Managing Localization Uncertainties for Intelligent Vehicles

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FRANCE

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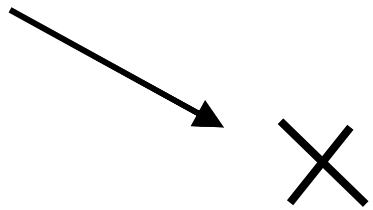
Introduction

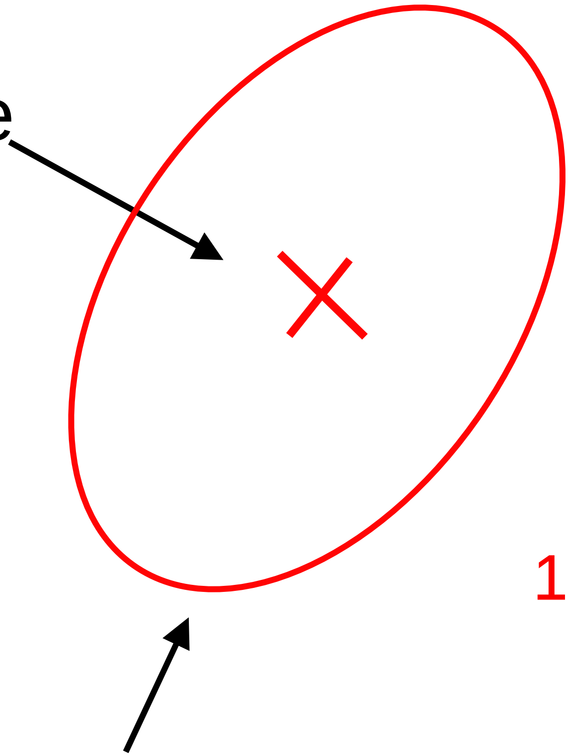
The good old days

You are here!



Modern Times

Maybe you are here...

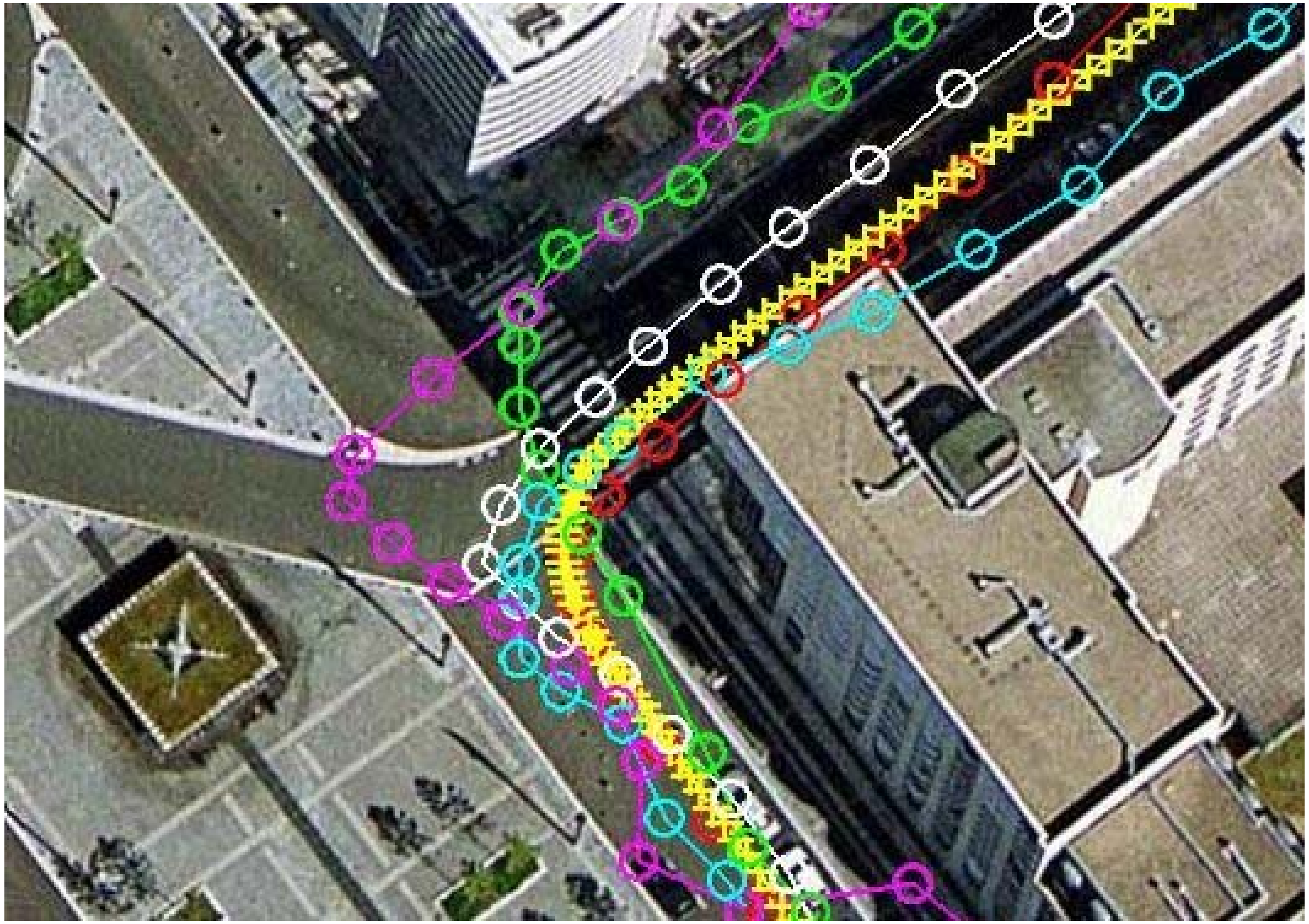


in this area with a confidence of 99%

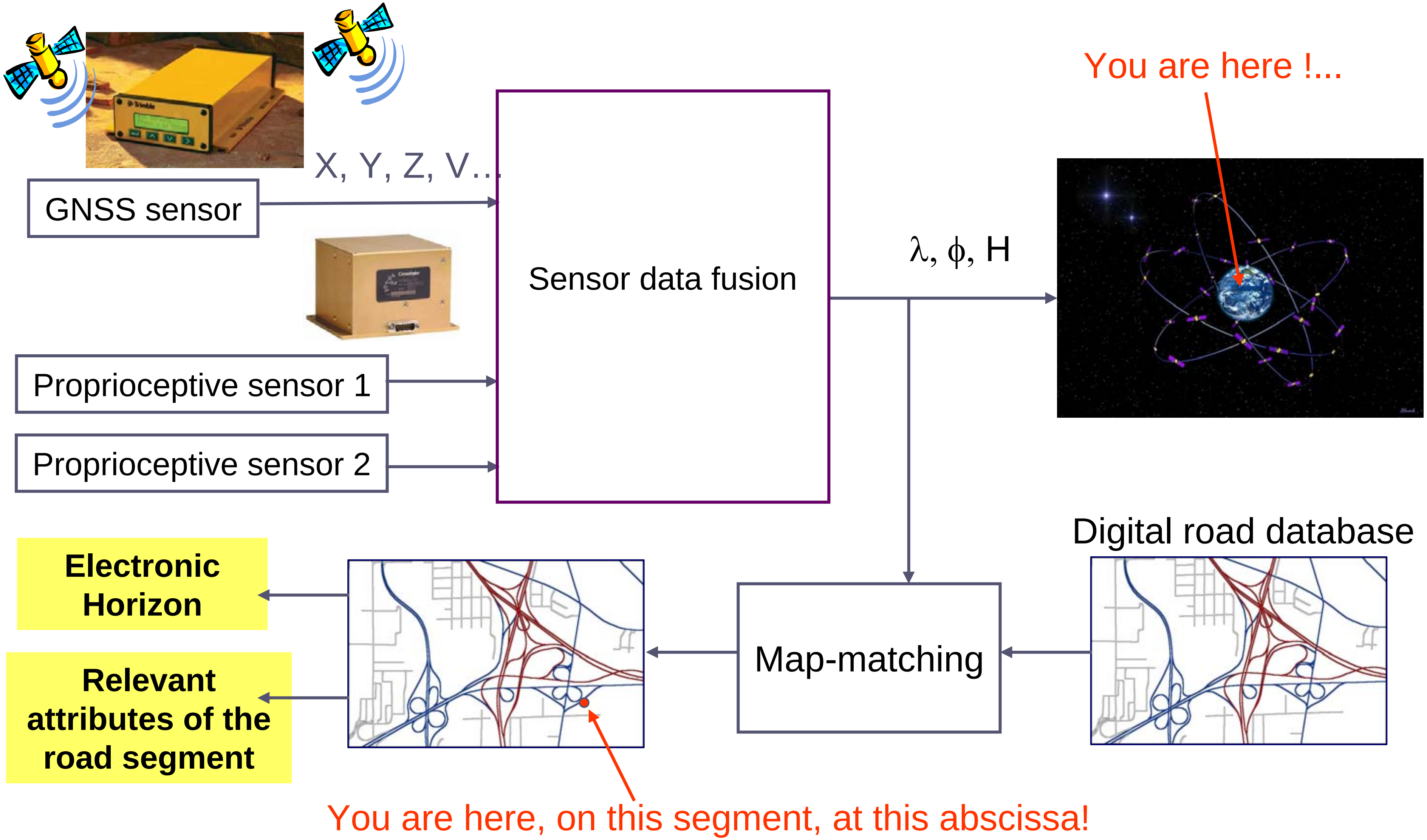
1. Localization errors change often
2. They are often non negligible

Intelligent land vehicles

GPS-alone land localization examples



Land vehicles



Quality of service

- What are the attributes that characterize the needs and the performance of a localization system for Intelligent Vehicles?

Required Navigation Performance
International Civil Aviation Organization

- Accuracy
  - the degree of conformity of information concerning position, velocity, etc. provided by the navigation system relative to actual values.
- Integrity
  - measure of the trust that can be put in the information from the navigation system, i.e., the likelihood of undetected failures in the specified accuracy of the system.
- Availability
  - a measure of the percentage of the intended coverage area in which the navigation system works
- Continuity of service
  - the system's probability of continuously providing information without non-scheduled interruptions during the intended working period.

Outline of the presentation

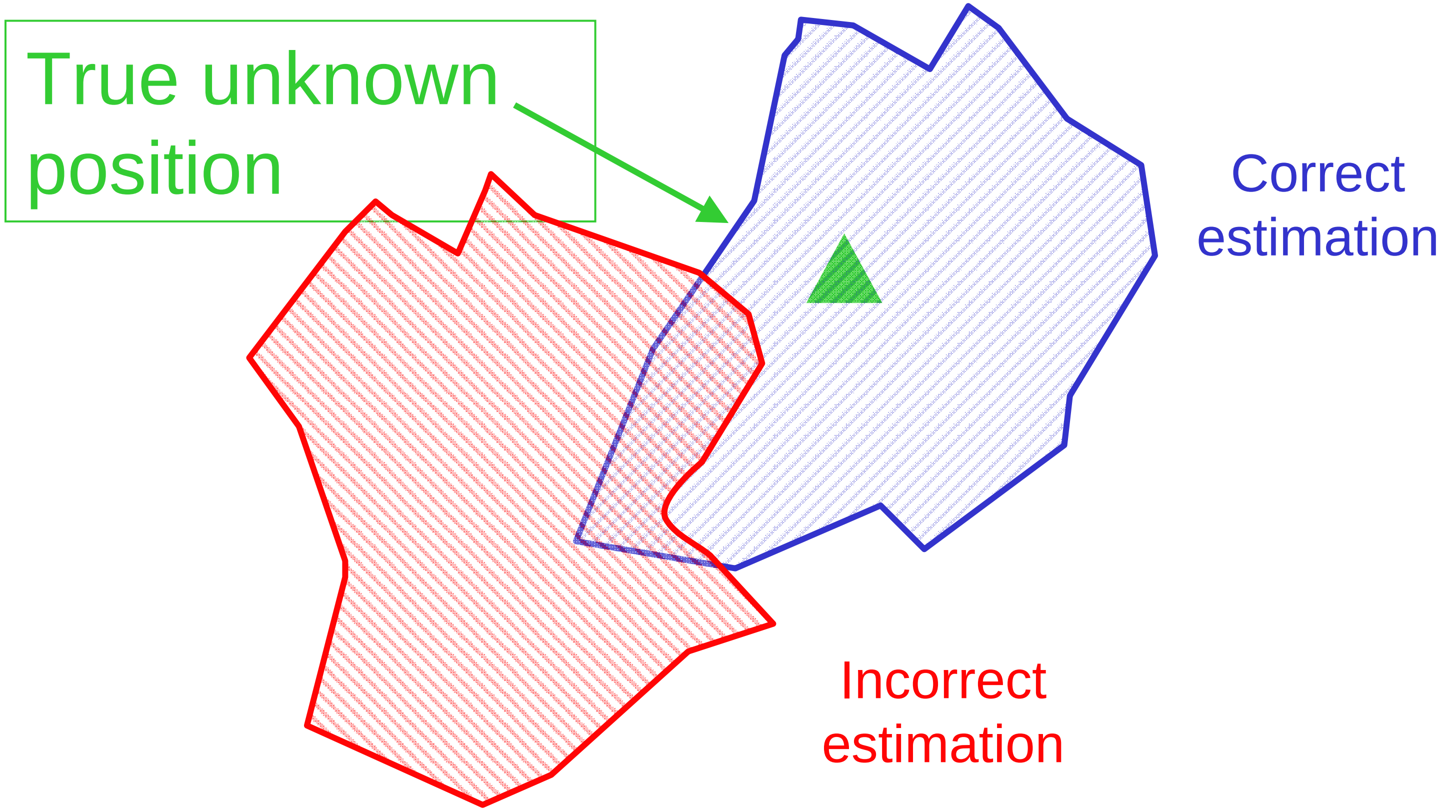
- Localization integrity
- Map-Matching integrity monitoring
- An unified scheme to merge {GNSS, GIS, DR}

Localization integrity

Part One

Integrity of a localization system

- Measure of confidence that can be accorded to the exactitude of the positioning delivered by this system.



