How to model the positioning error

High Quality Positioning: a Key to Success for Autonomous Driving

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Abstract (3 subsections)

- Error sources and influencing parameters
- Learning process based on field testing
- Error modeling and simulation, and validation

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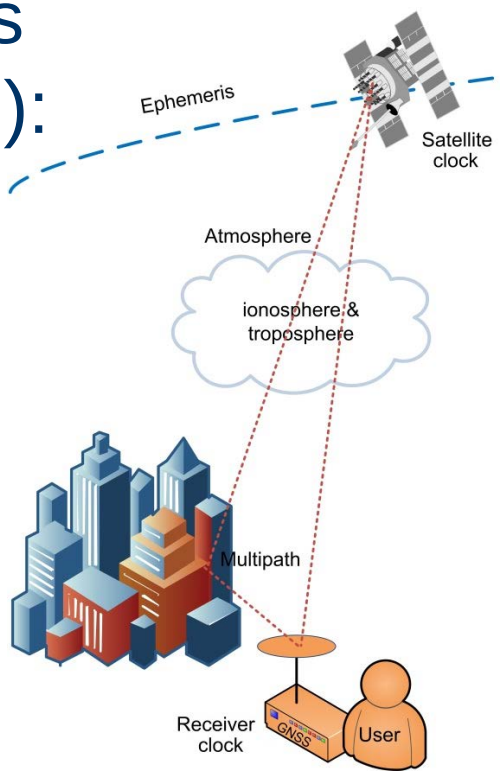
Error sources (1st §)

- Errors originating from the satellites (to which one measures a distance): clocks, orbits
- Errors originating from propagation through atmosphere: iono, tropo
- Errors originating from propagation locally at receiver level (multipath): malicious attacks not being considered here



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Typical error standard deviations

Source	Range error (standard deviation, 1 sigma)
Residual satellite ephemeris and clock errors	0.5 m
Residual ionosphere error (single-frequency)	4.0 m
Residual ionosphere error (dual-frequency)	0.1 m
Residual troposphere error (assuming latitude and season dependent model)	0.2 m
Multipath error for code meas. (~100 x less for phase)	**=> Several tens of m**
Tracking noise for code meas. (~100 x less for phase)	< 1.0 m

- Multipath error have non random nature: bias and possibly 3D modeled

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Last, but not least, system DOP

- Even if no bias would impact ranging…
- Ranging noise to positioning noise statistics through the mathematics of trilateration
- Non isotropic error (lat / lon / alt)
- DOP, system coverage, Earth poles issue
- Street along / cross errors satellite geometry

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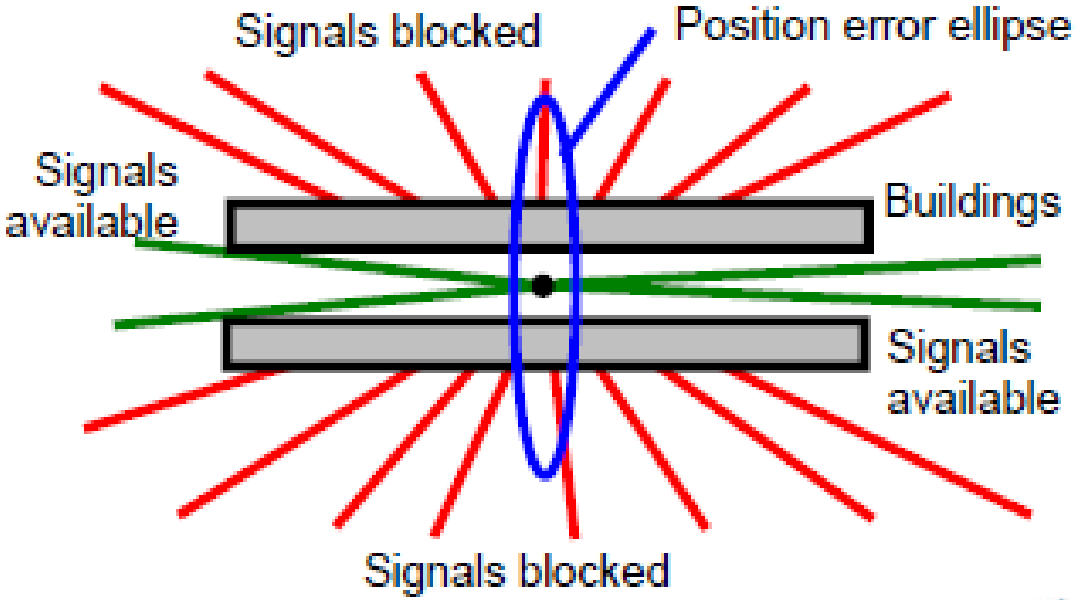
Non isotropic error in urban GNSS

