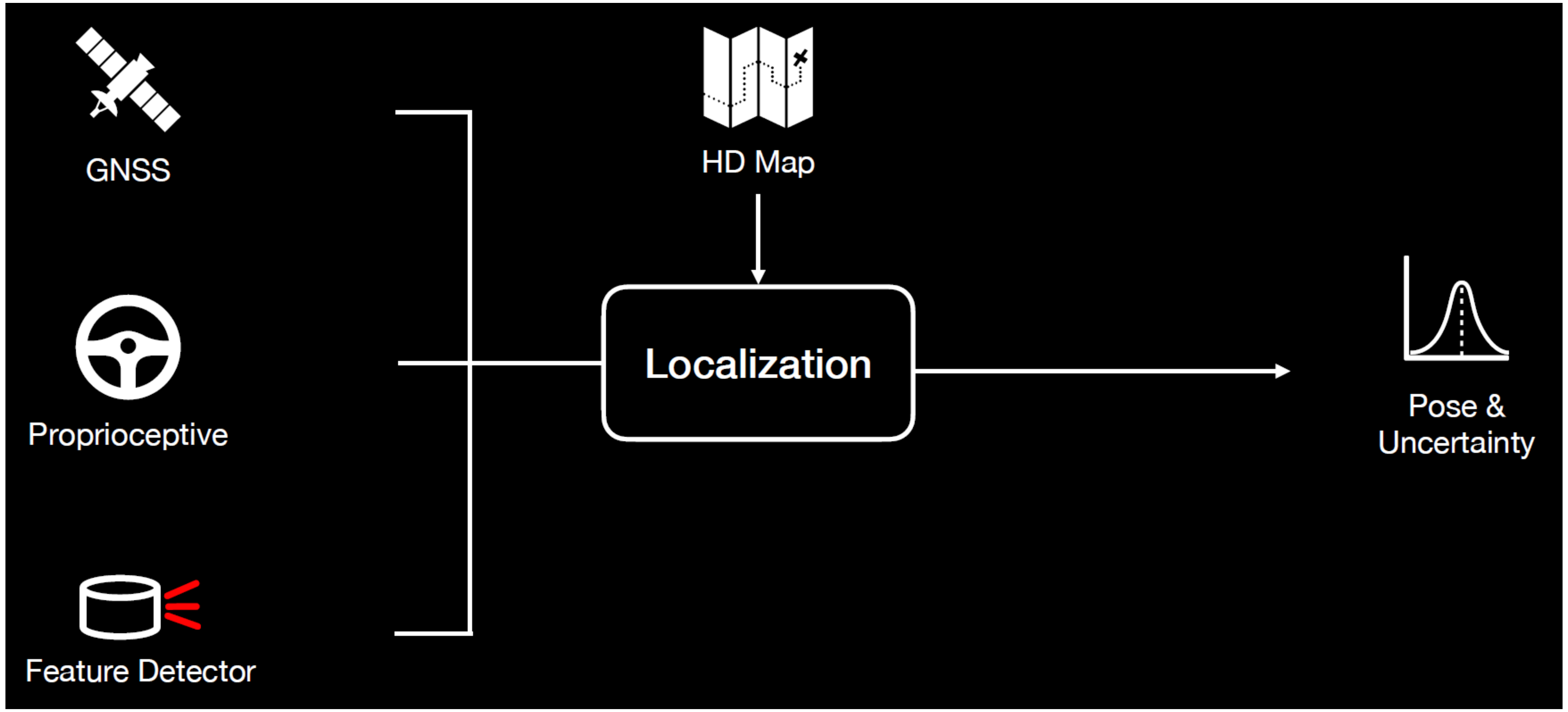
Nominal case e<PL<AL



The error is correctly bounded. OK!

The bound is in the limit (AL) ➔ use

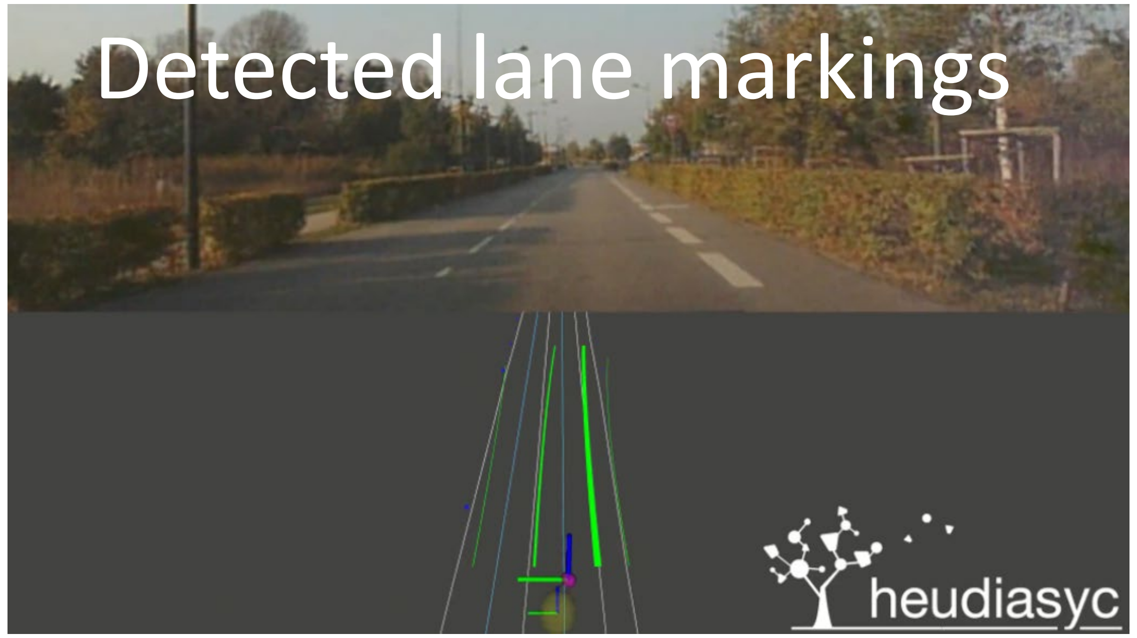
Typical localization system for Intelligent Vehicles