Integrity at work

- Usual scheme
  - apply successive checks to ensure that the input information is valid
    → detect and eliminate aberrant measurements
    “internal integrity”
  - estimate a location zone
    “external integrity”

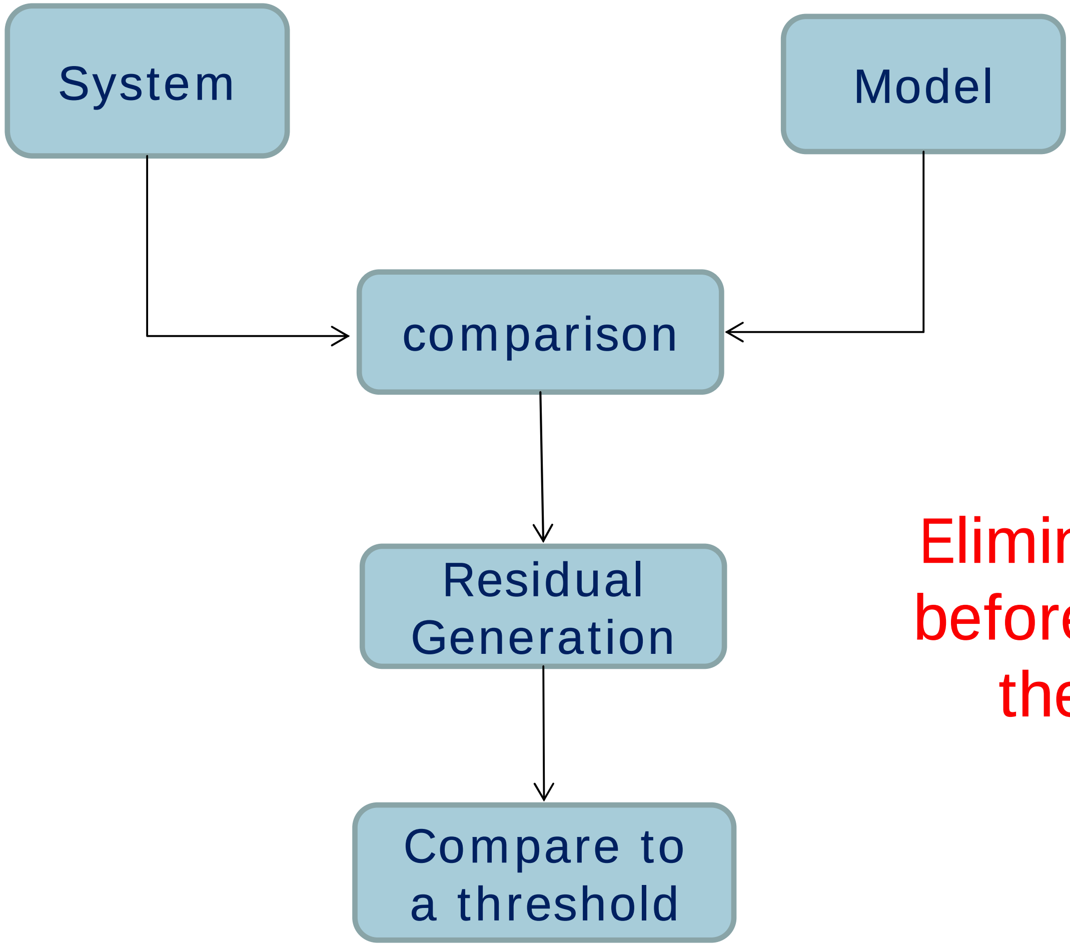
GNSS loose of integrity

- Satellites failures
- Interferences
- Malicious damage

Solutions

- External Monitoring (collaborative)
  - Satellite Based Augmentation Systems
  - EGNOS, WAAS, MSAS
- Internal Monitoring (autonomous)
  - RAIM
  - Data redundancy

RAIM
(Receiver Autonomous Integrity Monitoring)



Eliminate outliers before computing the location

Usual Fault Detection Scheme

Principle

1. Residuals computation
2. Hypothesis test on the norm of the residuals

If there is no fault and

if the noise on the measurements is zero mean and Gaussian

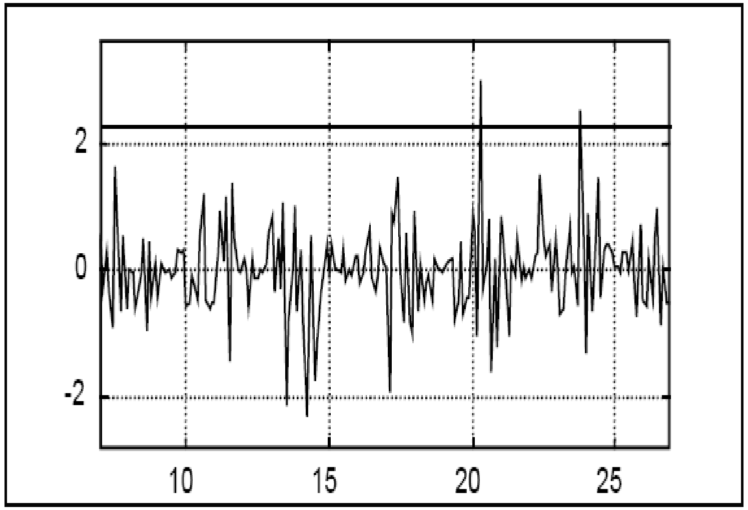
Then the norm of the residuals follows a Chi2 distribution

$$\sigma_{\varepsilon}^{2} = \sum_{i=1}^{n} \frac{\varepsilon_i^2}{\sigma_i^2} \sim X_{(n-m)}^{2}$$

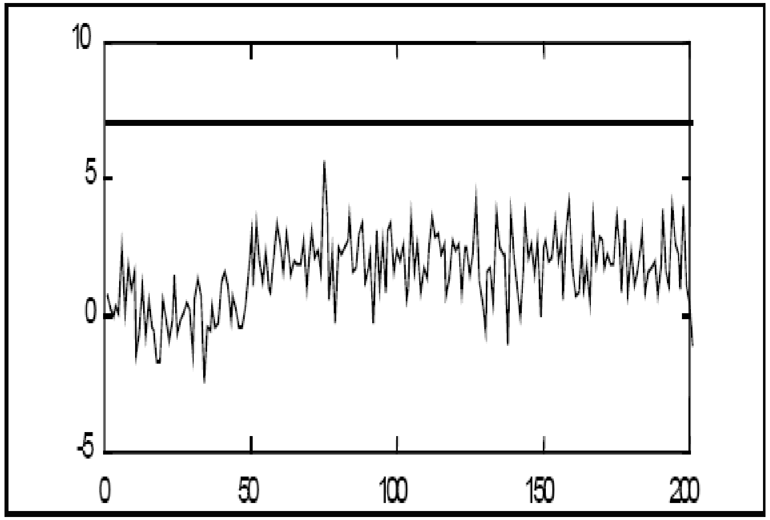
If the test fails, then a fault is likely to occur

The most likely biased data is removed and the process is iterated
➔ M-estimator, Median least Squares, RANSAC...

Fault detection typical problems



False alarm



Missed detection

Risk: to eliminate good data and so to loose information.

Risk: to keep misleading information (which doesn't respect the hypotheses)

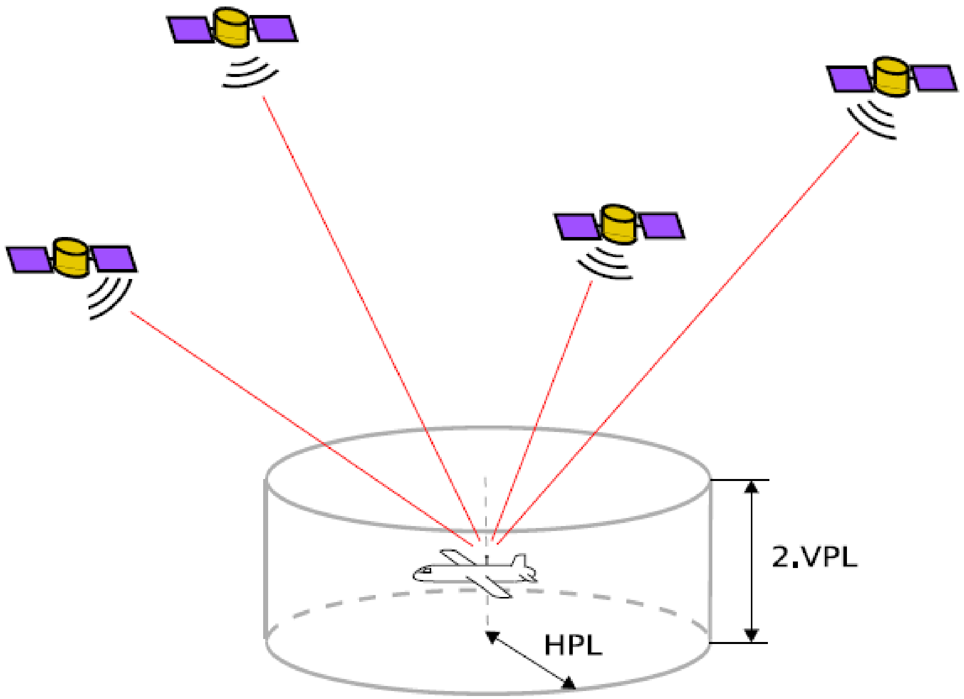
➔ to compute a bad localization zone

Internal Integrity

- Capability of detecting faults using redundant information
- It depends on the
  - Amount of redundancy (degree of freedom)
  - Measurement noise
    - The smallest detectable fault depends on the chosen probability of false alarm, Minimum Detectable Bias
  - Geometrical configuration

External Integrity

- Protection Computation (HPL, VPL)



Maximum error due to an undetected fault

Classical application: GNSS fix computation

$$Y = h(X) \Leftrightarrow \begin{bmatrix} \rho_1 \\ \vdots \\ \rho_n \end{bmatrix} = \begin{bmatrix} \sqrt{(x-x_{s1})^2 + (y-y_{s1})^2 + (z-z_{s1})^2} + c.dtu \\ \vdots \\ \sqrt{(x-x_{sn})^2 + (y-y_{sn})^2 + (z-z_{sn})^2} + c.dtu \end{bmatrix}$$

The resolution $Y = h(X)$

can be done using an iterative scheme $dY = H.dX$

Residuals $\varepsilon = Y - h(\hat{X}) = (I - HH^{+}) \cdot dY = S \cdot dY$

Residuals with faults $\varepsilon = S \cdot (dY + E)$ noise + fault

➔ One can apply the superposition principle

So, let's forget the noise

$$\varepsilon = \left(I - HH^{+}\right) \cdot E$$

If there is only one fault *b* on satellite i then $E = \begin{bmatrix} \underset{1}{0} & \dots & \underset{i}{b} & \dots & \underset{N}{0} \end{bmatrix}$

The error is the horizontal plane is

$$e^{i}{}_{hor}{}^{2} = \left(H^{+}_{(1,i)}{}^{2} + H^{+}_{(2,i)}{}^{2}\right) \cdot b^{2} = HSlope_{i} \times \left\|\varepsilon\right\|^{2}$$

At the end of the fault detection, the impact of an undetected fault is considered in the worth case

$$\left\|\varepsilon\right\|^{2} < Thd\left(P_{fa}\right) \Rightarrow \forall i \;\; e^{i}_{hor}{}^{2} < HSlope_{i} \times Thd$$

Approximate Radius of Protection (ARP)