- From Paul Groves' IUP (Intelligent Urban Positioning)



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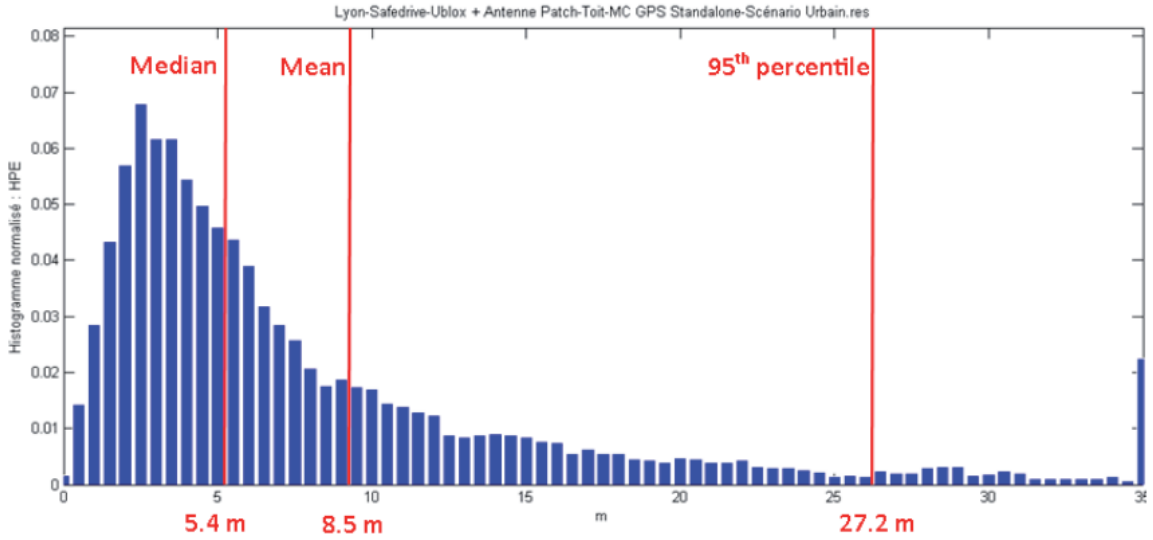
Influencing parameters

- MAIN error source due to MULTIPATH
- Local obstacles, buildings, foliage, vehicle itself (windshield vs roof antenna placing)
- Non Line Of Sight satellite tracking leads to significant tail position error distribution



Source: M3 Systems, EGNOS on the road, 2009

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Field testing (2nd §)

- Every GNSS terminal model being specific… one needs to experiment
- Similar using conditions lead to receiver (hw and sw) dependent performance
- Testing campaign

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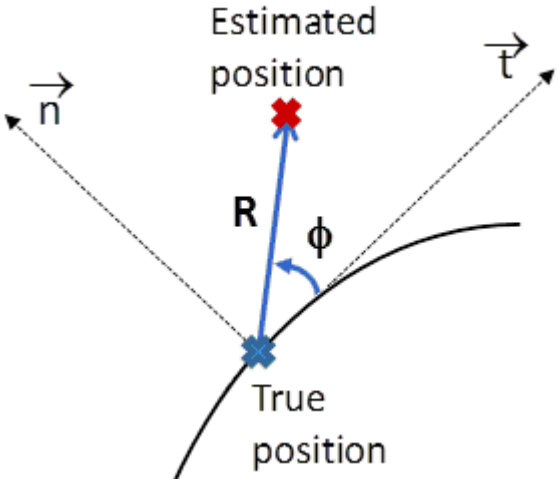
Reference trajectory