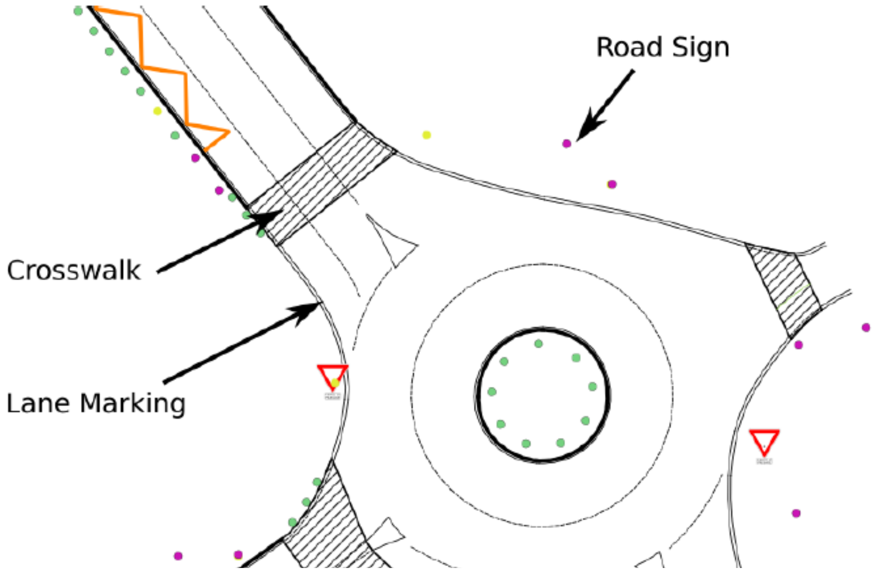


Research questions addressed in this paper:

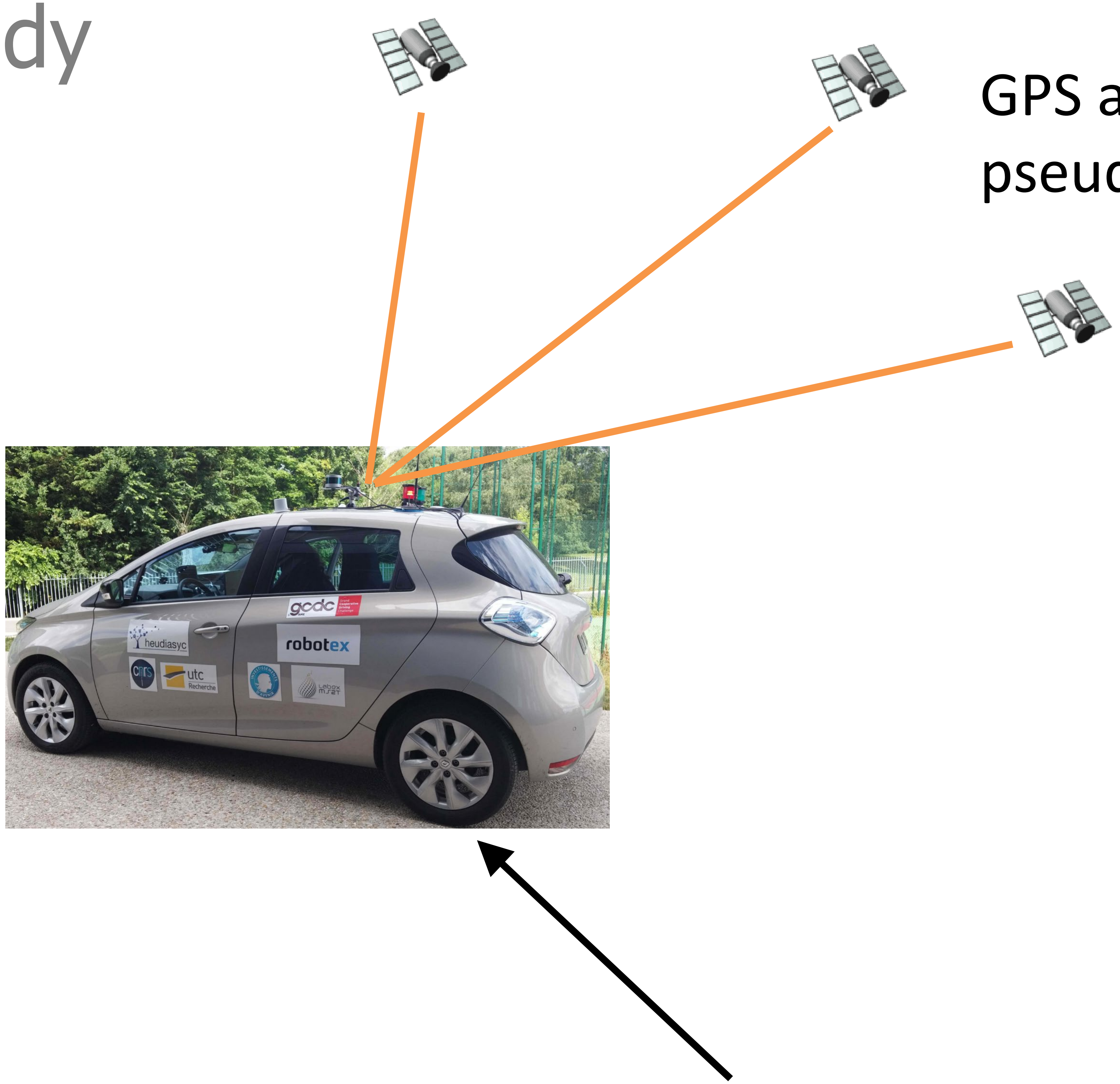
1. How to achieve the optimal accuracy (given a set of information sources)?
2. How to achieve high integrity without being too pessimistic?
3. How to achieve simultaneously high integrity and high accuracy?

