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Vehicle Self-Localization with High-Precision Digital Maps

Fahrzeugeigenlokalisierung mit hochgenauen digitalen Karten

Florian Janda, Andreas Schindler
FORWISS, Universität Passau

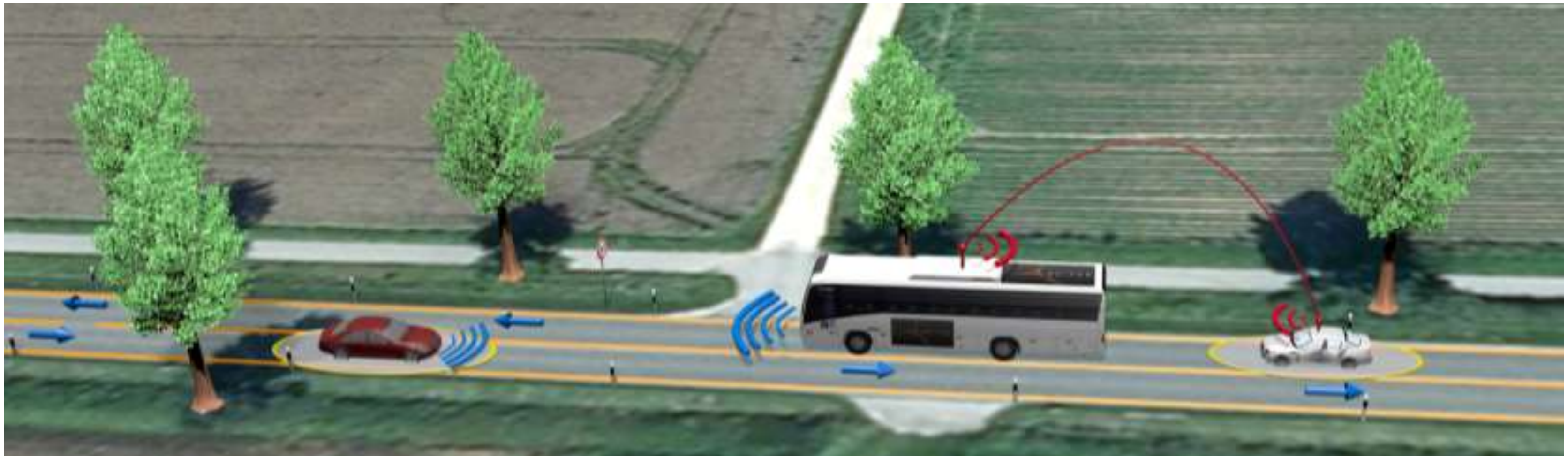
Supported by:

Federal Ministry of Economics and Technology

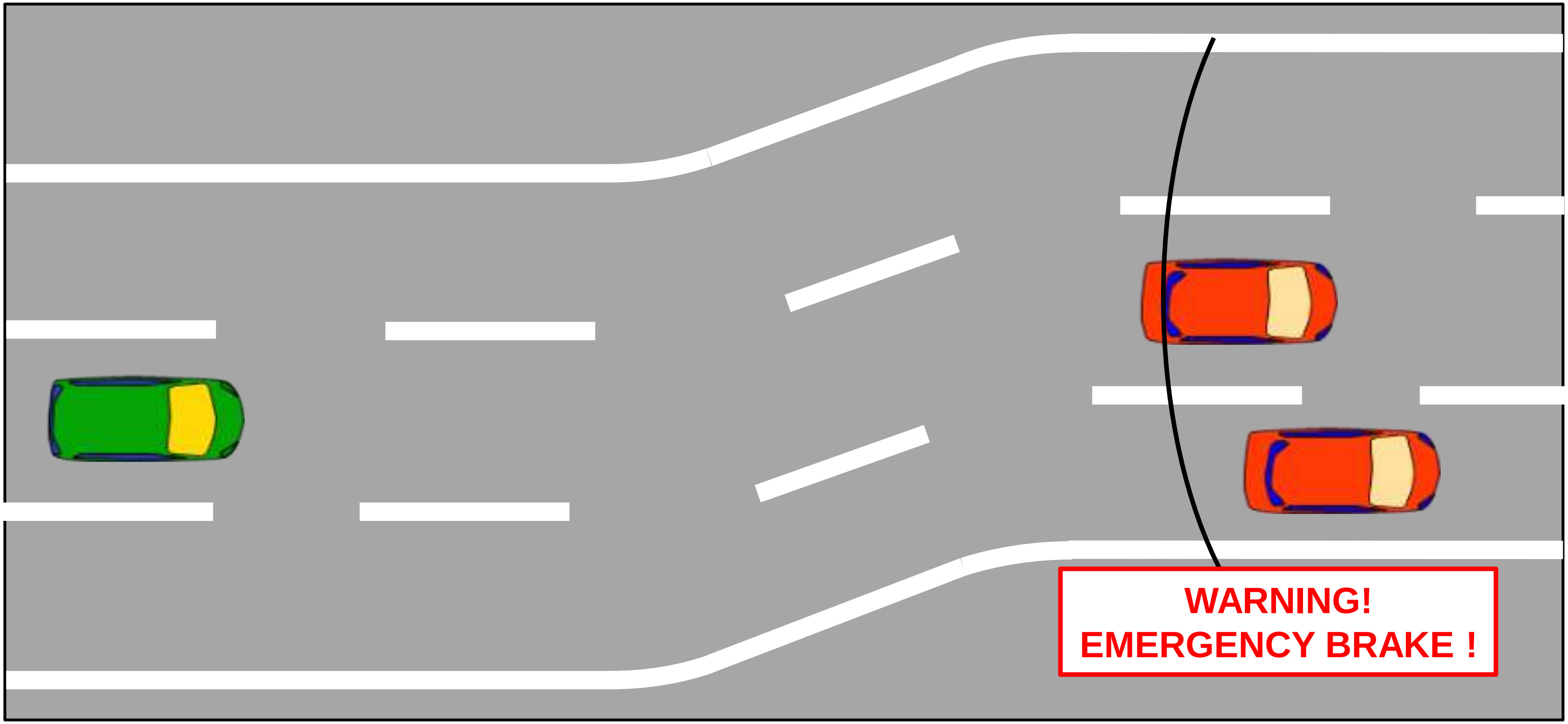
on the basis of a decision by the German Bundestag

Motivation for self-localization

- Cooperative ADAS require precise localization strategies
- Global accuracy below 1m
  - Association of vehicles and lanes
  - Consistent integration of environment models



Motivation for self-localization



High-Precision Digital Maps

Digital map

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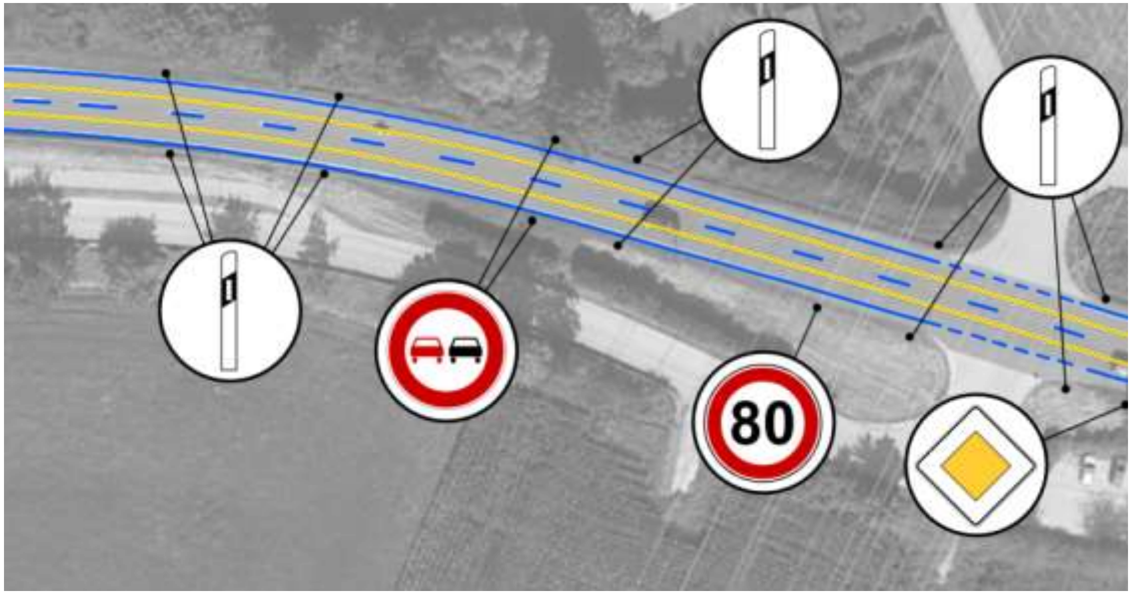
Elements:

- Individual lanes (including elevation profile)
- Landmarks
  - Road markings
  - Traffic signs
  - Trees



Requirements:

- High global accuracy
- Compact representation
- Efficient calculations / usage of map elements

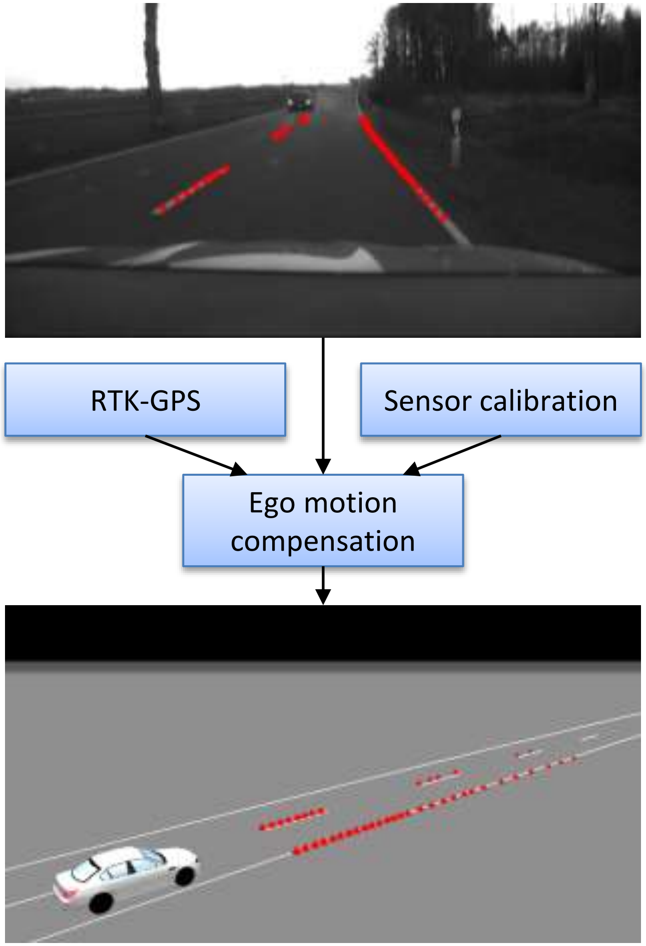
Lane recognition

- Estimation of local road model parameters
- Video based extraction of measuring points on road markings
- Reconstruction in
  - vehicle frame

    $P^{(V)} \subset \mathbb{R}^2$ (→ Localization)

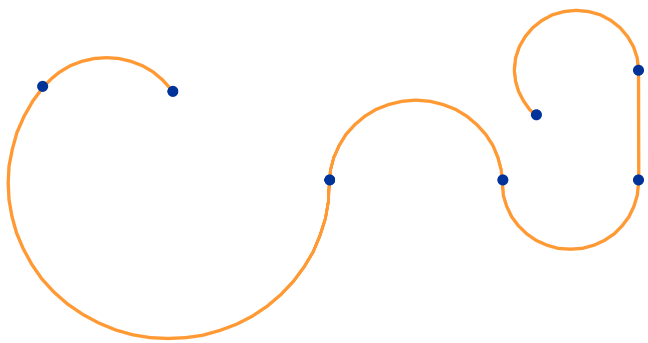
  - world frame using RTK-GPS data

    $P^{(W)} \subset \mathbb{R}^2$ (→ Mapping)



Smooth circular arc splines

- Curve composed by **circular arcs** and **line segments**
- Smooth transition at breakpoints (G^1 continuity)