- Field testing is based on a time-to-time difference between positions provided by:
  - the equipment under investigation and
  - a reference system (e.g. Ifsttar VERT)



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Positioning error characterization

- Error time series
- Distribution
- Auto-correlation

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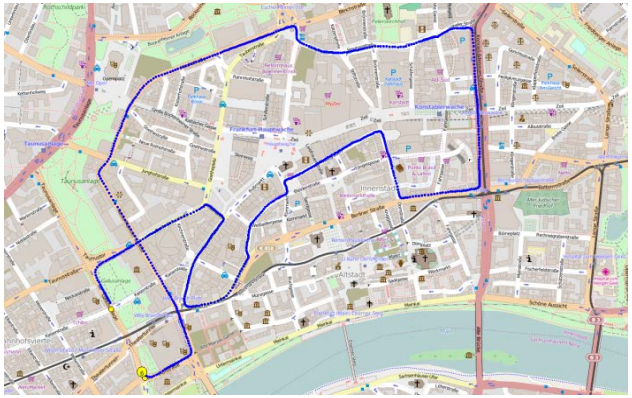
Illustration: QFree tests in Frankfurt 5km in deep urban canyons with dense traffic 15kph



Ground truth GNSS-aided Inertial Navigation System

Ground truth antenna

Automotive GNSS antenna and receiver in test

Rx considered: **uBlox LEA5-T**.

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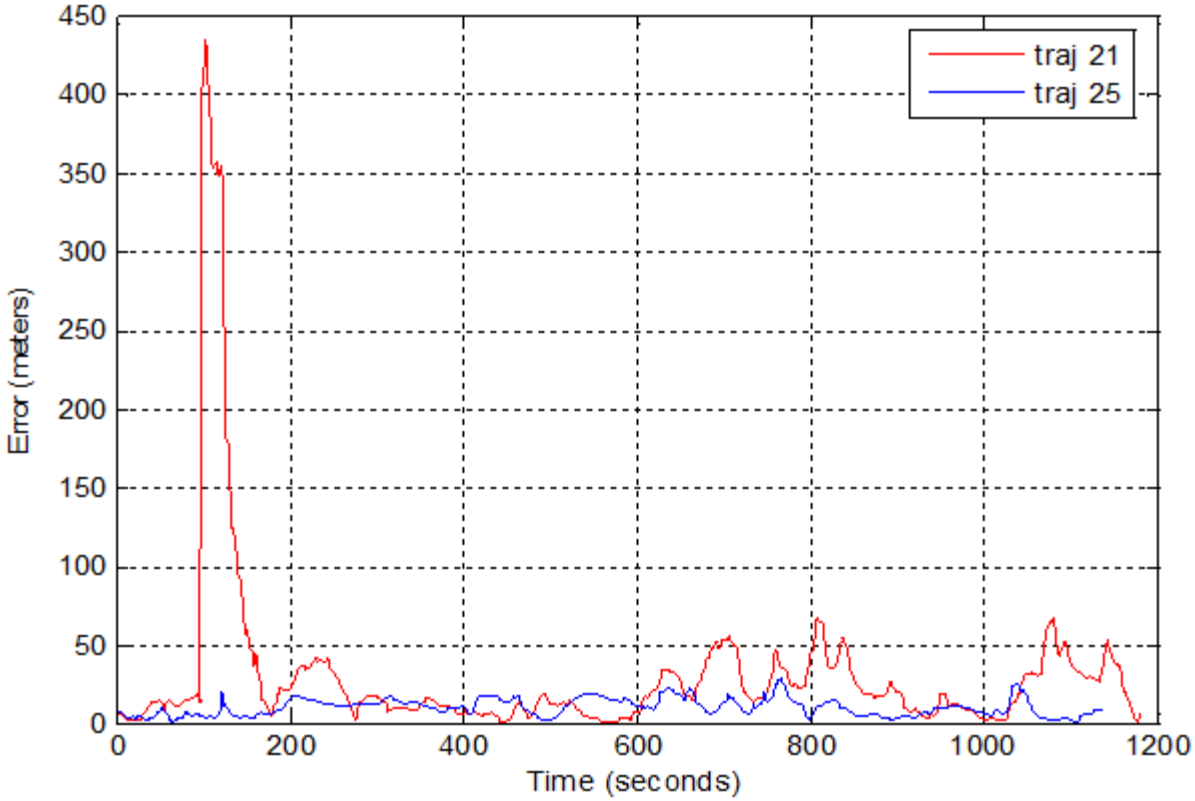
Position error of best & worst trajectories (/ 28 loops)