Sensors used in this study





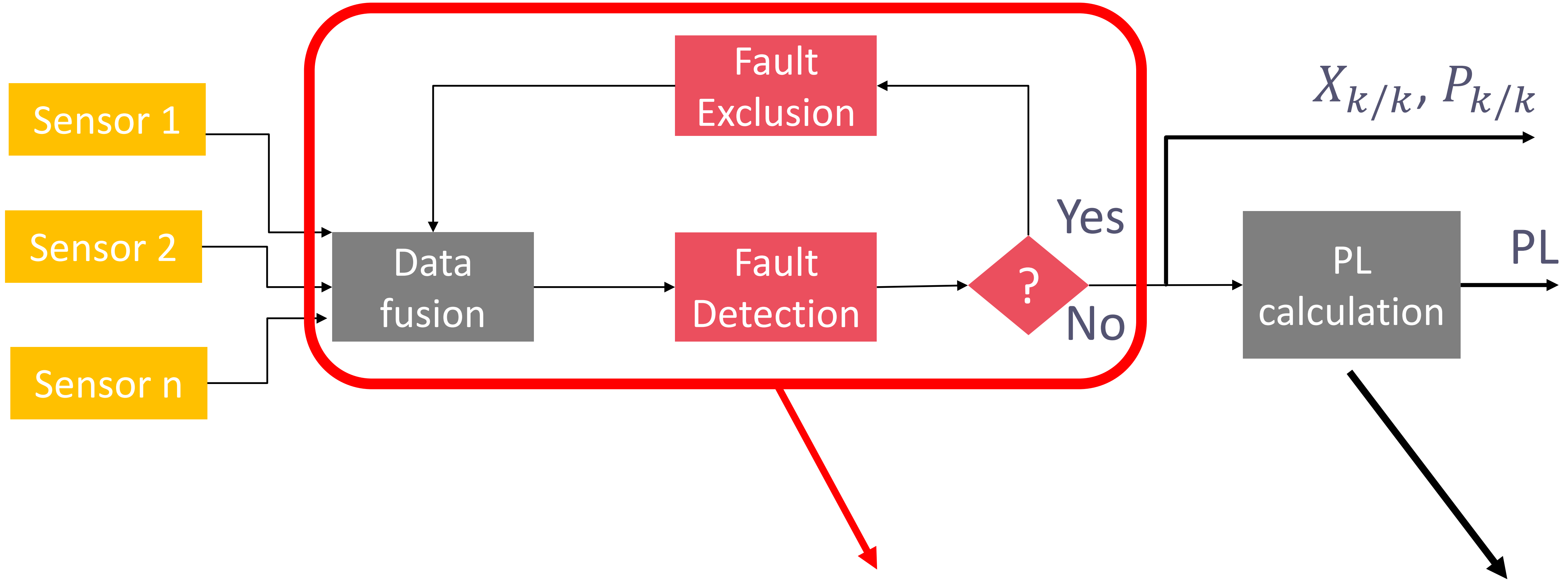
HD map with georeferenced lane markings



GPS and Galileo pseudoranges

Wheel speeds and yaw rate gyro

Classical multi-sensor data fusion



Faults are due to:

— GNSS multipath and NLOS

— Poor camera measurements

— Data association errors with the HD map

— Errors in georeferenced features

Common approach:

— White Gaussian errors

— Kalman Filtering

There are many methods

- Parameter = Target Integrity Risk (TIR)

Student’s t distribution for integrity

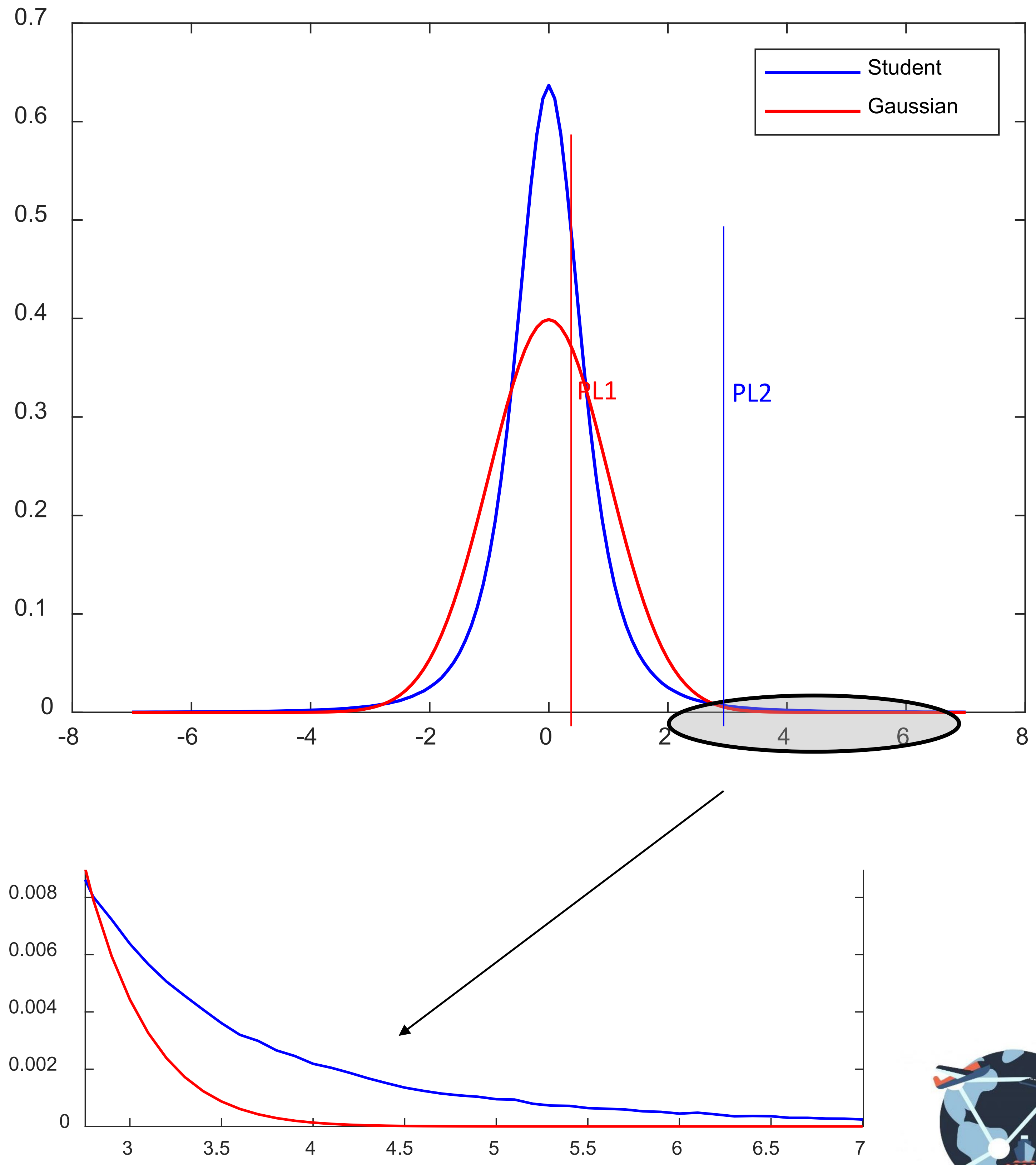
$X \sim St(\mu, P, \nu)$: follows a Student’s t distribution with mean μ, scale matrix P and degree of freedom (dof) ν.