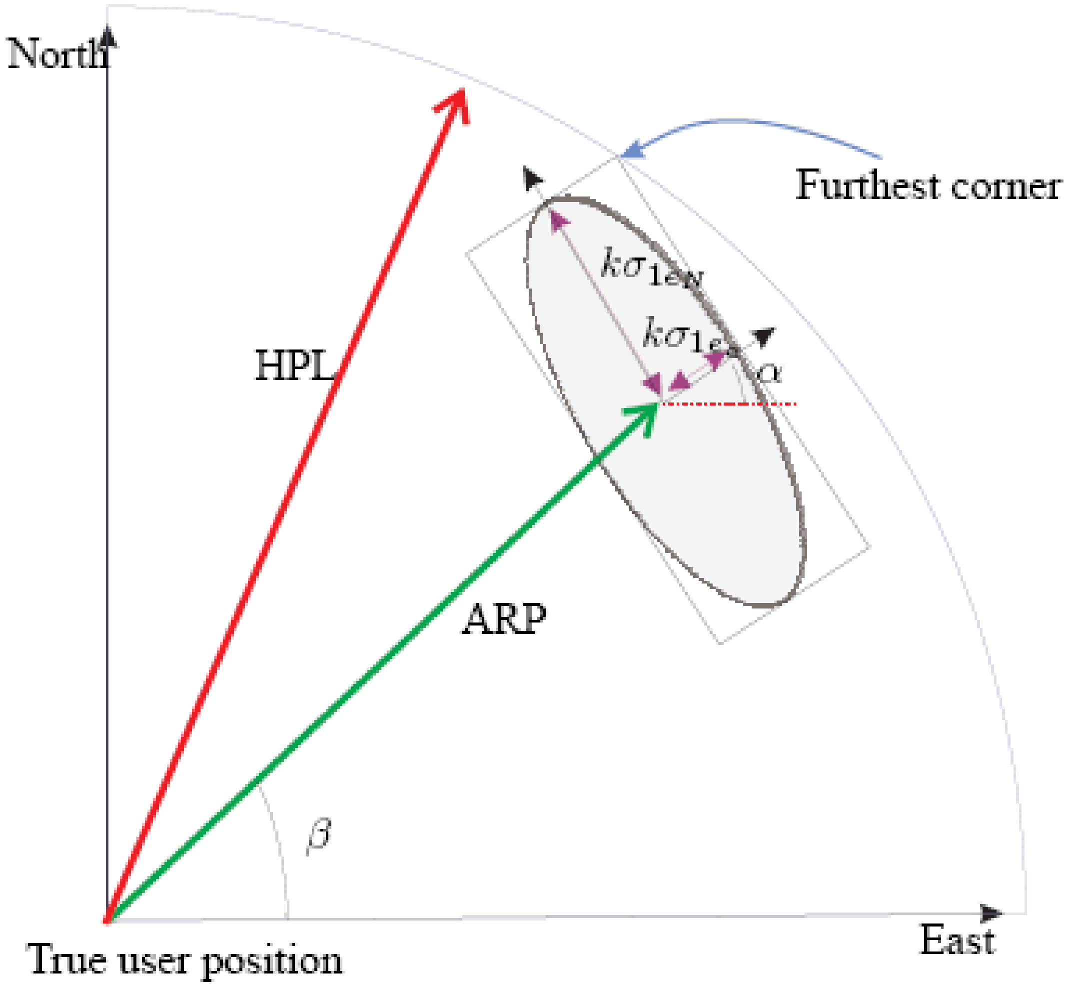
$$ARP = \max_{i} HSlope_{i} \times Thd$$

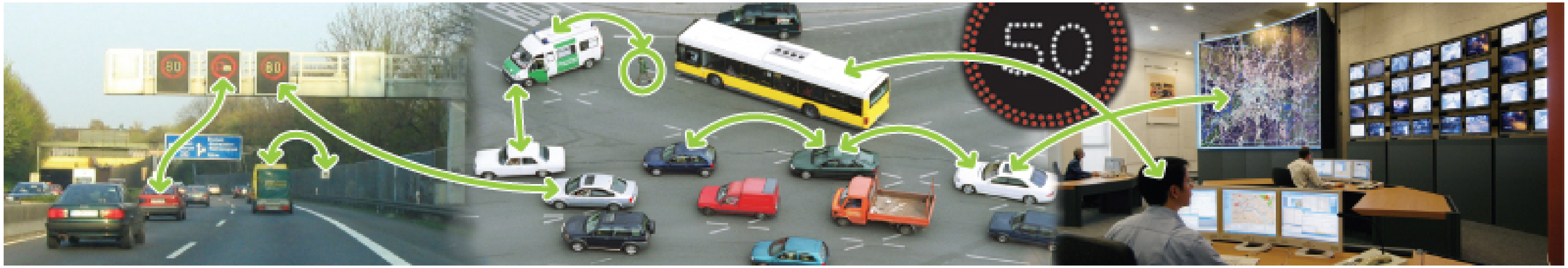
The effect of the noise is added

Superposition principle

$$HPL = ARP + Ellipsoid$$

B. Belabbas and F.Gass. 2005.





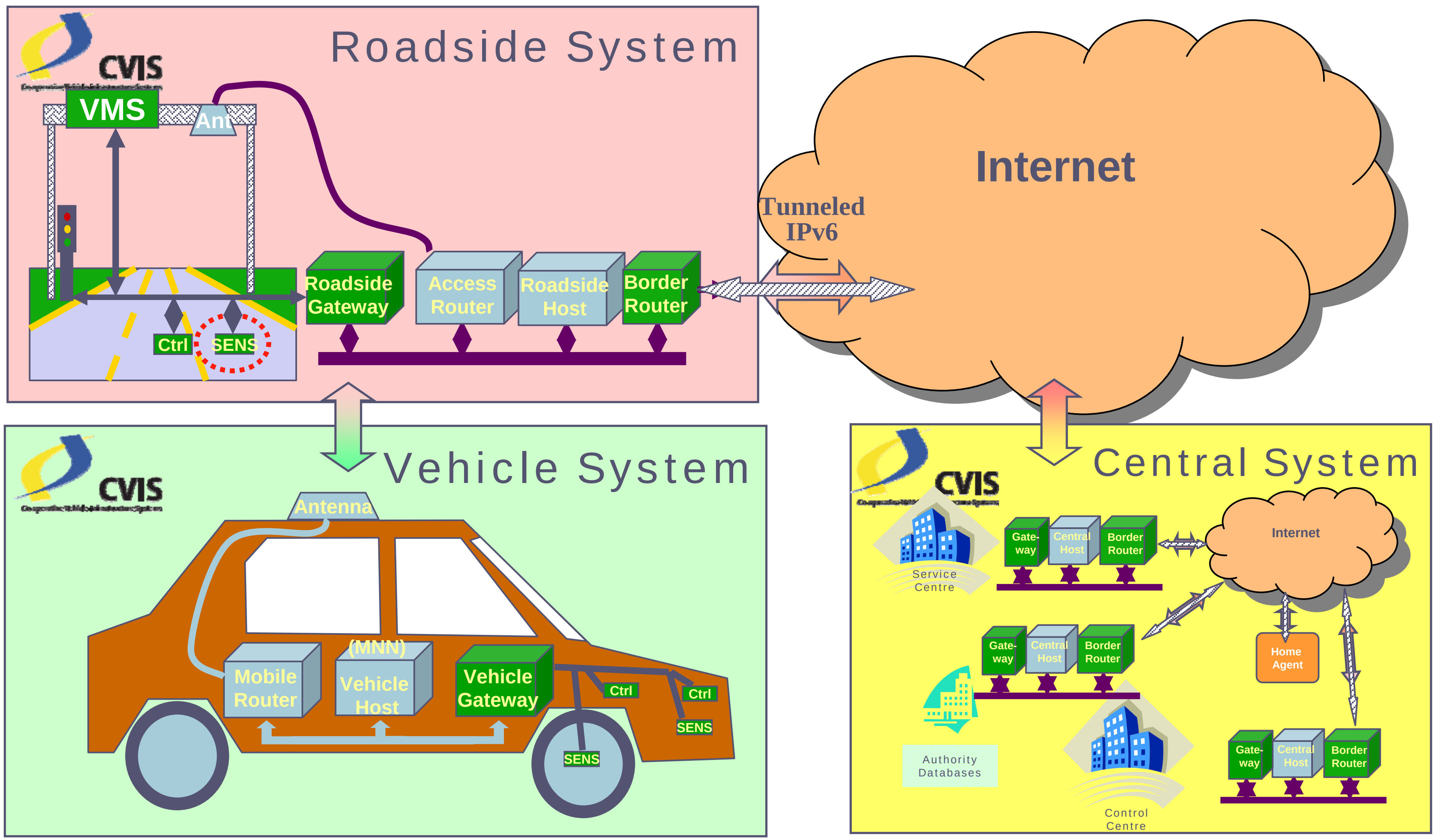
Characterization of the confidence in the map matching process of a localization system