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Error modeling & simulation (3rd §)

- For large testing applications based on positioning
- Simulation of non Gaussian distributed error with dynamic (and not only static) shaping in order to make trajectory error cloning

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Positioning error simulation

- In quite nice environment, despite it makes non ergodic non stationary error, a simple AR model is convenient (by Telespazio in GP-Start): $error_k = a * error_{k-1} + noise_k$
- If large NLOS severe environment, the distribution changes suddenly, stepwise model seems more adapted (suggested by Ifsttar): heuristic approach (Hutter identifier modified)

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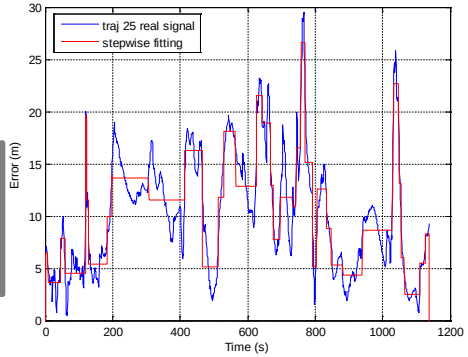
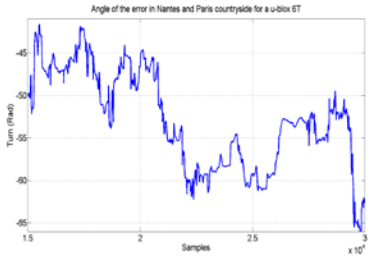
Focus: stepwise model identificat°

ε_R ε_θ error data sets obtained from real field tests

ε_R radius error



ε_θ angle error



Hutter identificat° (Gaussian assumption)

p, m, σ

probability of step change, mean and std of the step height (Gaussian distribution)

σ_b std of the additive noise (Gaussian distribution)

Laplace parameters adjustment

μ, b, min, max

mean, b parameter and limits of the step height (truncated Laplace distribution)

Cauchy parameters adjustment

x_0, γ, min, max

mode, scale parameter and limits of the additive integrated noise (truncated Cauchy distribution)

Cauchy parameters adjustment

x_0, γ, min, max

mode, scale parameter and limits of the angle random walk (truncated Cauchy distribution)

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Focus: stepwise model identificat°

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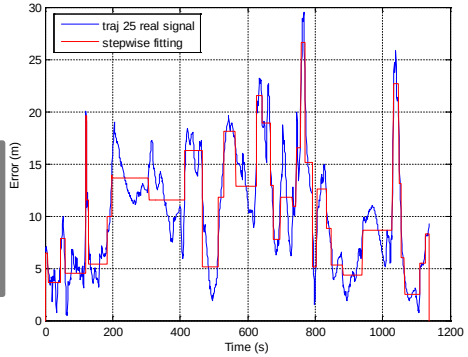
ε_R radius error

Hutter identificat°
(Gaussian assumption)



p, m, σ

probability of step change, mean and std of the step height (Gaussian distribution)

ARMAX filter identificat°

a_1, a_2, a_3, b

parameters of the ARMAX filter for smoothing

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Random cloned trajectory generat°

p probability of step change

μ, b, min, max mean, b parameter and limits of the step height (truncated Laplace distribution)

x_0, γ, min, max mode, scale parameter and limits of the additive integrated noise (truncated Cauchy distribution)

x_0, γ, min, max mode, scale parameter and limits of the angle random walk (truncated Cauchy distribution)