The covariance matrix is defined as ($\nu > 2$):

$$\Sigma = \frac{\nu}{\nu - 2} P$$

If $\nu \to \infty$: The t distribution converges to a Gaussian distribution

Well adapted to model the measurements with some outliers and to compute PL with small TIR



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Dead-reckoning Modeling

Evolution model:

$$X_{k+1} = f(X_k, u_k) + v_k$$

$u_k = [\Delta_k, \Omega_k]$ input vector contains the elementary displacement and rotation obtained from the wheel-speed sensors and the gyro

$$v_k \sim St(0, Q_k, \gamma_k)$$

If the dof γ is high, this a Gaussian distribution

GNSS observations modeling

Measurements:

ρ_k= pseudoranges = $R_j + cdt$

Euclidean distance between the receiver and the satellite

Receiver clock offset

Observation model:

$$\rho_k = h_G(X_k) + \omega_k$$
$$\omega_k \sim \ St(0, R_k, \delta_k)$$

Camera observations modeling

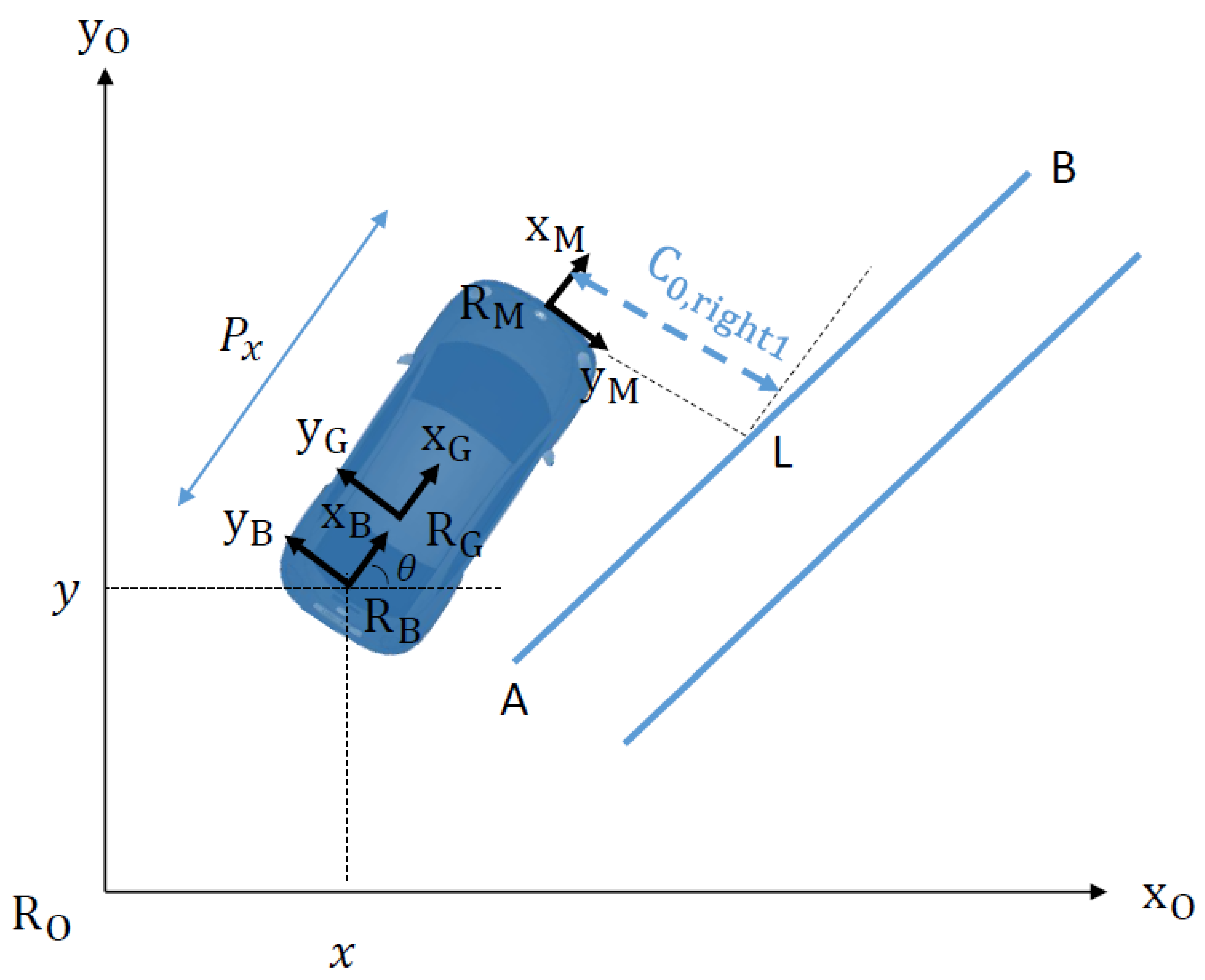
Measurements:

$C_{0,k}$ = lateral offset between R_M and L (up to 4 simultaneous meas.)

$$C_{0,k} = h_C(X_k) + \omega_k$$

$$\omega_k \sim St(0, R_k, \delta_k)$$

Improve the integrity in presence of poor perception data



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End-to-End Student's t Filter (StF)

Student's t distributions are used to :