Part 2

CVIS, FP6 IST EU project

4 years: 2006-2010, 61 partners

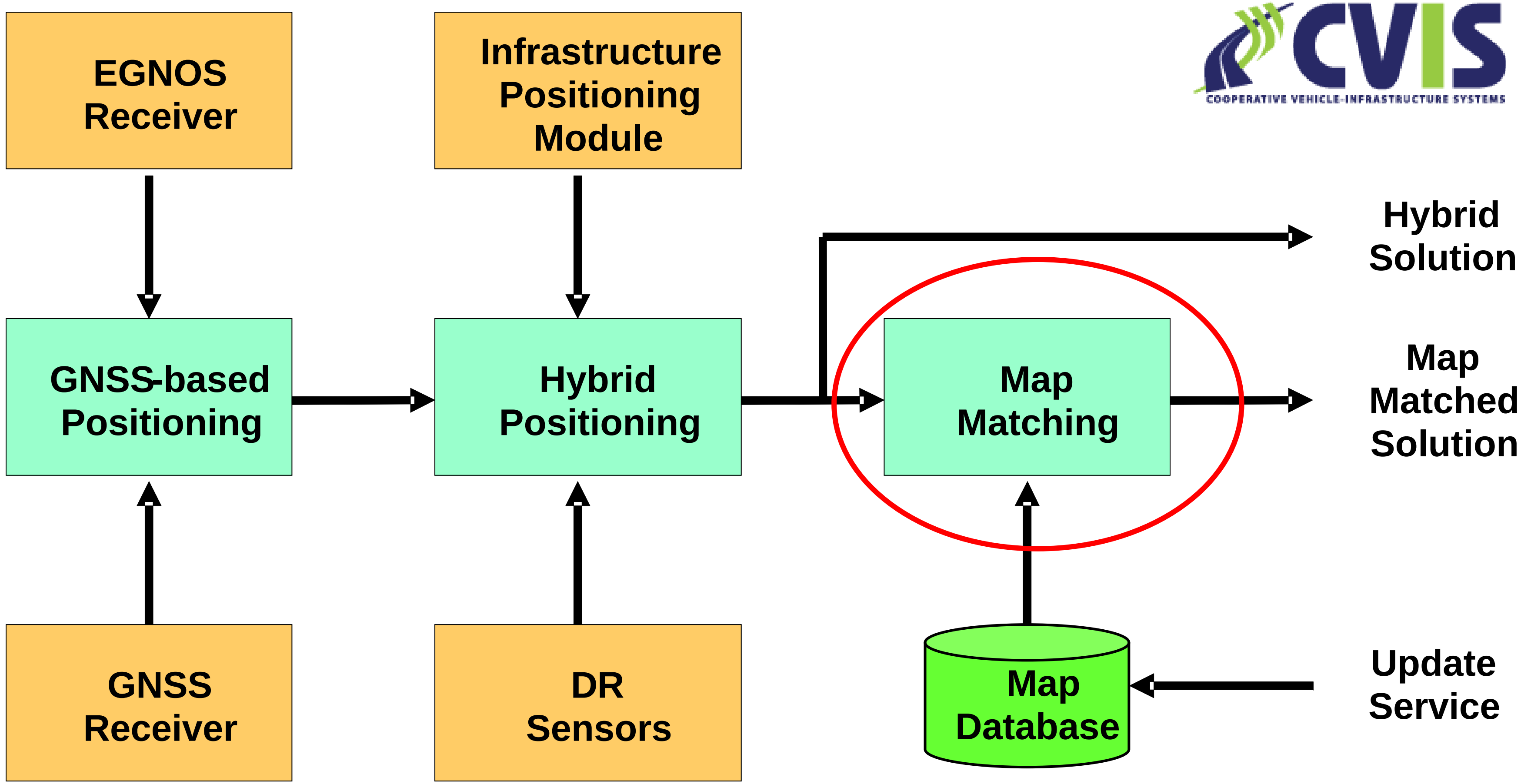
CVIS European project



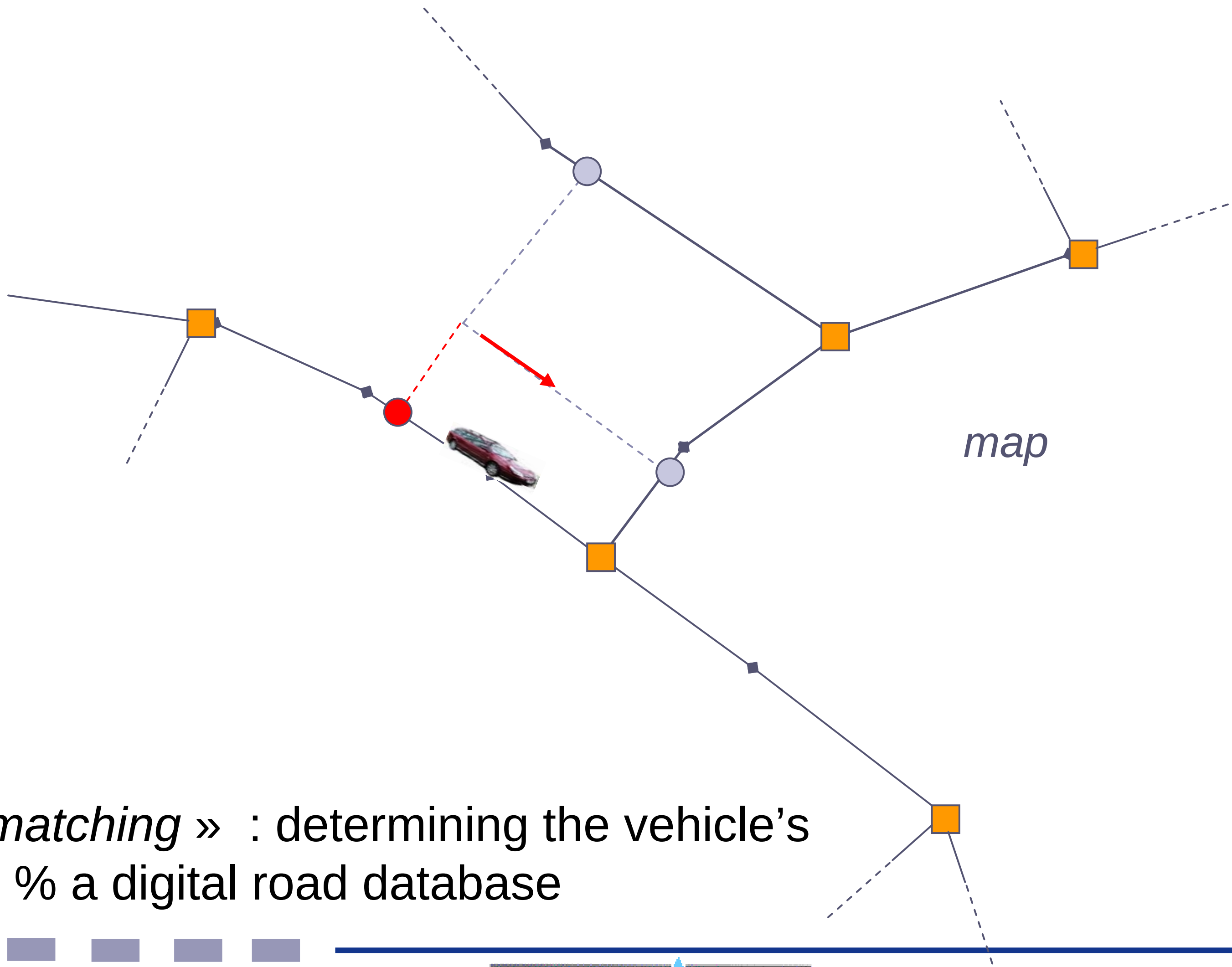
POMA – Subproject of CVIS
Main requirements

- Sutdy cost-effective and reliable **positioning solutions**
- Integrate **on-board sensors** and **road-side sensors**
- Enhance current **map-matching solutions**
- Formulate **confidence levels** of the estimates
- Implement POMA interface within CVIS applications

Main functions of the position calculation process in POMA

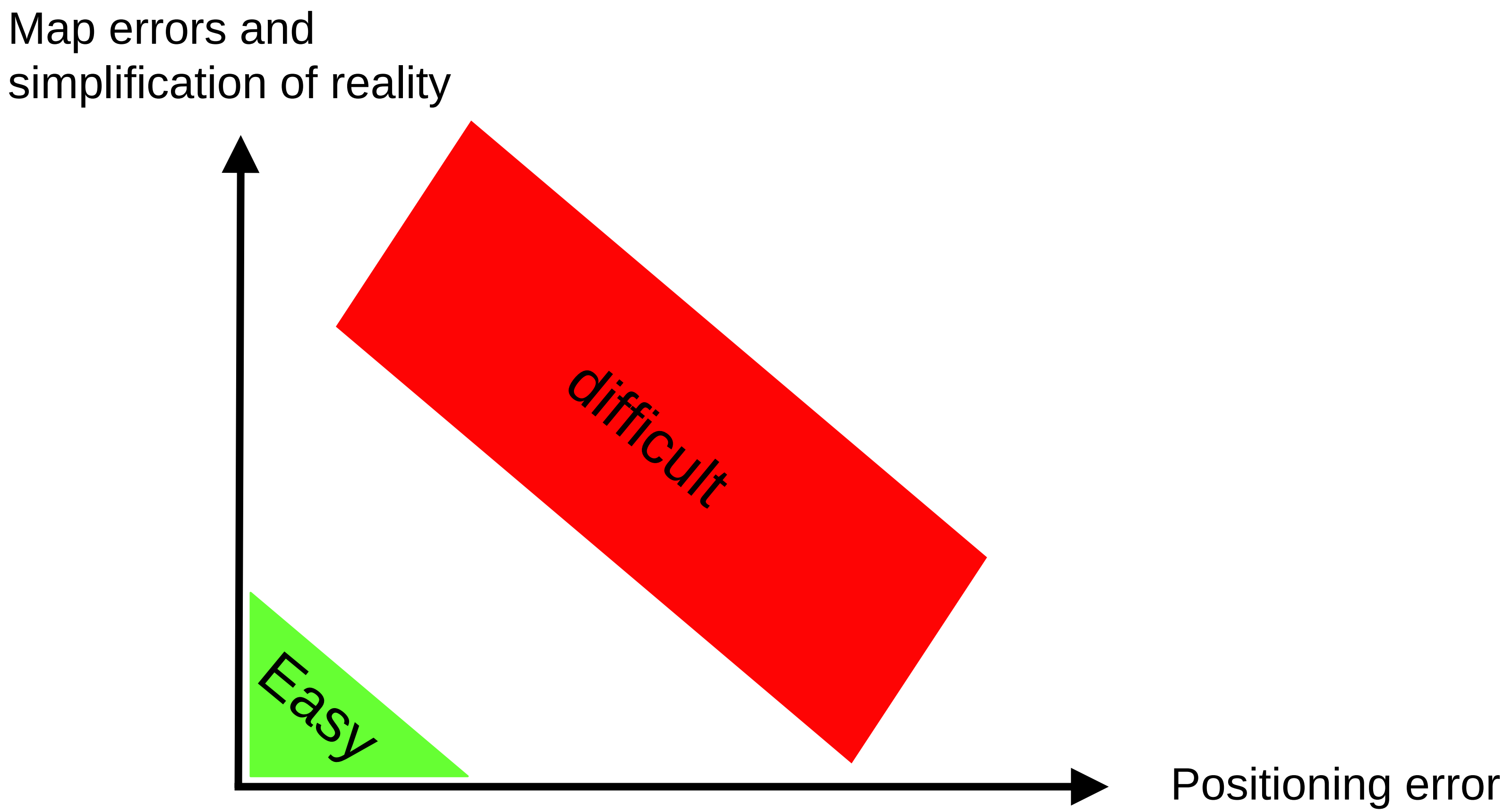


Map Matching - Definition

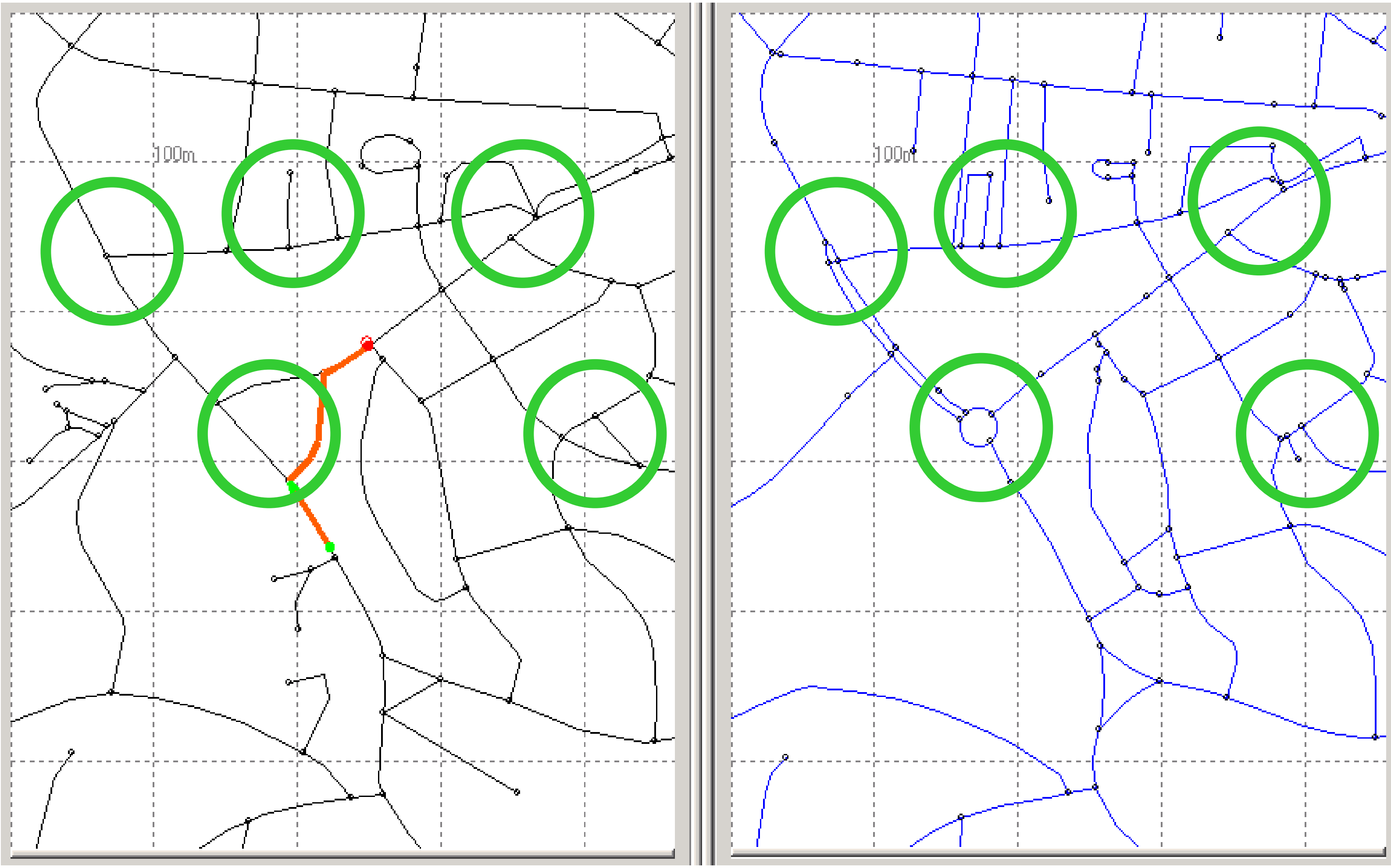


« *map-matching* » : determining the vehicle's position % a digital road database

MM errors sensitivity



Our European Maps!

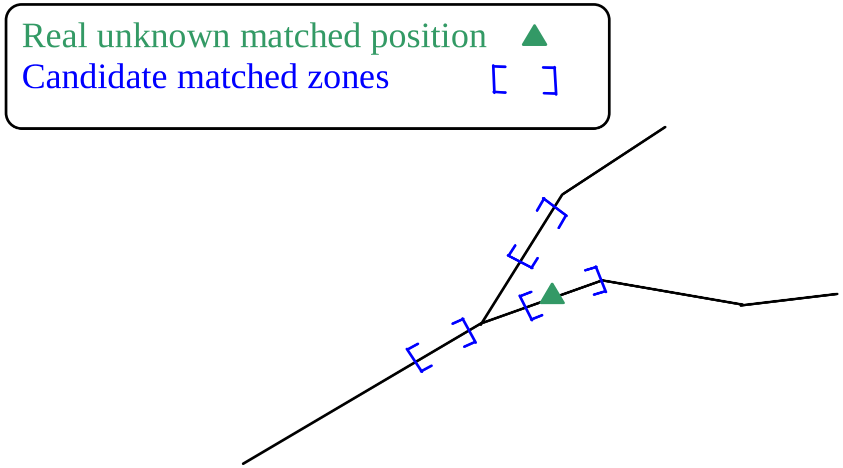


Modern Map-Matching Outputs

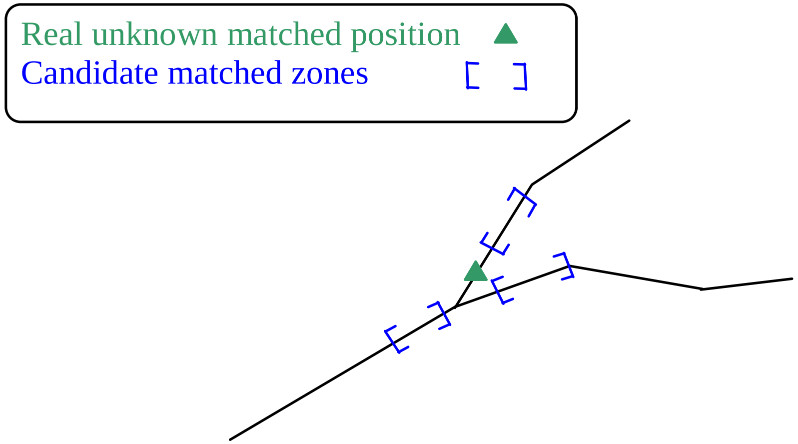
- MM outputs :
  - up to 10 matched candidates (Map-Matched hypothesis)
  - with confidence indicators
- Very often it is the hypothesis with the maximum probability that is used: for navigation tasks or fleet management applications it is acceptable.
  But for many other applications, like eCall or “ISA”, it is important to manage all the hypotheses.

Integrity of a map-matching system

- Map-Matching Integrity definition (proposal)
  - A map-matching process is reliable (or safe) if the matched ground truth is located within the hypotheses zones provided by the system.