Generation of Laplace steps + additive integrated Cauchy noise

Autoregressive filter (ARMAX)

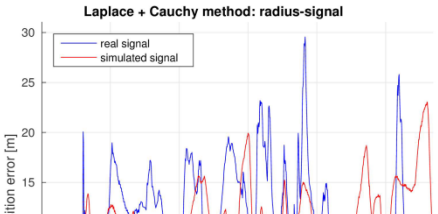
a_1, a_2, a_3, b

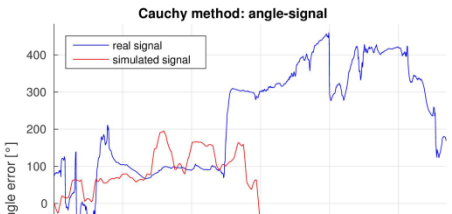
Cloned radius error ε_R

Generation of Cauchy random walk

Moving average (10) filter

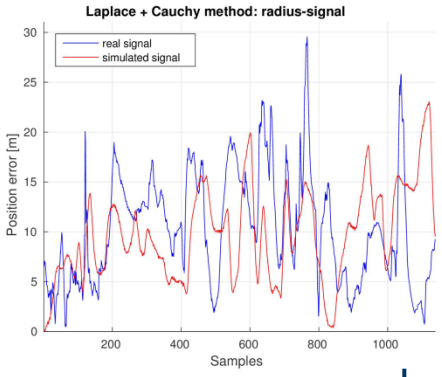
Cloned angle error ε_θ



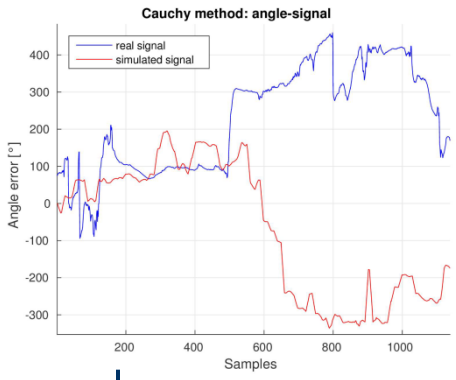


Random cloned trajectory generat°

Cloned radius error ε_R



Cloned angle error ε_θ

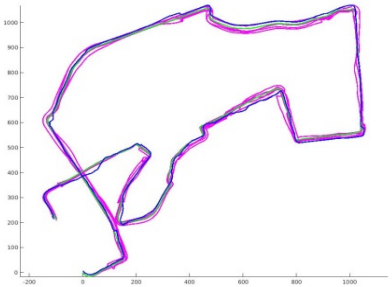


Polar to Cartesian

$$\begin{cases} \varepsilon_X[n] = \varepsilon_R[n].\cos(\varepsilon_\theta[n] \\ \varepsilon_Y[n] = \varepsilon_R[n].\sin(\varepsilon_\theta[n] \end{cases}$$