- Estimate the state
- To model any error or uncertainty

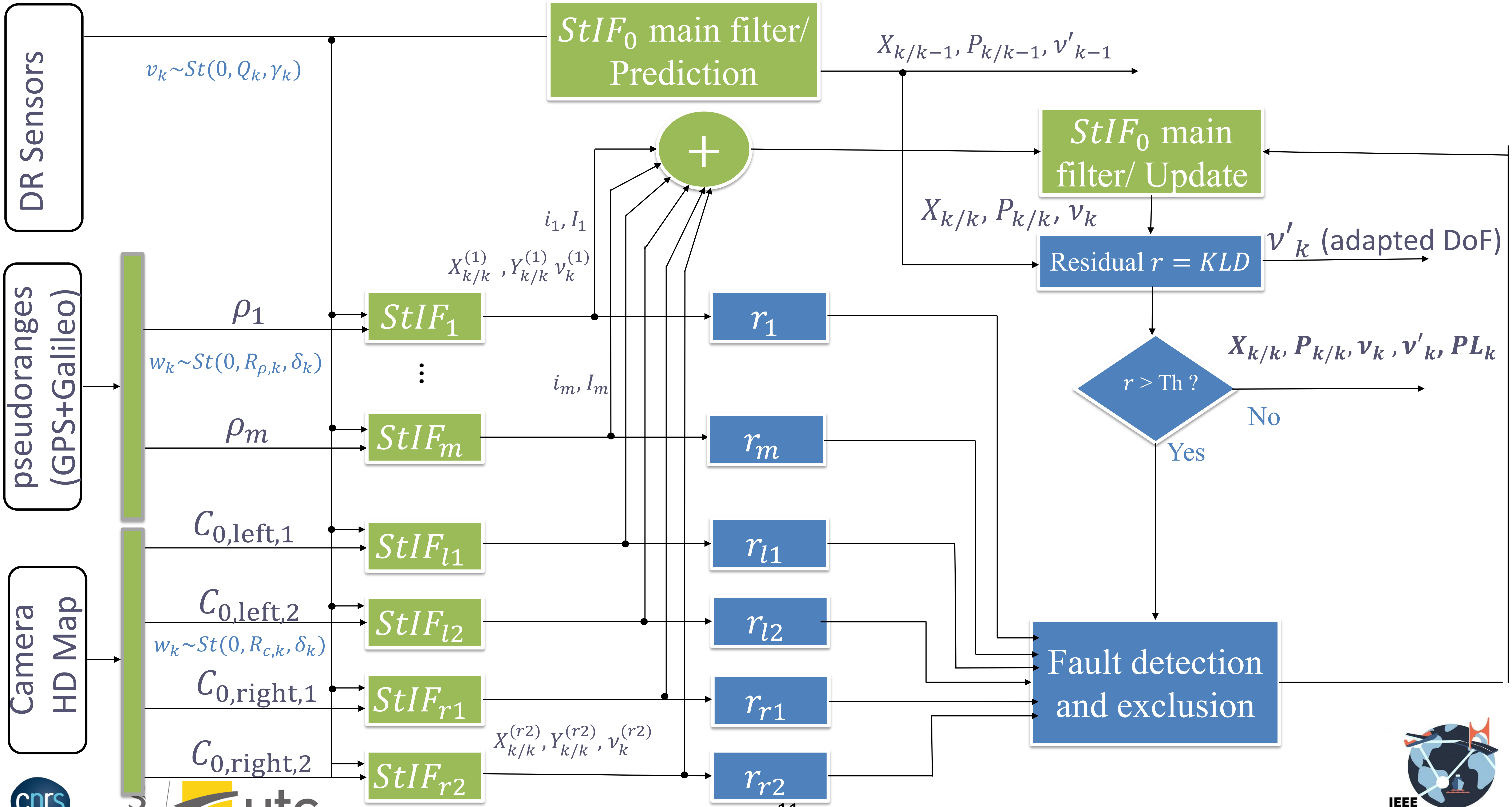
If the DoF is not controlled, it tends to infinity and the StF becomes a KF

- Often, the DoF is fixed to a chosen value
- Here, the DoF is adaptive in a given interval and it depends on a residual computed by a Fault Detection and Exclusion (FDE) stage

— Based on the Kullback-Leibler divergence in the state space

Jacobian matrices are used for linearization (Extended Student's t Filter)

An Information StF has been implemented (for efficient FDE)