Safe

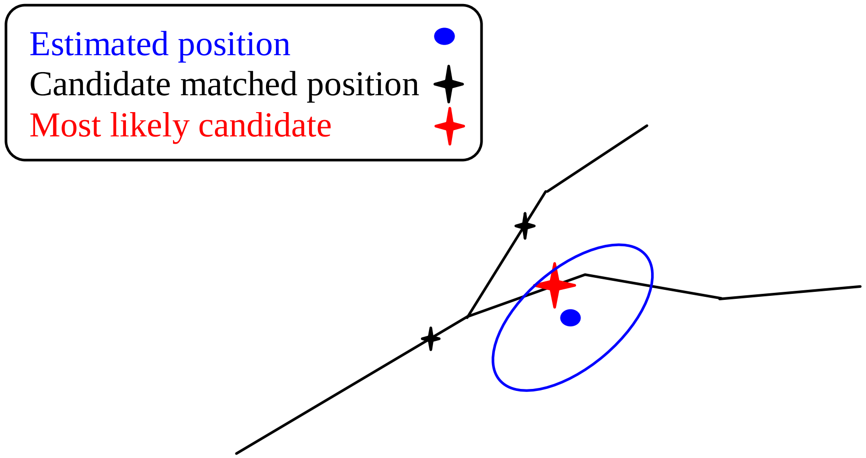


Misleading

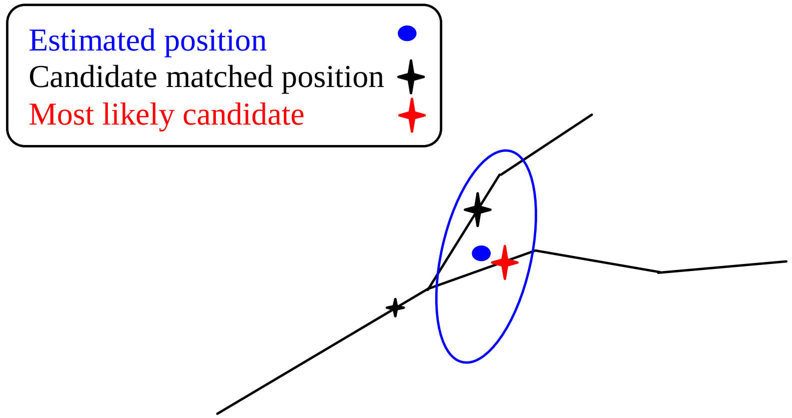
How to characterize MM integrity in real-time?

- Multi-Hypothesis Map-Matching (MHMM)
- Estimate the probability of each hypothesis with respect to the others
- Compute Normalized Residuals for each hypothesis
- Apply a decision rule (depending on the application)

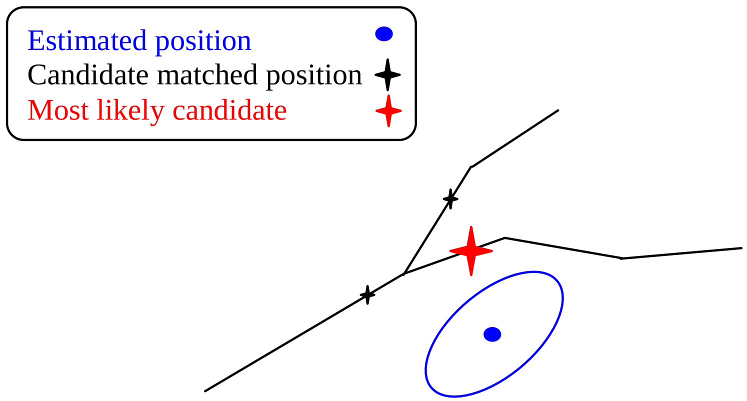
Monitoring integrity using MHMM outputs



Case 1 : confident MM



Case 2 : ambiguous MM

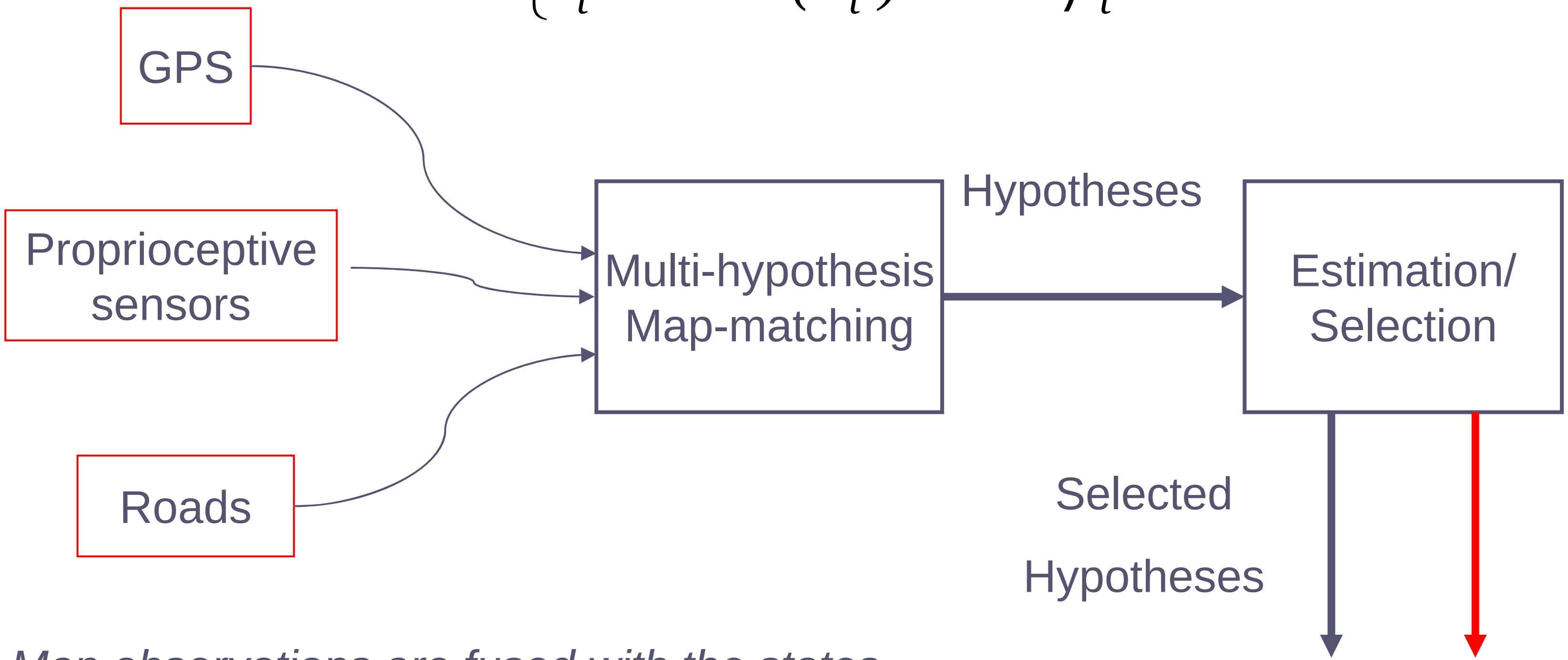


Case 3: inconsistent candidates

First approach

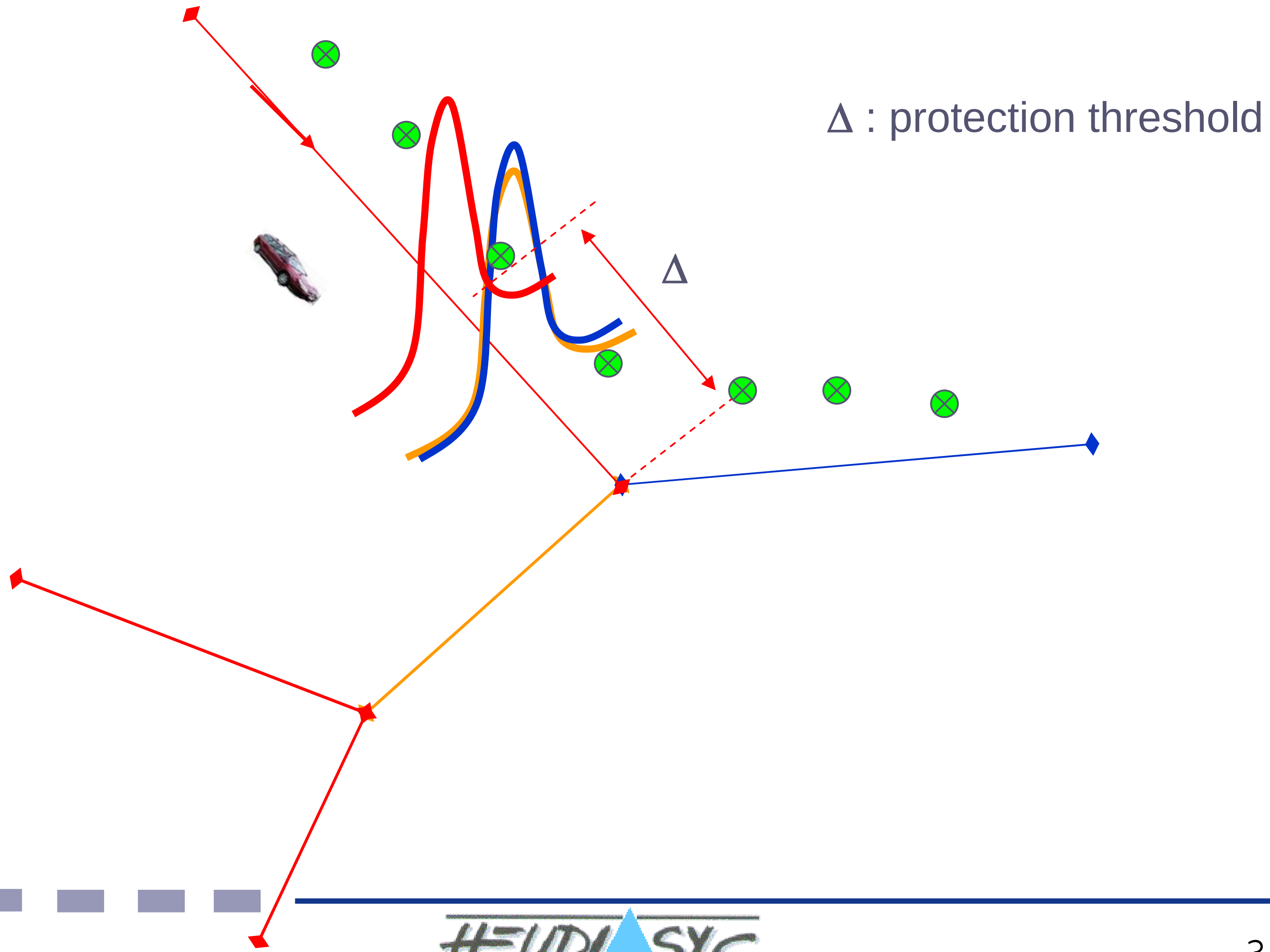
- **M**ultiple **O**bservation **M**odels **K**alman **F**ilter

$$\begin{cases} x_t = f(x_{t-1}) + \alpha_t \\ z_t = o(x_t) + \beta_t \end{cases}$$



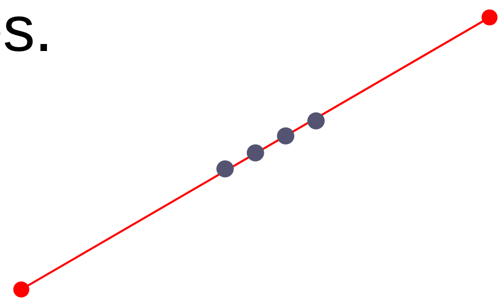
Map observations are fused with the states

MOMKF - Hypothesis Creation



Second approach

- Multiple Evolution Model **Particle Filter** (MEMPF)
- The MEMPF is a road tracking method that follows another strategy:
  - particles are constraint to follow the poly-lines representing the roads
- Noises added at each prediction step in order to explore randomly the different hypotheses.
- A map matched position is a hybrid state

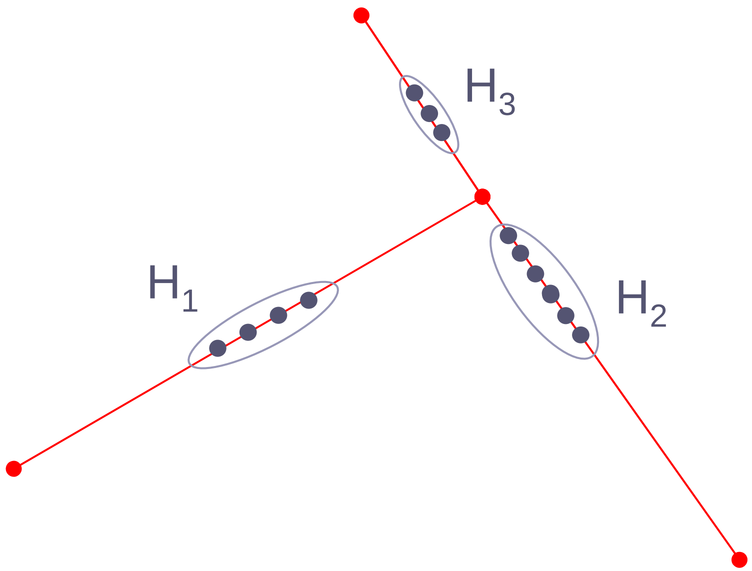


$$M_{(i)} = (s, ID)$$

MEMPF estimation stage

Hypothesis H_i : approximated by sub-particle sets

$$\chi_{h,t} = \{ \langle (s, ID)_t^n, w_t^n \rangle \mid ID = h \}_{n=1:N}$$



Managing the NIS of MHMM

- Criterion: heading + distance (for each hypothesis)