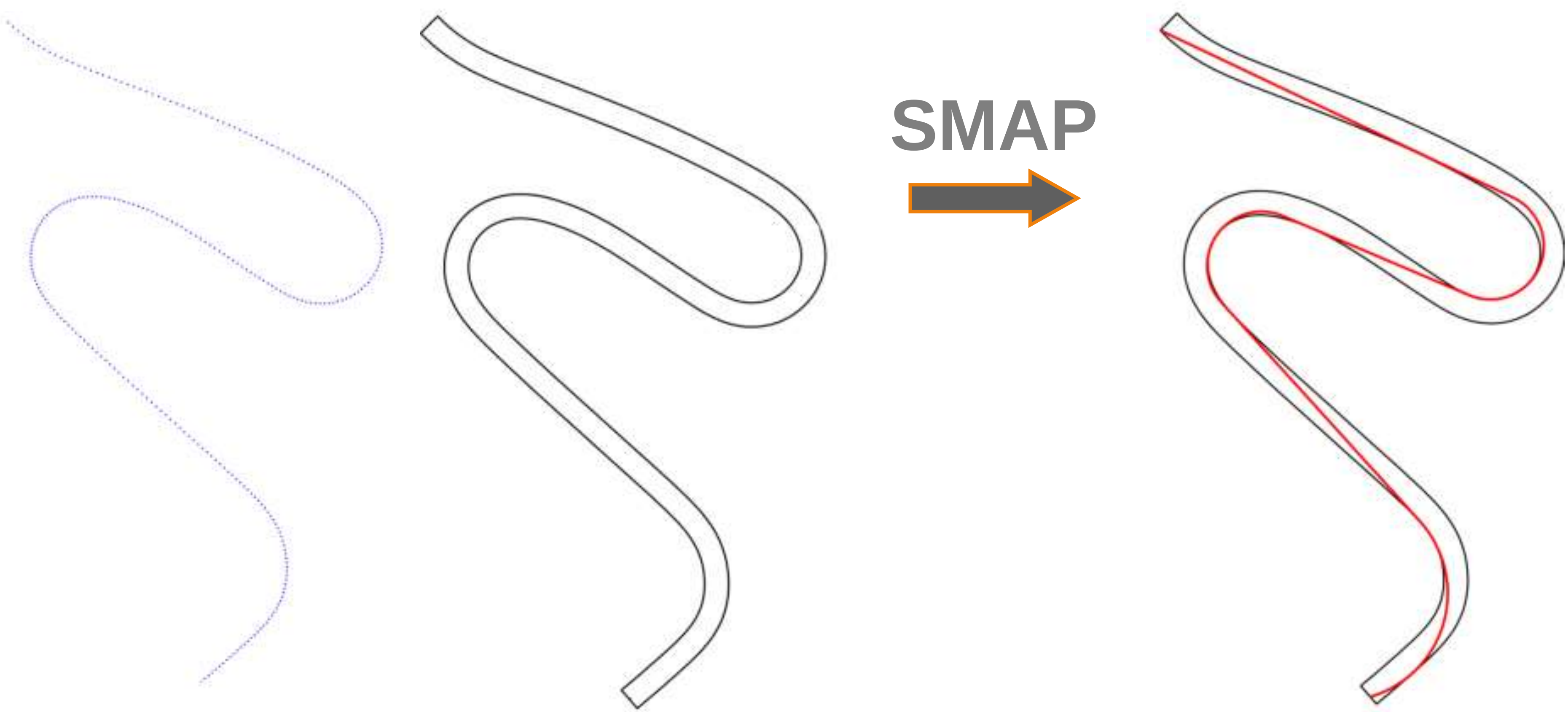


Properties:

- Invariant wrt. rotation, translation and isotropic scaling
- Exact and direct calculation of curve length and offset curves
- Distance calculation to segments in closed form
- Compatibility with CAD and GIS systems