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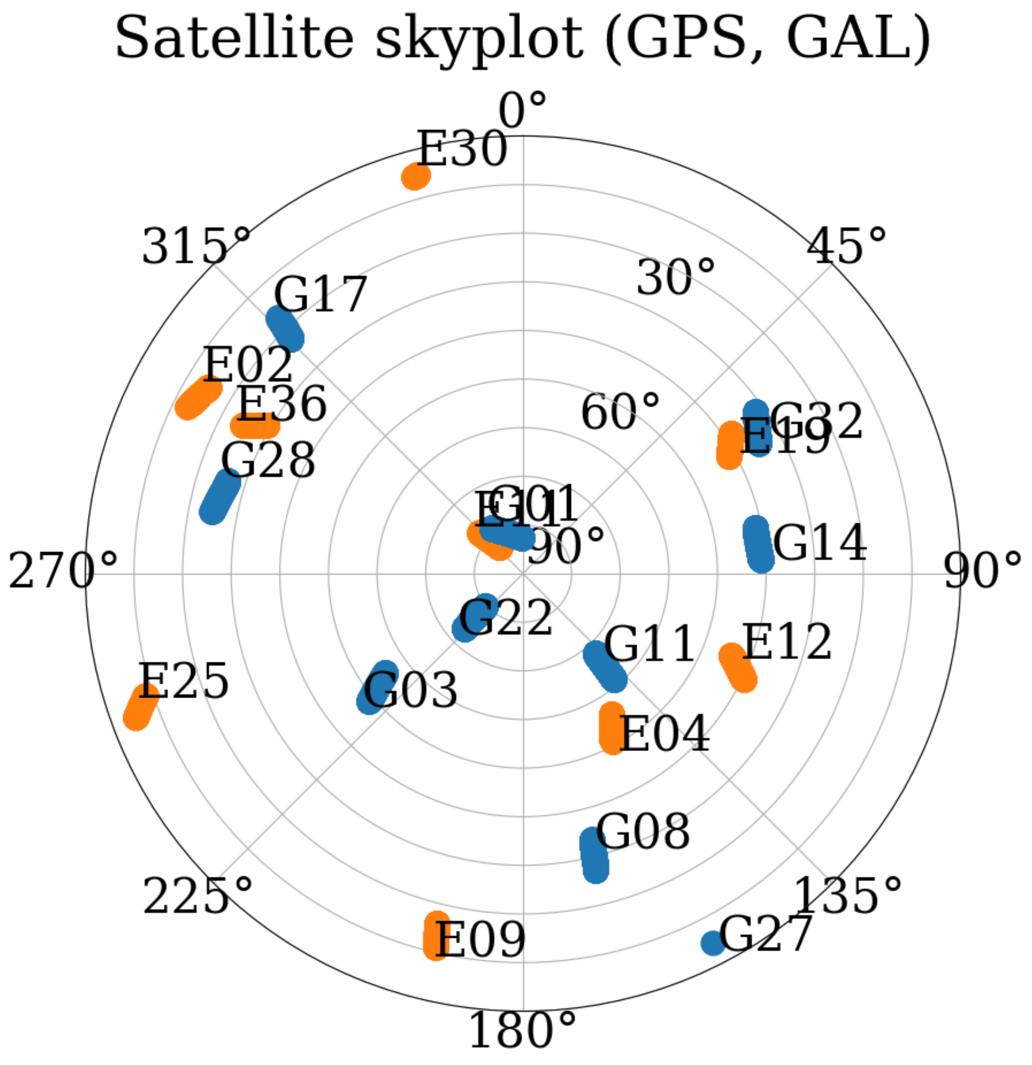
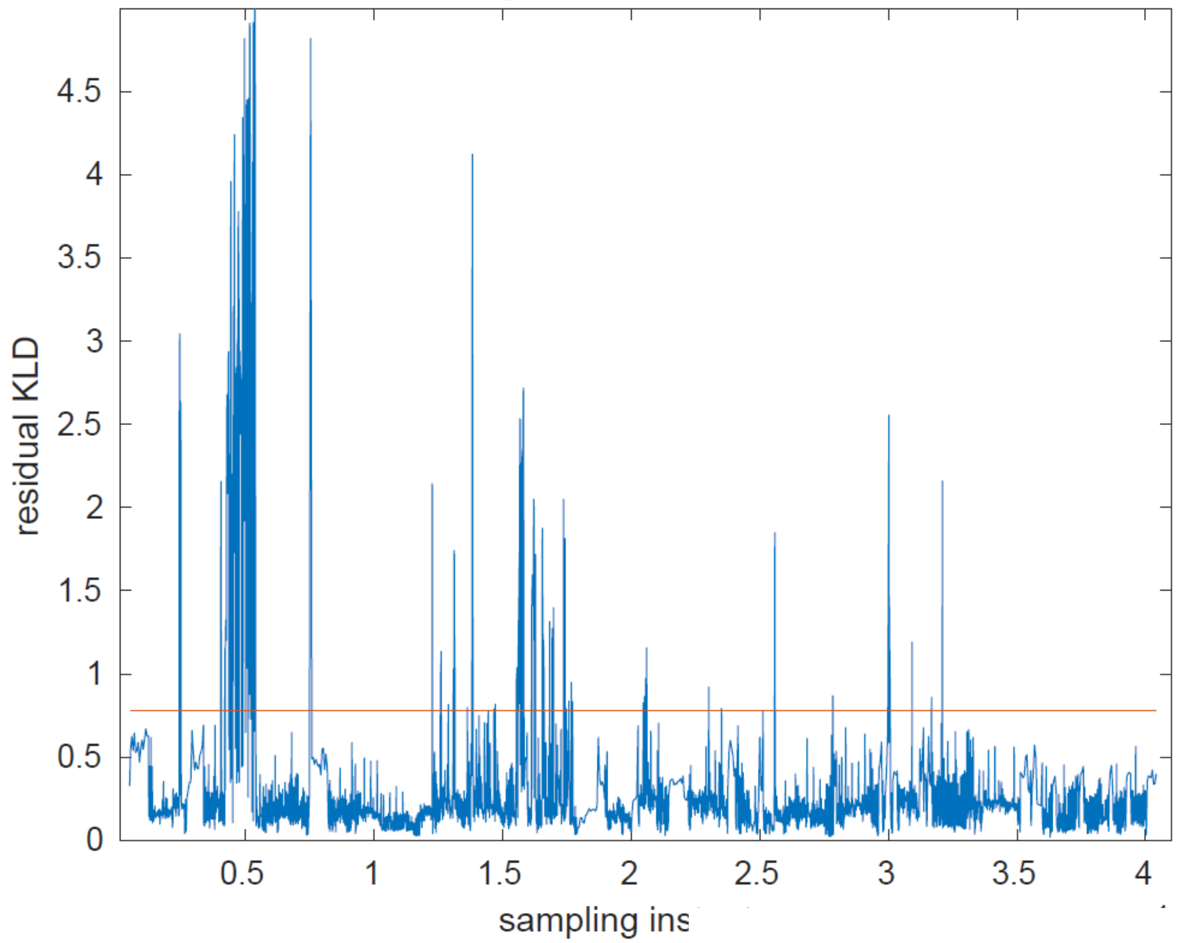
Experimental Results