$\varepsilon_X, \varepsilon_Y$

Reference trajectory + + Cloned trajectory



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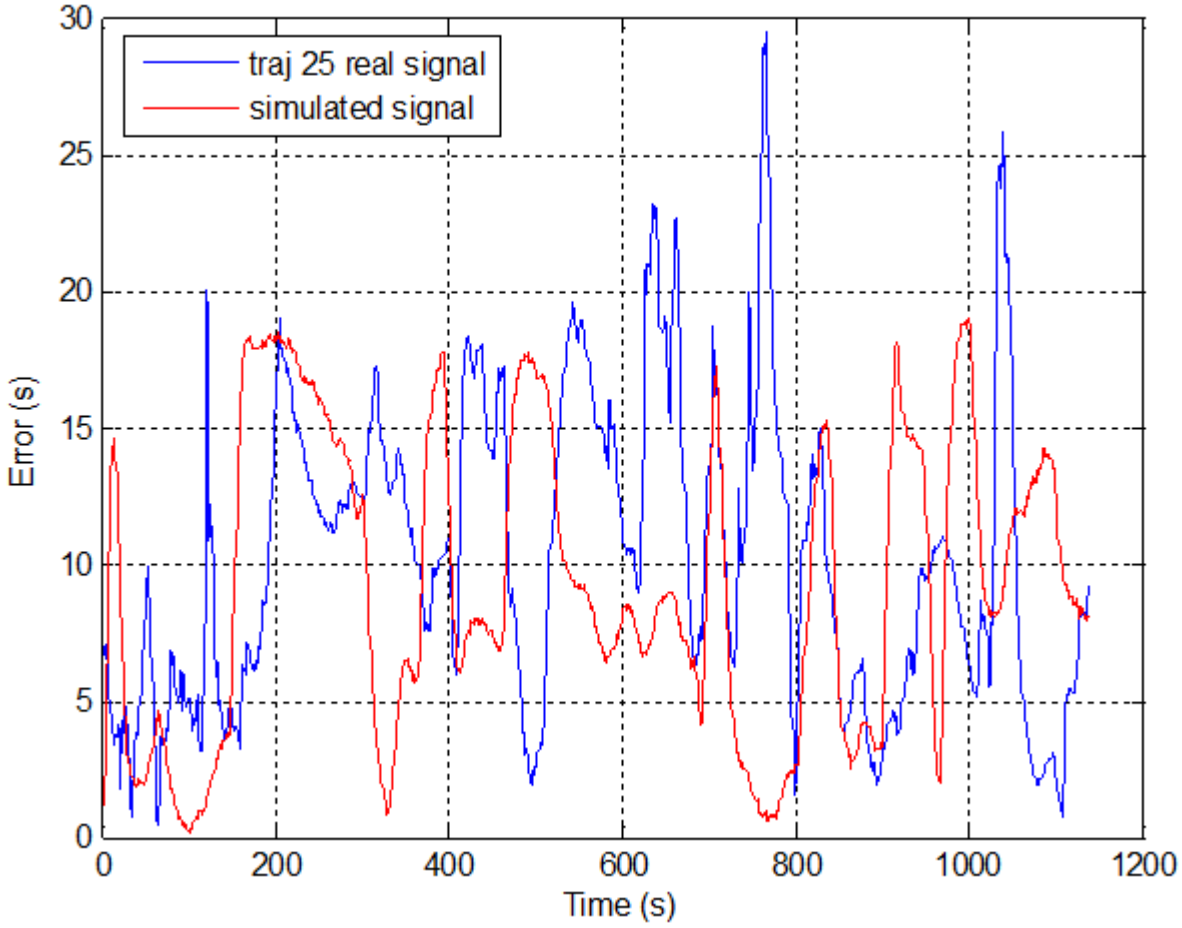
Ex. of error clone (step model)