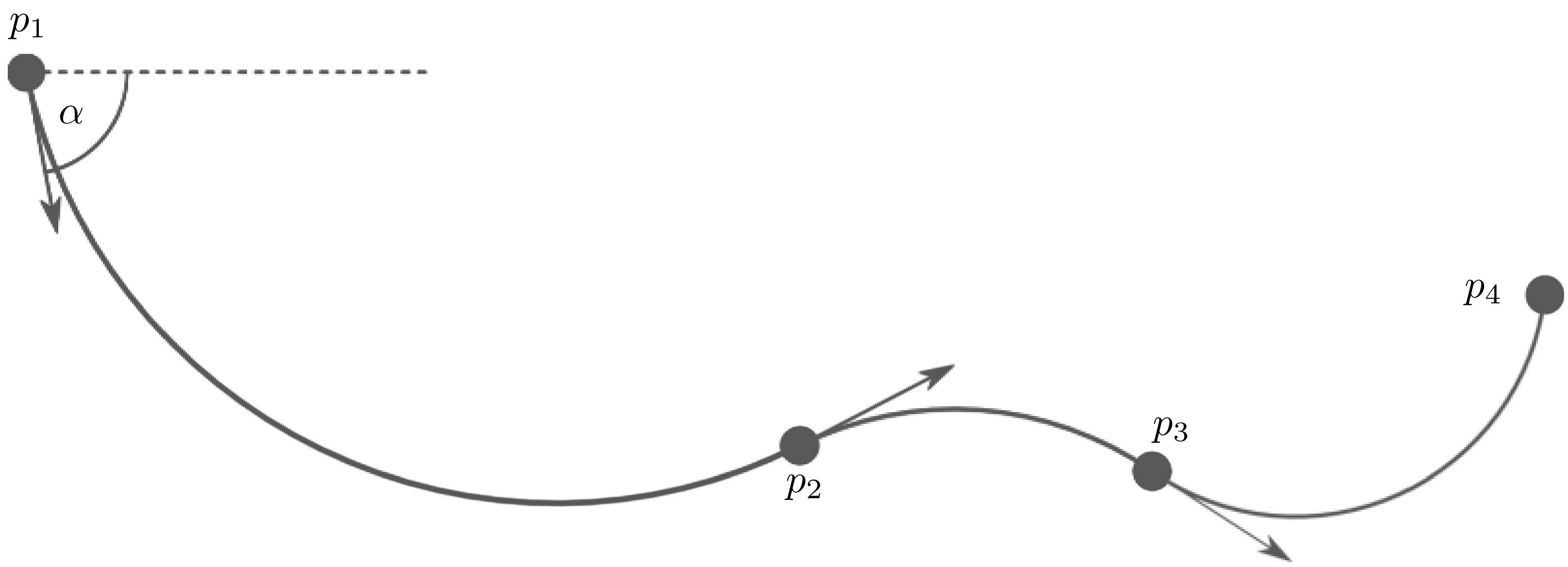
Arc spline approximation: **S**mooth **M**inimum **A**rc **P**ath