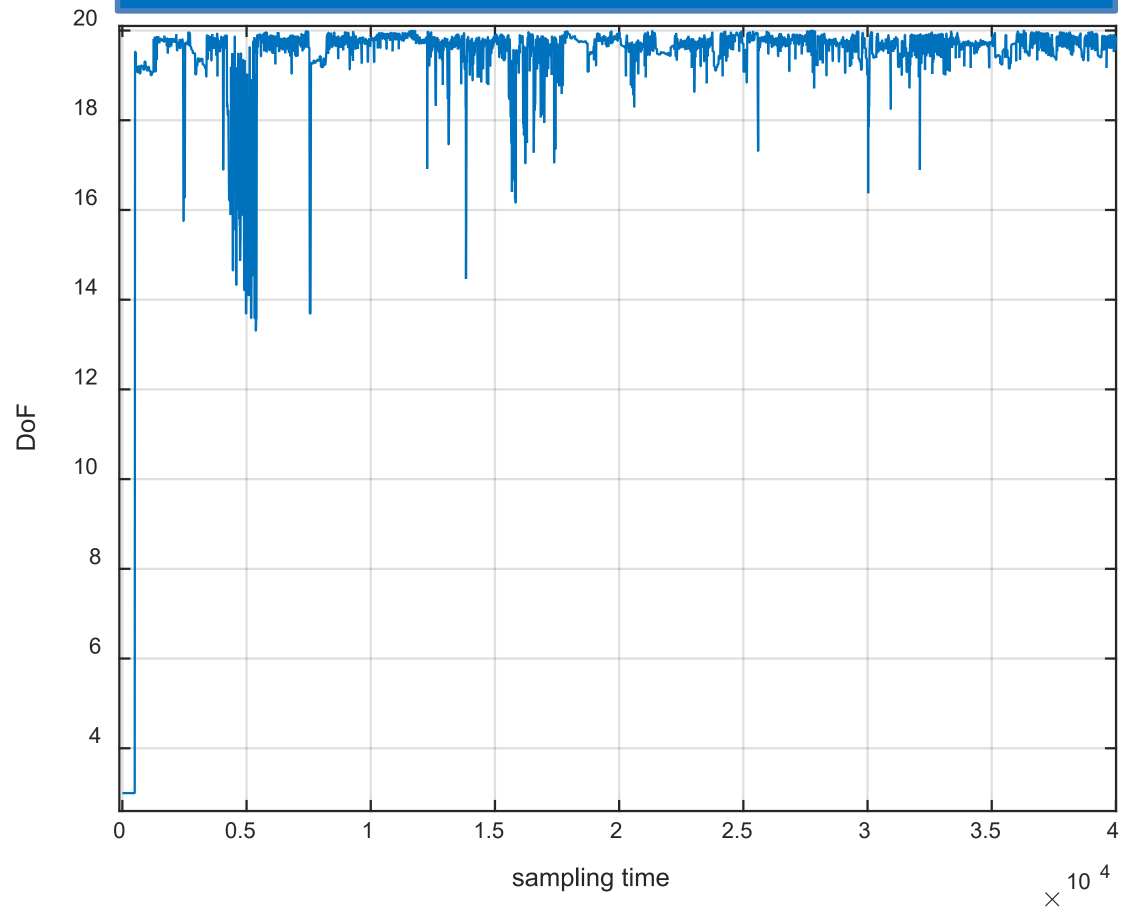


Compiègne, trajectory of 6km

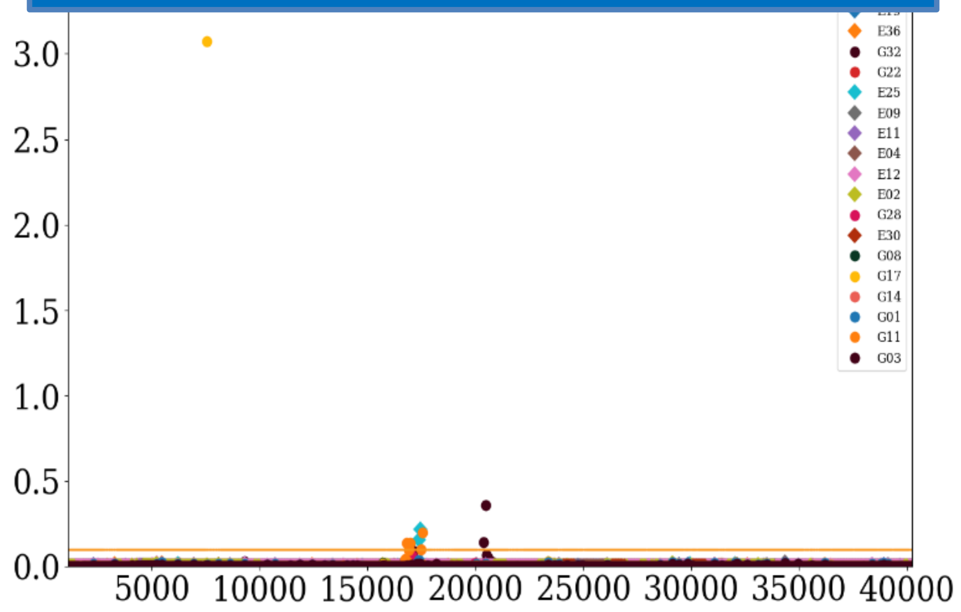
Residual for fault detection

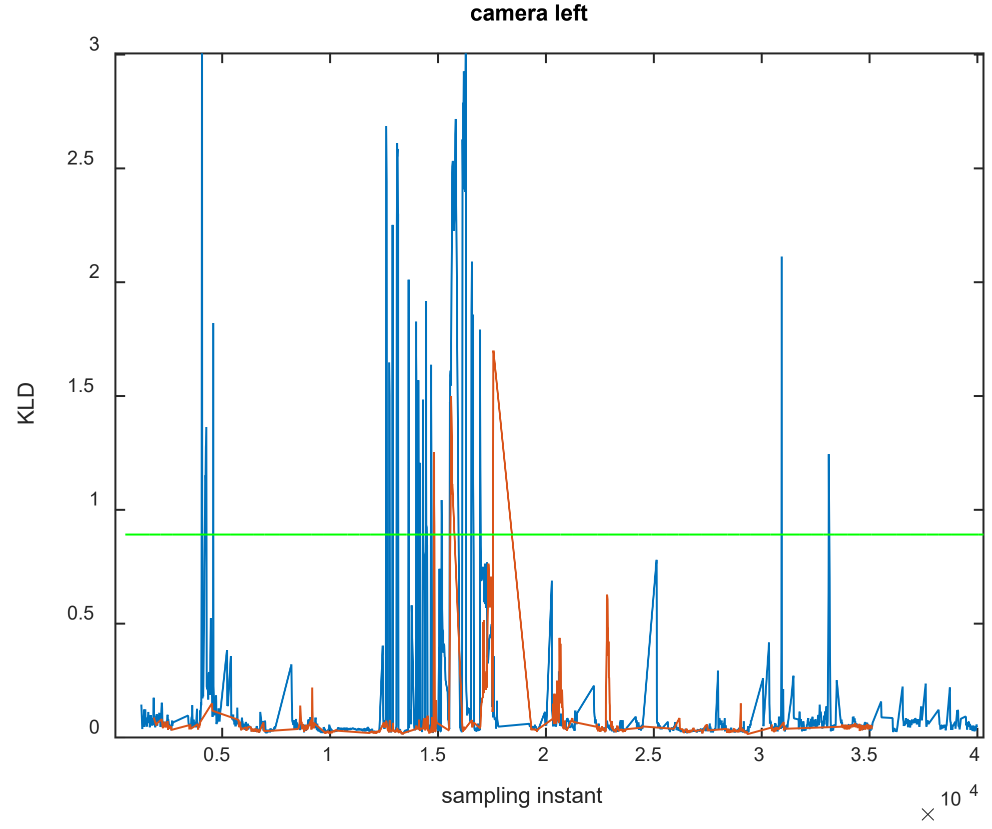


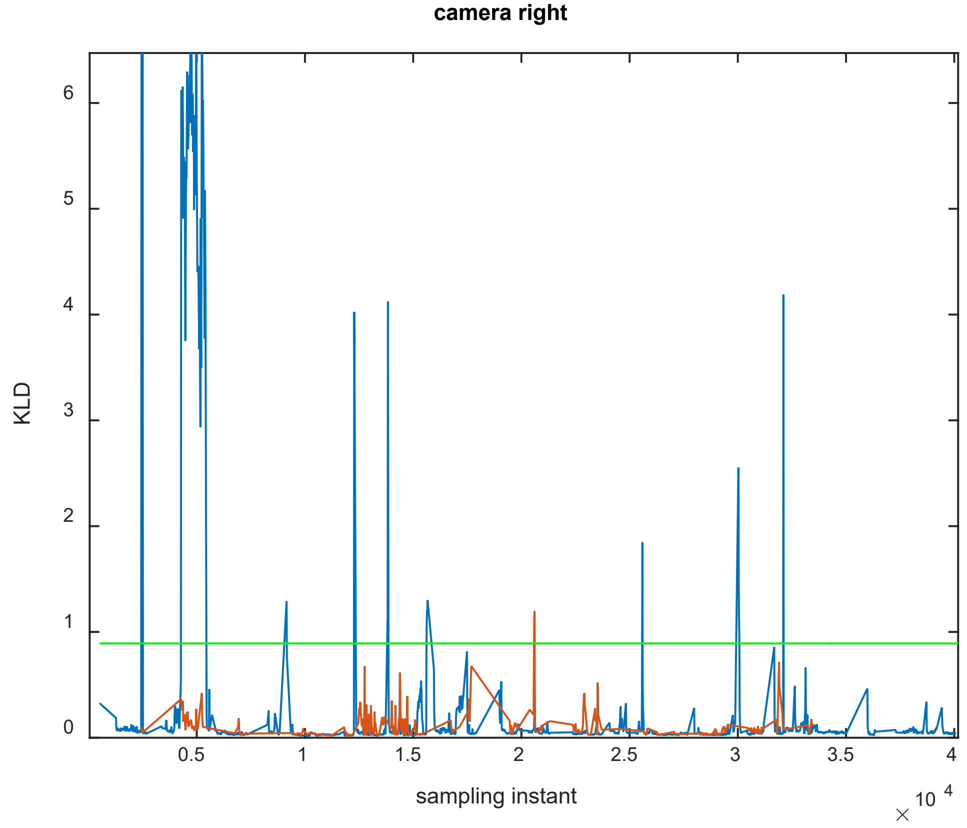
Degree of freedom



Residuals for fault exclusion







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Experimental Results

	Without FDE		With FDE	
	StF	KF	StF	KF
Mean absolute error[m]	0.76	0.74	**0.71**	0.72
$IR_{AT} \times 10^{-3}$	**1.1**	3.9	1.5	1.8
$IR_{CT} \times 10^{-3}$	6.8	22	**0.9**	15

$IR = P(e > PL)$

AT: Along Track
CT: Cross Track
$TIR = 10^{-3}$

Conclusions :

- StF is as accurate as KF (with or without FDE)
- StF is much more consistent is terms of integrity (with or without FDE)

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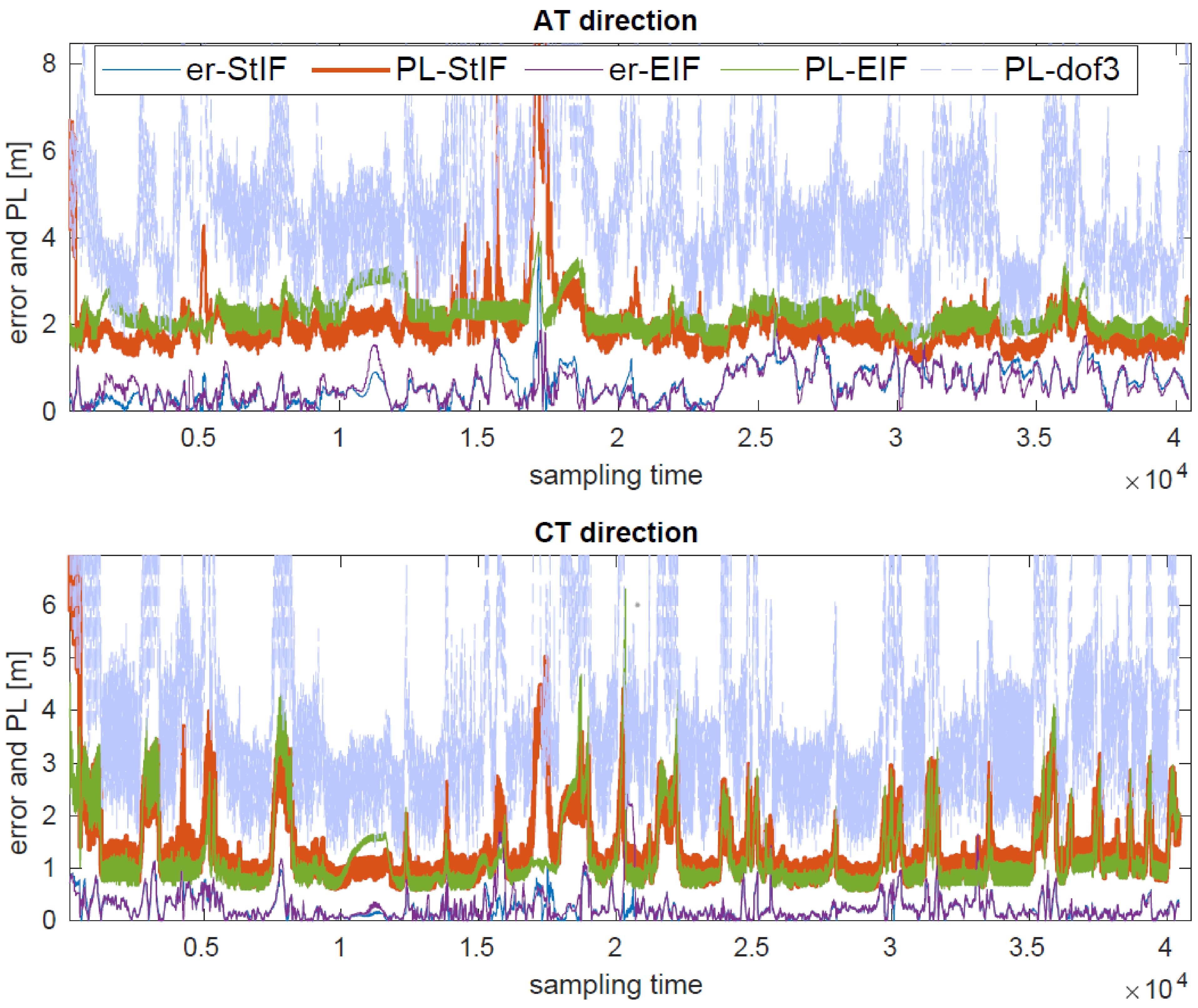
Protection Levels

Green: KF

Red: StF with adaptive DoF

Blue: StF with fixed DoF = 3

DoF dynamic adaptation is therefore important to reduce pessimism



Results with FDE and $TIR = 10^{-3}$

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Conclusion

Student't filtering for:

— Raw data fusion and PL computation

— Fault detection and exclusion based on KLD

— DOF adaptation according to the quality of the observations

Experimental evaluation:

— Gives the same level of accuracy compared to Kalman filtering

— Improves external integrity while maintaining non pessimistic uncertainty values

StF parameter setting is more complex than KF

— Future work: Use data driven techniques to simplify this issue

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