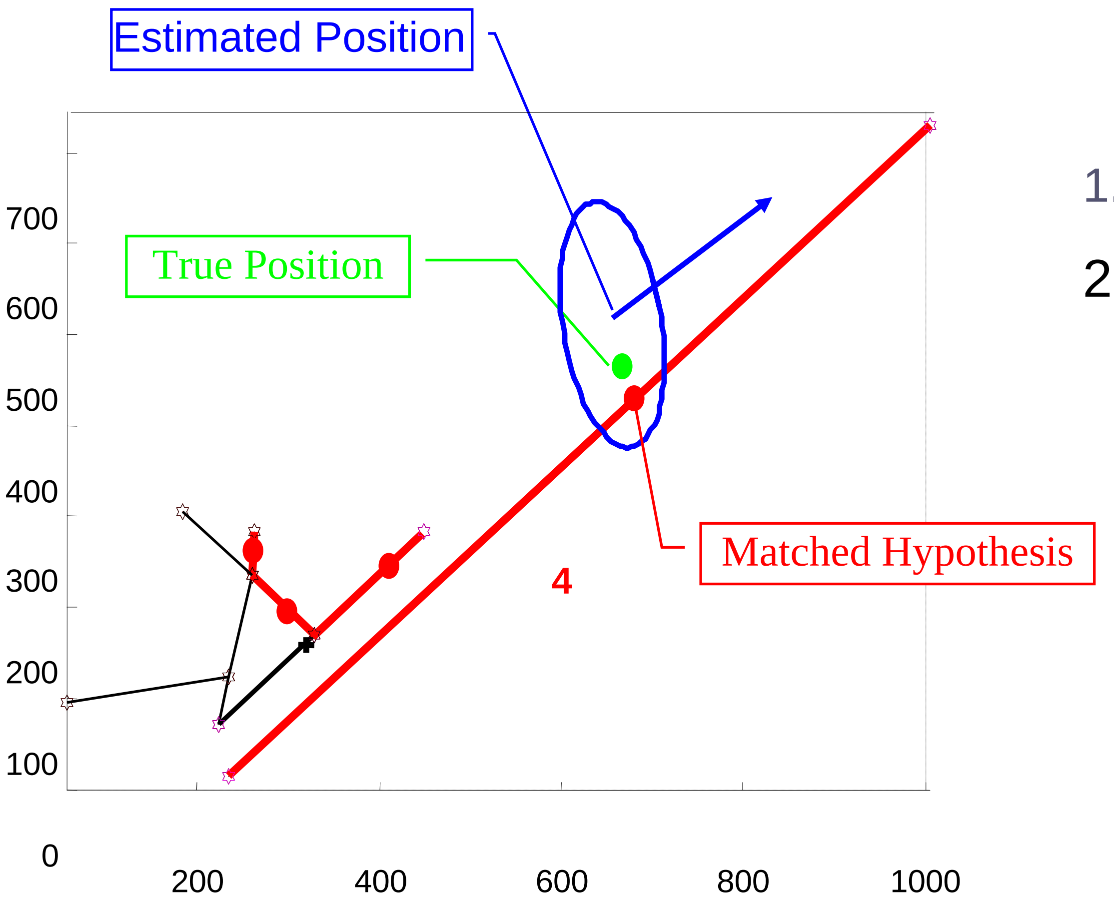
  ➔2 degrees of freedom
- Gaussian hypothesis

  ➔ NIS should follow a Chi Squared distribution
- Decision rule: compare each NIS with a Threshold
  - accept hypothesis "i" if NIS(i)<Th(P_{FA})
  - P_{FA} = 10% ➔ Th = 4.6
  - P_{FA} = 1% ➔ Th = 9.2
  - P_{FA} = 0.1% ➔ Th = 13.8
  - P_{FA} = 0.01% ➔ Th = 18.4

Managing the probabilities of MHMM

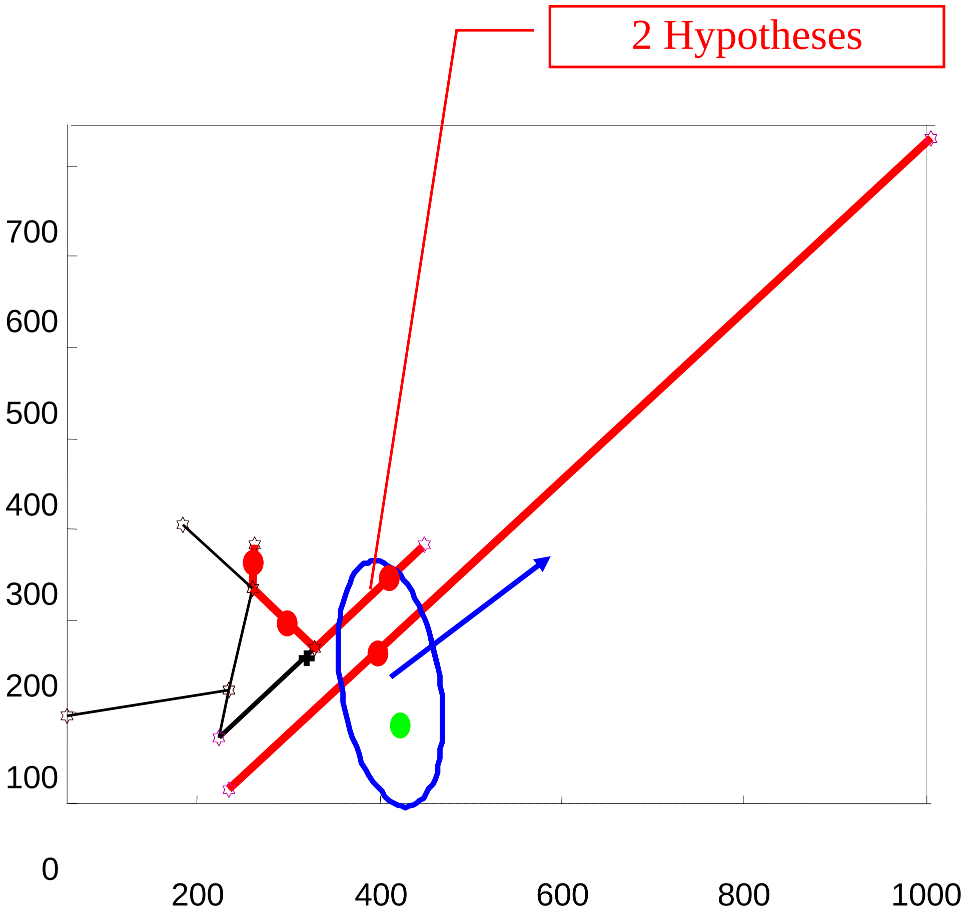
- It depends on the application!
- Navigation typical rule
  - Take the most likely hypothesis if $P_i > 0.5$
- Intelligent Speed Adaptation
  - If $P_i < 0.8$ then confirm the extracted speed limit with the one detect by the on board camera
- Road charging
  - Charge the use of the road if the less likely hypothesis j is such that $P_j < 0.1$

MM confident

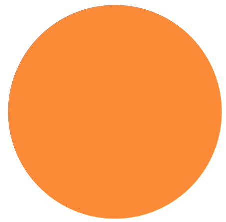


1. One likely hypothesis
2. NIS < Th

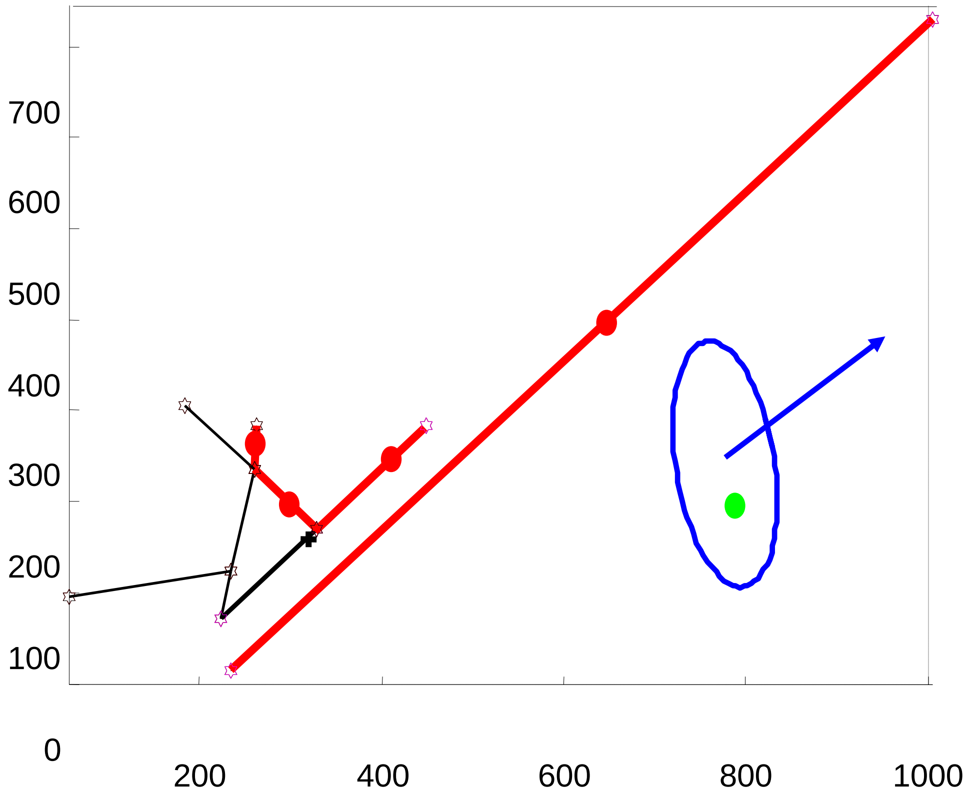
MM ambiguous



- Several likely hypotheses
  - Ambiguity
- For each hypothesis
  - NIS < Th



MM misleading



- Neither hypotheses present small residuals
  - NIS > Th

MM decision rule - Summary

	Conditions	Decision
Case 1	$P > 0.5$, NIS <Th	**MM is declared confident**
Case 2	P < 0.5, NIS <Th	**MM is declared ambiguous**
Case 3	NIS >Th	**No safe hypothesis Don't use the MM**