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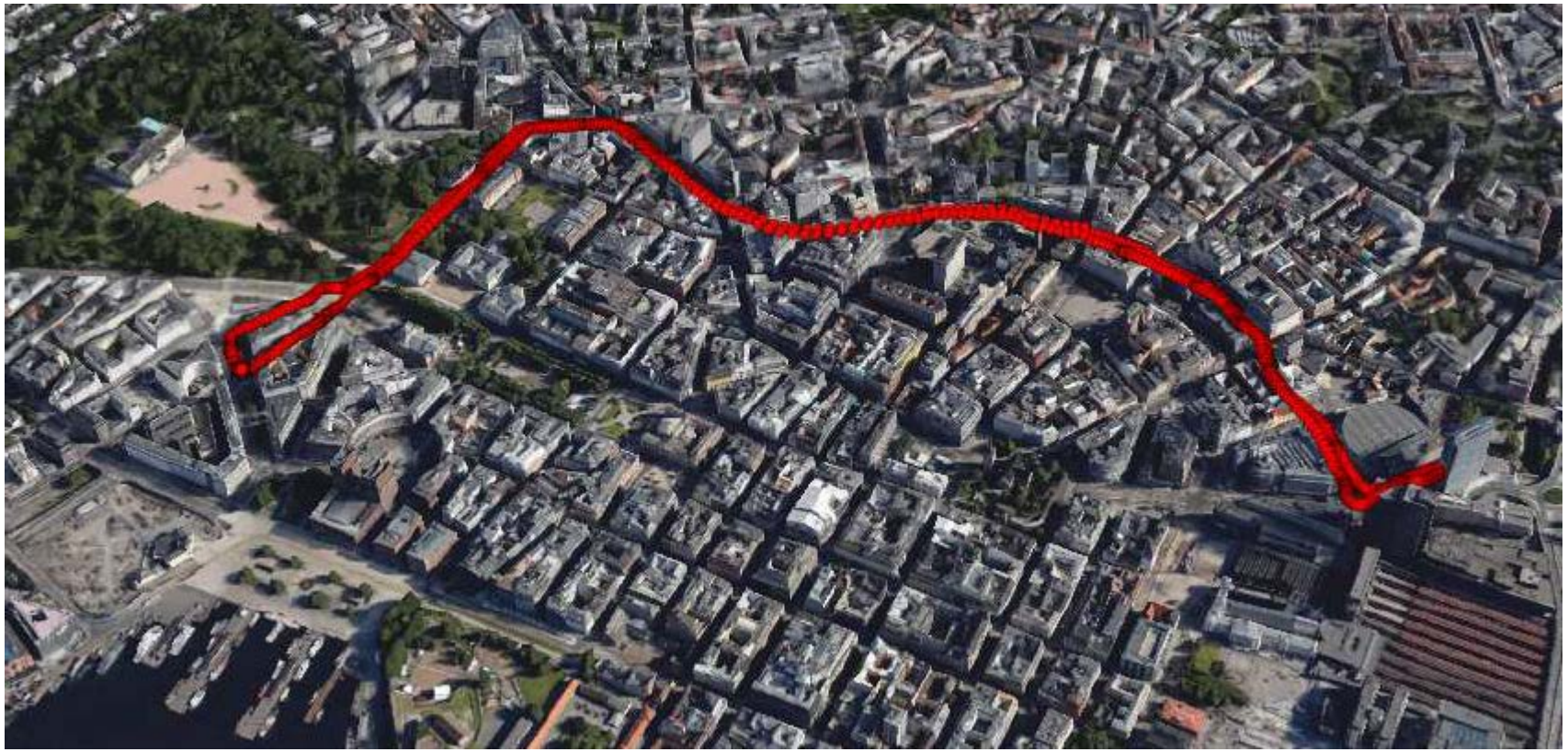
Reference traj in Oslo



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Clones in Oslo (AR model)

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Validation

- A neural network validation tool is under development at Telespazio (GP-Start pj)
- Measuring the similarity of a generated signal with a signal data set vs different criteria:
  - time/frequency domains
  - distribution
  - autocorrelation