- Controllable accuracy
- Minimal segment number

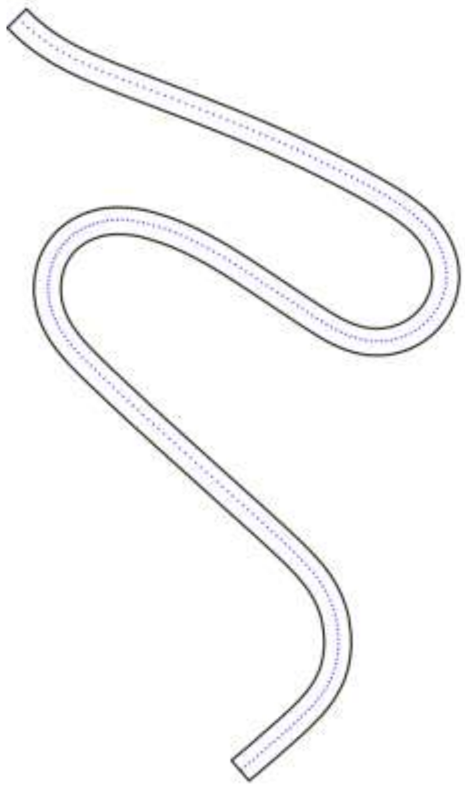


Data volume of Smooth Arc Splines as compared to Polylines

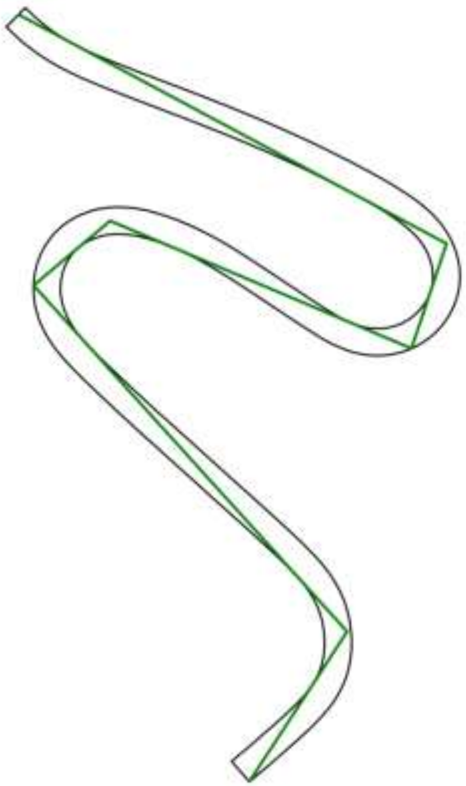
Any smooth arc spline with *n* segments can be encoded using *2n + 3* floating points (or fixed points)
(In comparison: Any polygon requires *2n + 2* floating points)



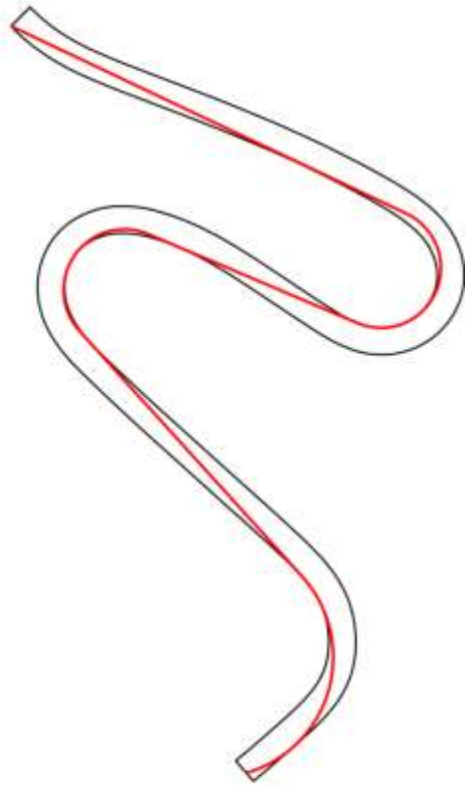
MLP vs. SMAP



Point sequence



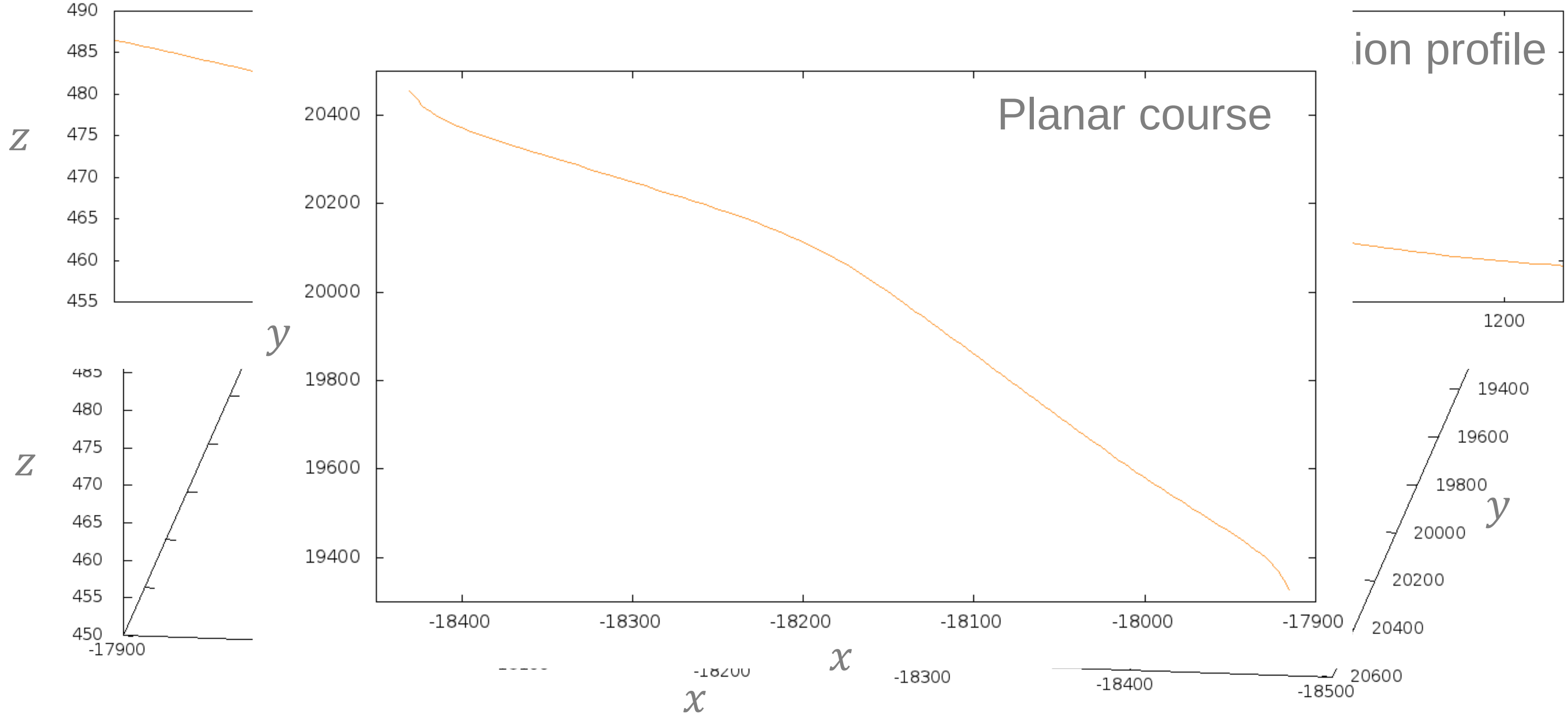
Minimum Link Path (MLP)