Experimental Results

Göteborg test track

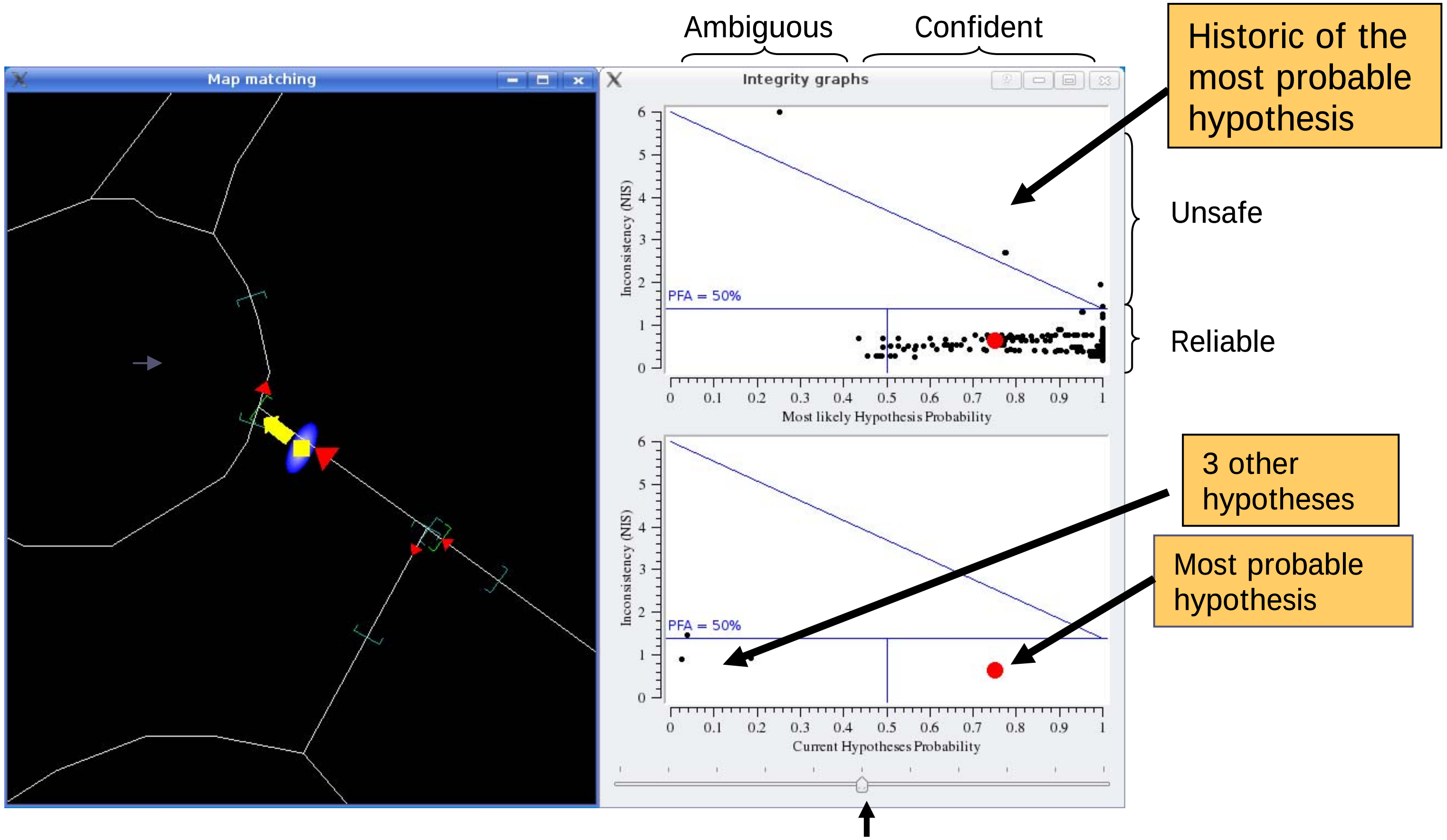
Map-matching integrity monitoring

Map display

-The yellow square and the arrow are the position and the heading of the car

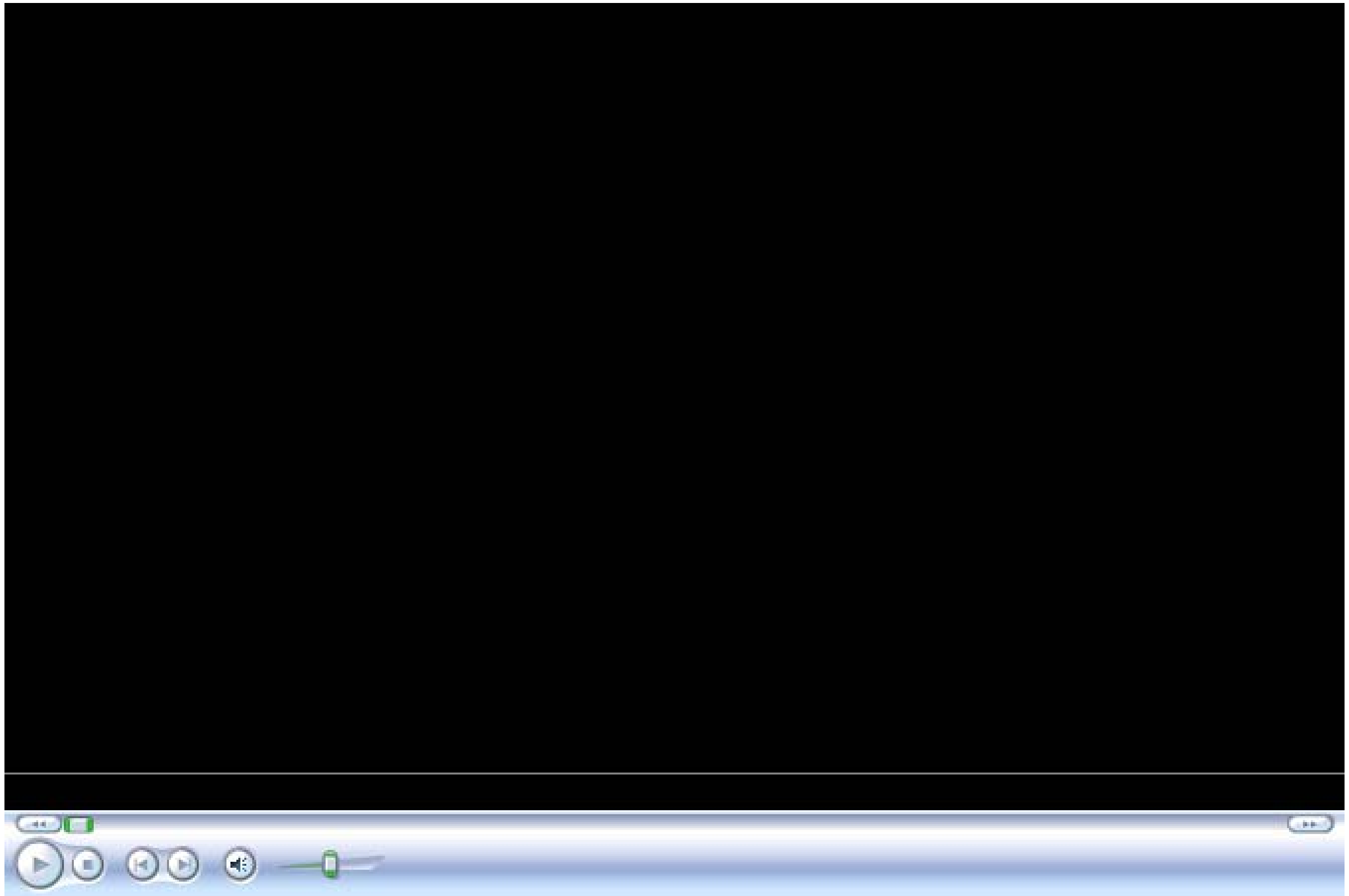
-The 4 red triangles correspond to the hypotheses

-The brackets represent the confidence interval of the track

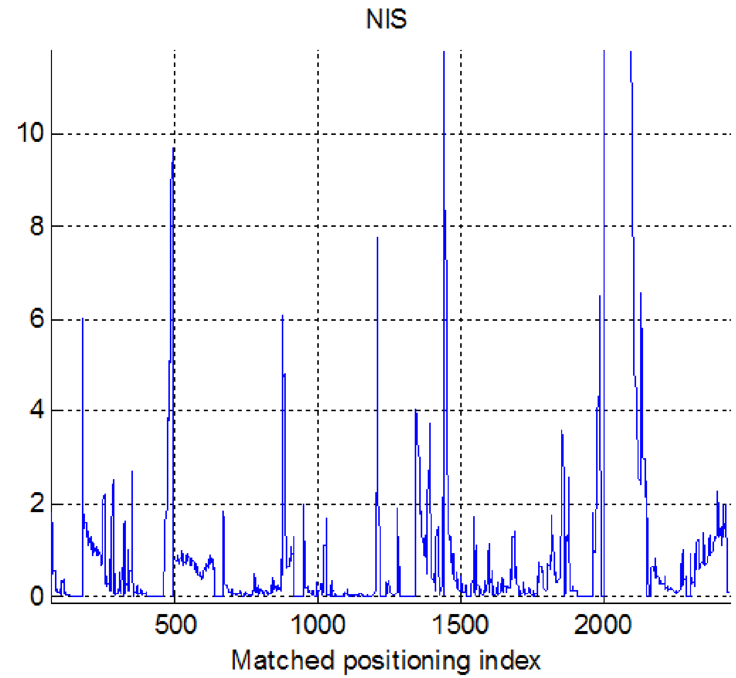


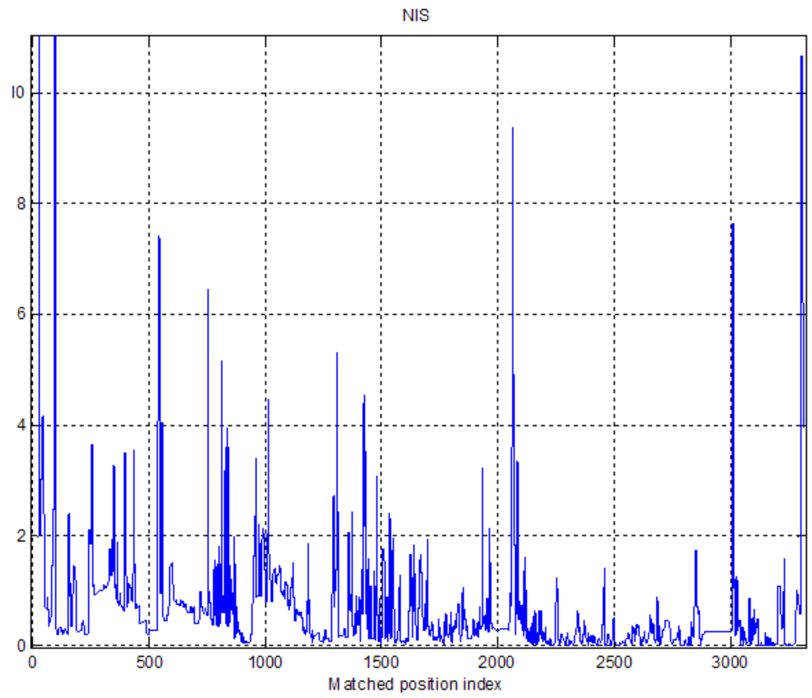
Safety level of the output : the lower the PFA (Probability of False Alarm), the more reliable the hypothesis

MM demo overview



NIS results for both approaches



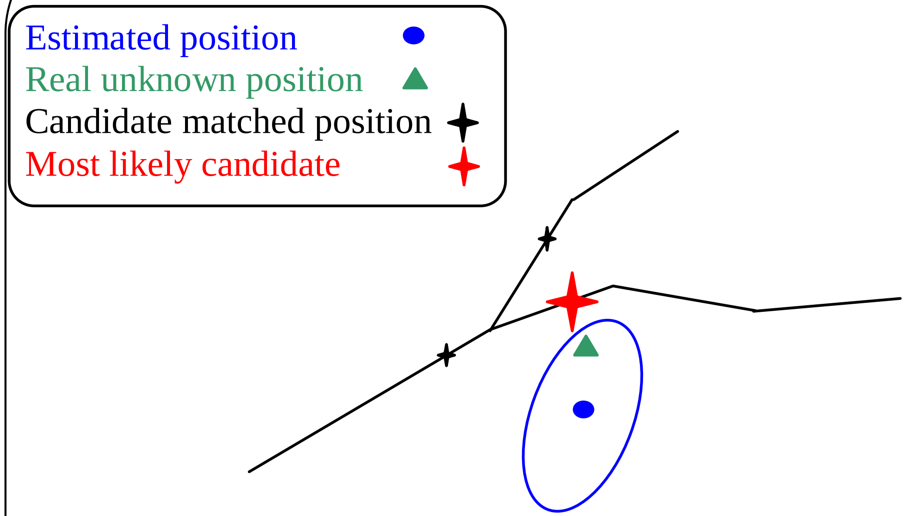


Similar results!

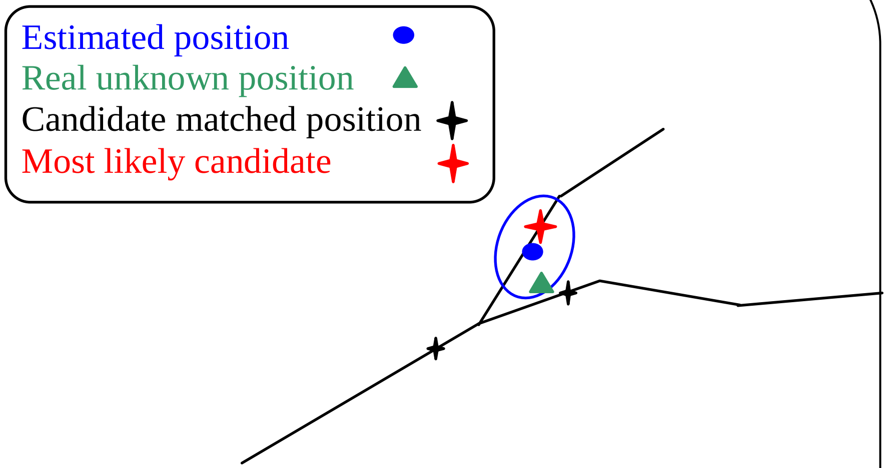
Performance Analysis

- Real data has been recorded on several trials
- The data has been replayed using a player (post-processed)
- The MHMM results have been studied manually

False Alarms and Missed detections



Example of false alarm. The matched point is good but it is declared unsafe by the system



Example of missed detection. The most likely matched point is bad and the system is confident in its map-matching

missed-detection = wrong MM

Performance Analysis of the studied decision rule

Map	**FAR (%)**	**MDR (%)**	**OCDR (%)**
Map *i*	0.66	0.57	98.77
Map *j*	1.33	0.91	97.76

3000 Map-Matched positions

An unified scheme to merge {GNSS, GIS, DR}

Part 3

GPS drawbacks in urban areas

- Bad visibility
  - Satellite masked by high rise buildings
- Bad satellite configuration
  - Urban canyons
- Multipaths
  - Reflexion on Non Line Of Sight (NLOS) satellites
- With less than 4 satellites, it is impossible to fix a point

On the use of rough GNSS measurements

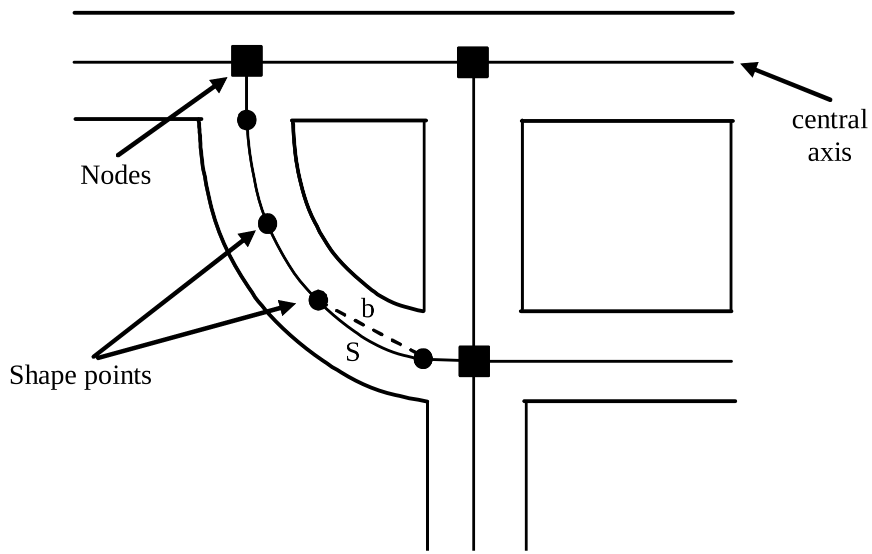
- Often in a urban canyon, 1 or 2 satellites are still visible
- Tightly coupled approach for the data fusion process
  - Pseudo-ranges

$$\rho_c^i = R^i + c \cdot dt_u \qquad \rho_c^i = h^i(x, y, z, dt_u), \ \forall i = 1, \cdots, n$$

