Multi-hypothesis Map-Matching using Particle Filtering
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Outline

- Map-matching
  - specifications
  - method
  - integrity monitoring
- Validation method
- Experimental results
On-Board Positioning and Map-matching

EGNOS Receiver

EGNOS Data Collection & Translation

EGNOS/PVT Computation

Hybrid fusion

Map Matching

Hybrid PVT + covariance

Map-matched position + confidence

Standard Map Data

PPS sync. GPS Time

TA

NT

EGNOS Messages

PVT, Integrity, Sat PV, UERE

Raw data

Sensor board

PPS Sync

L1 GPS Receiver

Time Stamp

DR Sensors

Hybrid PVT + covariance

PPS sync. GPS Time

Sept 2009

ITS Stockholm
Standard maps

One carriageway = one polyline

Longitudinal topology
Map Matching Specifications

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

POMA MM outputs :
• up to 10 matched candidates
• with confidence indicators
Multi-hypothesis Road Tracking
Solver Used

- Particle filter (PF)
- Sequential Bayesian state estimation technique that generalizes the Kalman filter

- Advantages
  - Can cope with non-linear systems and non-Gaussian noises
  - Solves efficiently data association problems
  - Can track several hypotheses
  - Handles naturally uncertainty propagation
PF with Multiple Evolution Models

- Road tracking method
- Particles are constraint to follow the polylines representing the roads
- Noise is added at each prediction step in order to explore randomly the different hypotheses.
- A map matched position is a hybrid state

\[ M(i) = (s, ID) \]
Estimation stage

Hypothesis $H_i$: approximated by sub-particle sets

$$\chi_{h,t} = \{ \langle (s,ID)^n_t, w^n_t \rangle | ID = h \}_{n=1:N}$$

The system provides several candidates with confidence indicators.
Map-Matching with confidence indicators
Map-Matching integrity monitoring

- Estimate the probability of each hypothesis with respect to the others
- Compute Normalized Residuals for each hypothesis
- Apply a decision rule for integrity monitoring
  - the risk depends on the application
Decision Function

- **Output:**
  - use, don’t use, ambiguous

- **Stages:**
  - Eliminates unlikely candidates
  - Compute an estimate of the number of efficient candidates

![Decision Function Diagram](image)
Normal conditions
The vehicle is in a parking lot
Approaching a junction
Map-Matching Validation

Proposed approach: to use a trajectometer

Method:

1. Extract the traveled roads
2. Match the trajectometer on this path
   This is the ground truth for MM
3. Compare the outputs of the real-time Decision Function with the ground truth
Versailles experiment (March 2009)

- Estimated trajectory
- 6.4 Km long trial
- 2300 MM points
Result of the map path selection

Goal: to select the roads traveled by the vehicle (and only them)
Map-matched reference trajectory

MM Trajectometer

Trajectometer LANDINS post-processed
Good match

use

ambiguous

Ground truth
False Alarm

Don’t use

Don’t use
Miss match (miss detection)

use

ambiguous
Miss match but good ID selection

GIDS = Good ID selection
Performance Analysis

~2300 Map-Matched positions

OCDR (overall correct detection rate)

GIDS (Good ID selection)

<table>
<thead>
<tr>
<th>Map</th>
<th>FAR (%)</th>
<th>MDR (%)</th>
<th>OCDR (%)</th>
<th>GIDS (%)</th>
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</thead>
<tbody>
<tr>
<td>Map i</td>
<td>0.4</td>
<td>4.3</td>
<td>95.3</td>
<td>99.7</td>
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<tr>
<td>Map j</td>
<td>0.2</td>
<td>6.3</td>
<td>93.6</td>
<td>99.9</td>
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Conclusion

- Integrity monitoring is crucial for ITS applications where safety is important
- Multi-hypothesis Map-Matching is essential for integrity monitoring
- This talk has presented
  - an MHMM implementation using PF
  - a decision function for integrity monitoring
  - a validation method