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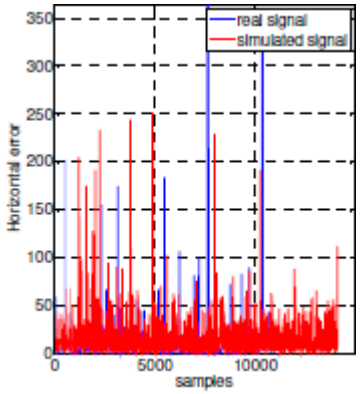
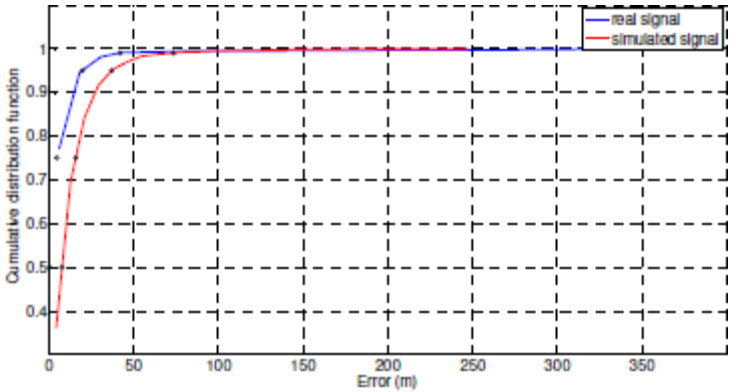
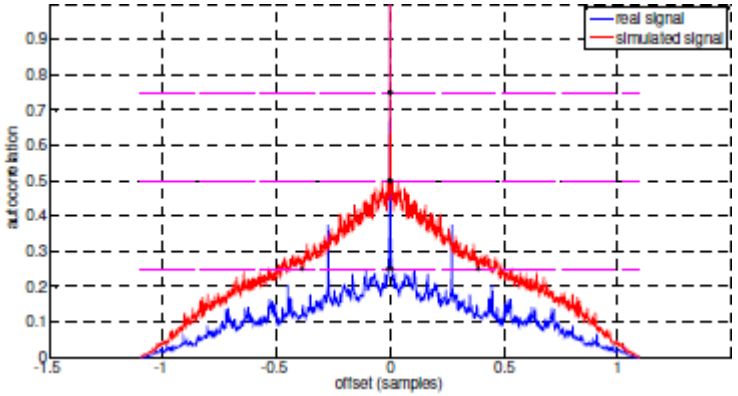
Example of a non-similar err. clone







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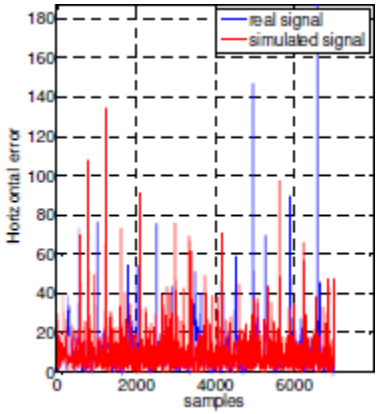
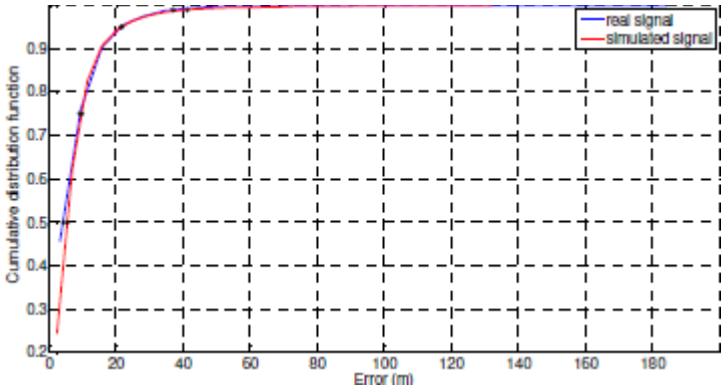
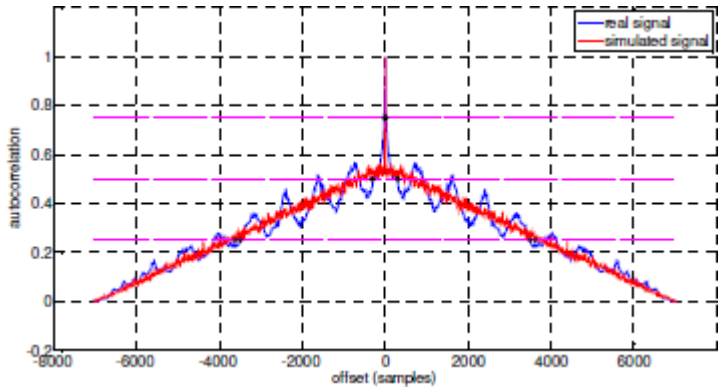
Example of similar err. clone







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Conclusions

- AR model (by Telespazio) versus Laplace-steps and Cauchy-random walk mixing model (by Ifsttar): model complexity and tuning vary from one environment to an other
- Validation based on autocorrelation and cdf seems promising
- Still a research question but progress have been made with extensive simulation of Road User Charging algorithm with QFree

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THANK YOU FOR YOUR ATTENTION !

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