  - Doppler measurements
  - Phase measurements

Navigable Maps

- Digital maps of the road network are available in all cities!
- Map can be interpreted as constraints



Tightly coupled GNSS/Map localization

GNSS sensor

Raw data

Proprioceptive sensor 1

Proprioceptive sensor 2

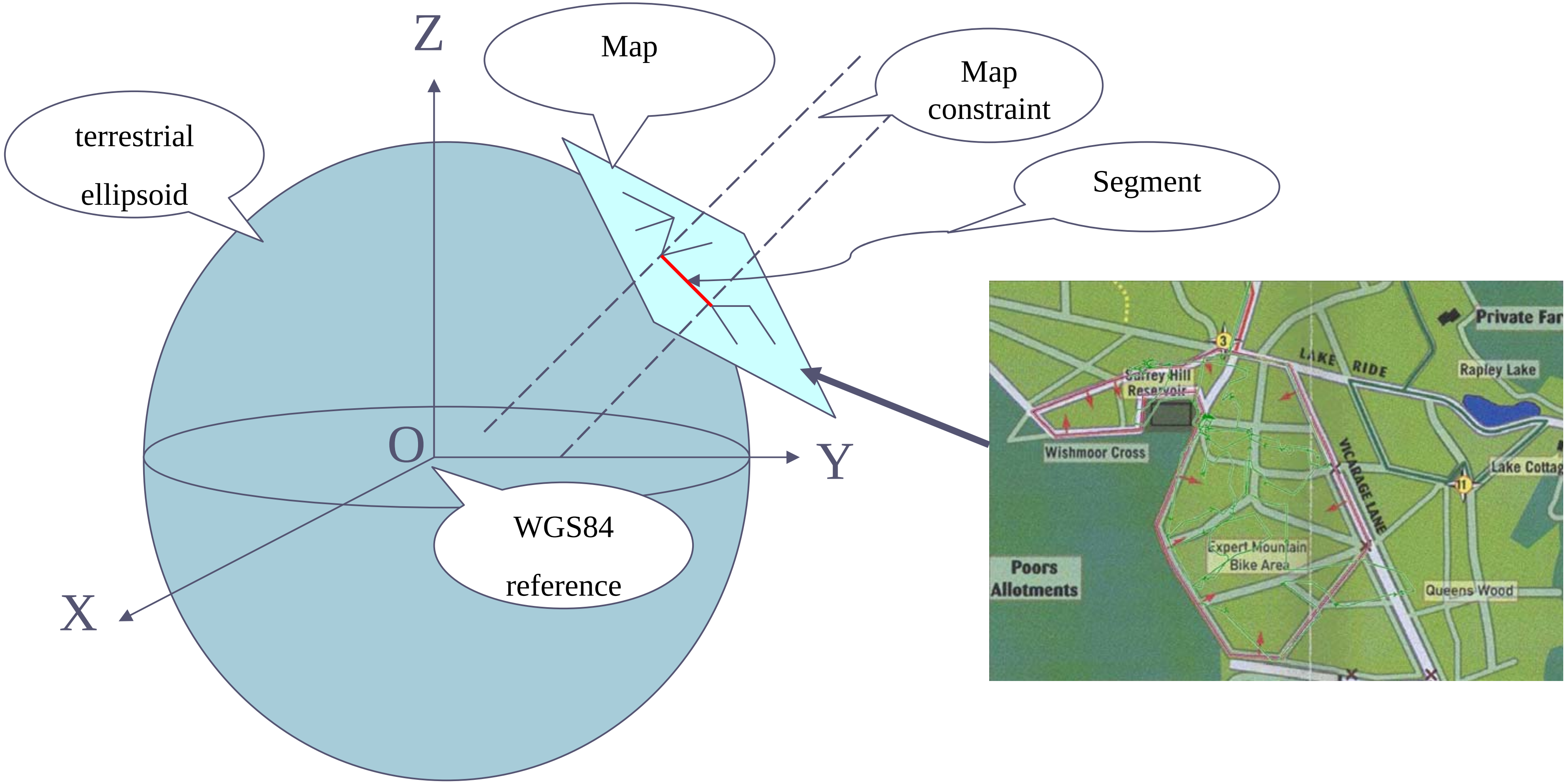
Sensor data fusion and map-matching

road database: **map**

Position on the map

Relevant attributes of the road segment

Tightly Coupling GPS and 2D map data

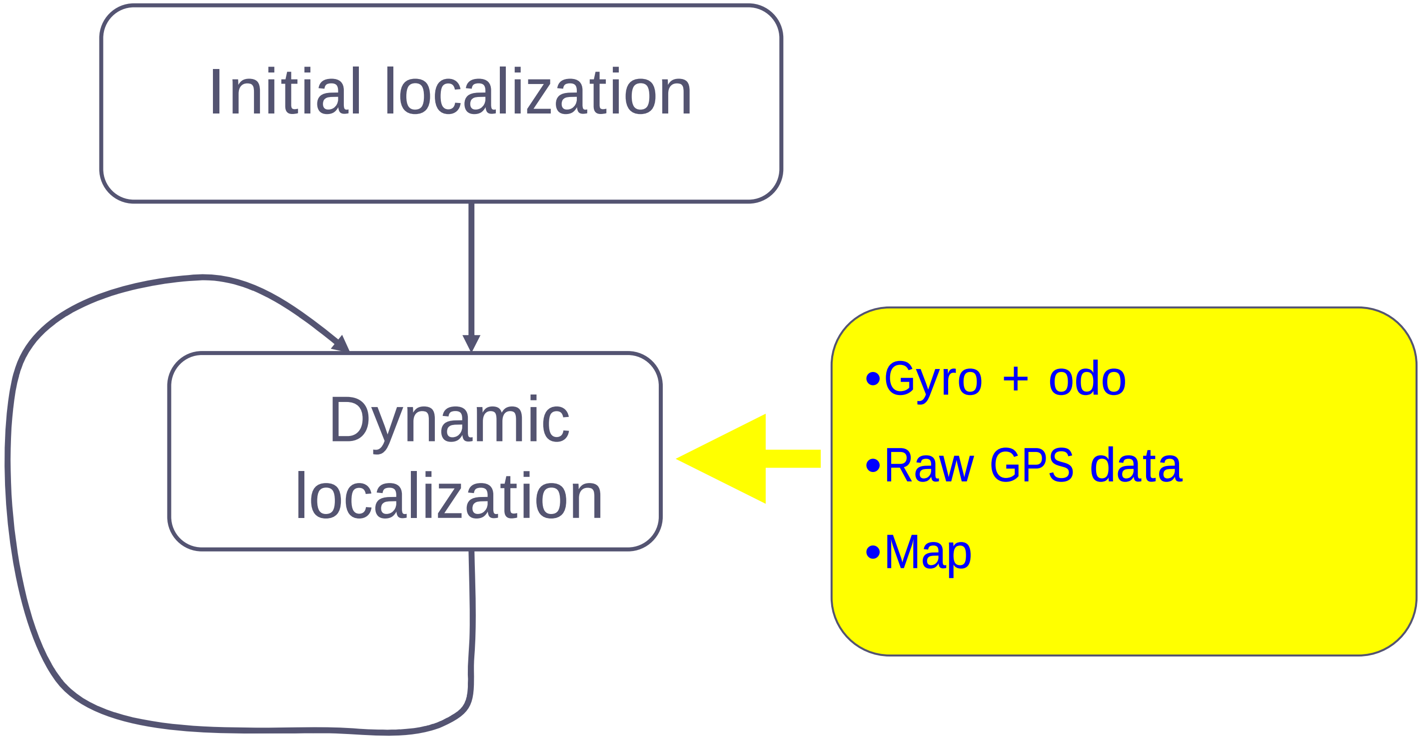


How to handle GPS and Map troubles

- GPS: multi-paths and interferences
- Maps: Inaccurate (bias), obsolete, rough representation of the reality, Ambiguous at junctions

- Proposed strategy:
To rely on dead reckoning and consider that integrity problems come from the GPS data and/or form the map
- Implementation:
  - Mono-hypothesis road tracking
  - Map used as a heading observation
  - Integrity tests on pseudo-ranges and on the map observation (NIS – Normalized Innovation Squared and Ch2 threshold)

Pose tracking



Mono-hypothesis
Kalman Filtering

Experimental results

NavTeQ or TeleAtlas Maps

L1 GPS receiver

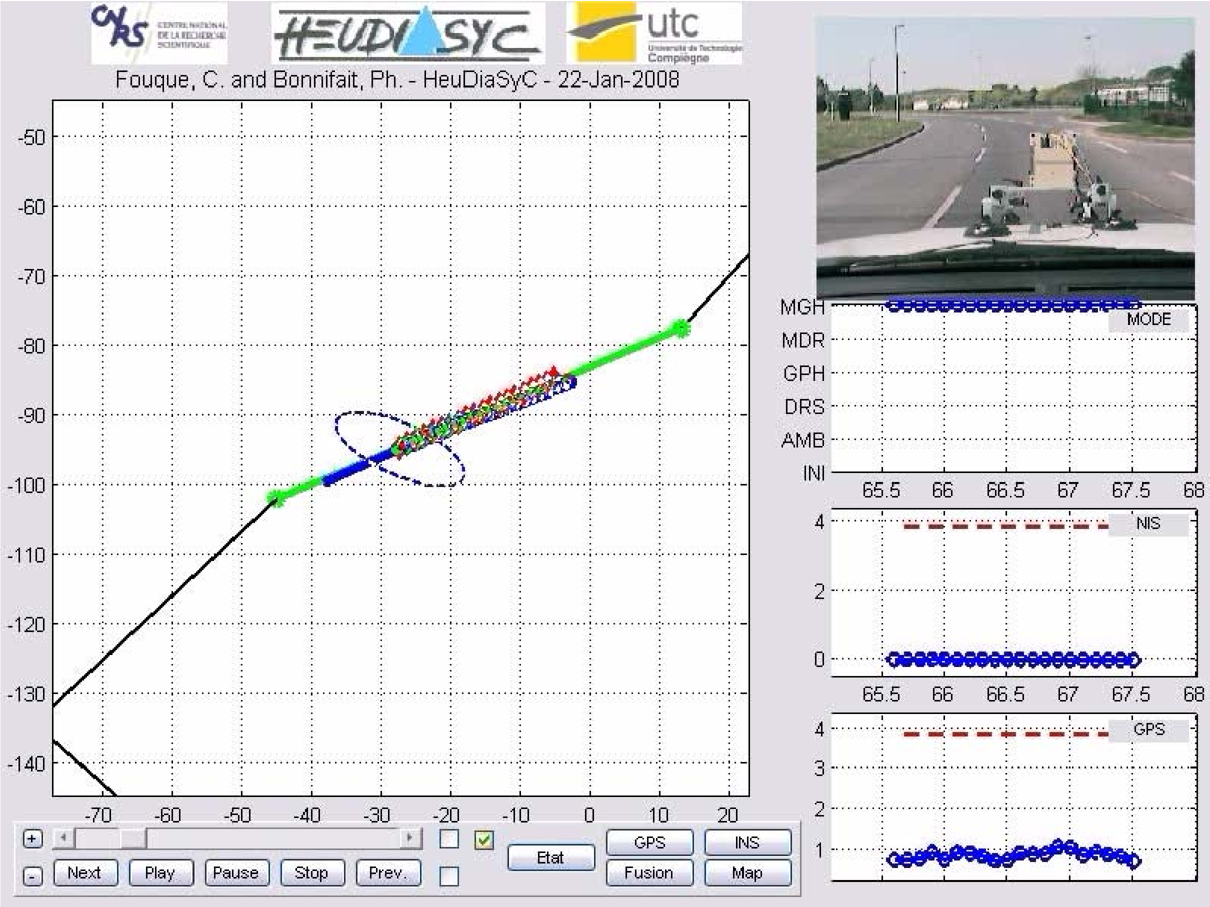
Odometer

Gyro

2D map

Multiple models observation Kalman filter (real data)

Only 7 states Kalman Filter



Conclusion

- Localization integrity
  - Internal (NIS monitoring)
  - Protection zone computation
- Map-Matching
  - An integrity definition of Map-Matching has been proposed
  - Multi-Hypothesis Map-Matching (MHMM) is crucial for Integrity Monitoring
  - Experimental validation with two map providers
- Tightly fusion of GNSS and Map has many advantages
  - Use of few satellite in LOS
  - Possibility to apply efficient integrity tests
  - Map-Matching is a sub-product of the method

Perspective

- Galiléo measurements (2013)
- 3D maps (CityVIP new French Predit project)
- Validate the confidence indicators that are useful for integrity monitoring

Thank you for your attention!

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