Smooth Minimum Arc Path (SMAP)

3D representation of lanes

Planar arc spline with separated elevation profile

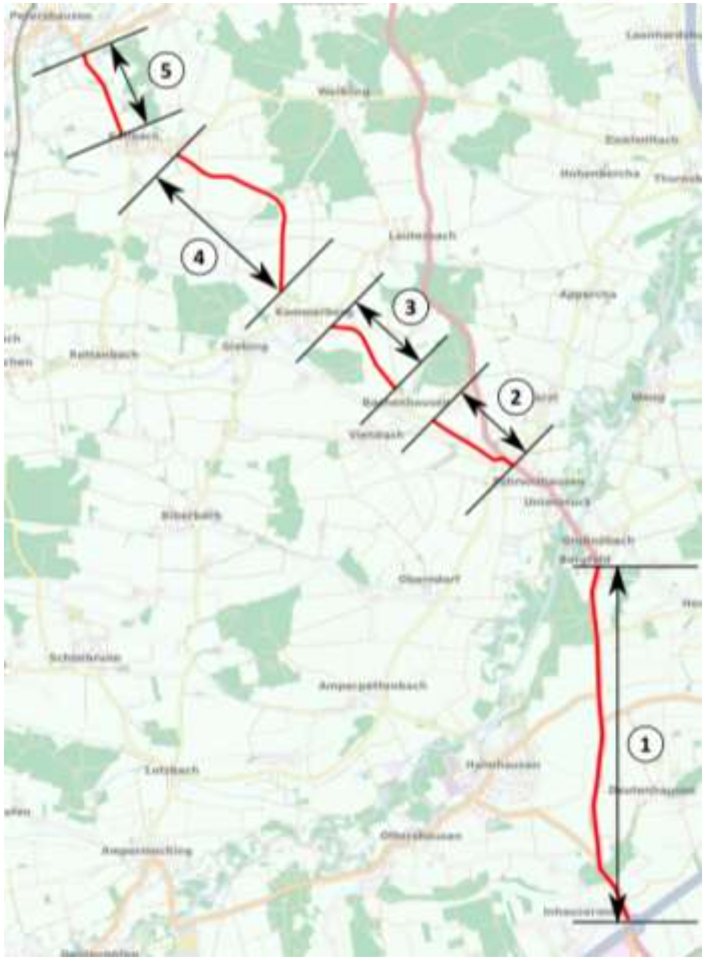


Rural example map north of Munich

- Statistics:
  - Total length: ca. 24 km
  - Ø segment length: ca. 70 m
  - Max segment length: ca. 316 m
  - Landmarks: ca. 2800

- Achieved global accuracy:
  - Road markings: ca. 10 cm
  - Landmarks: ca. 30 cm

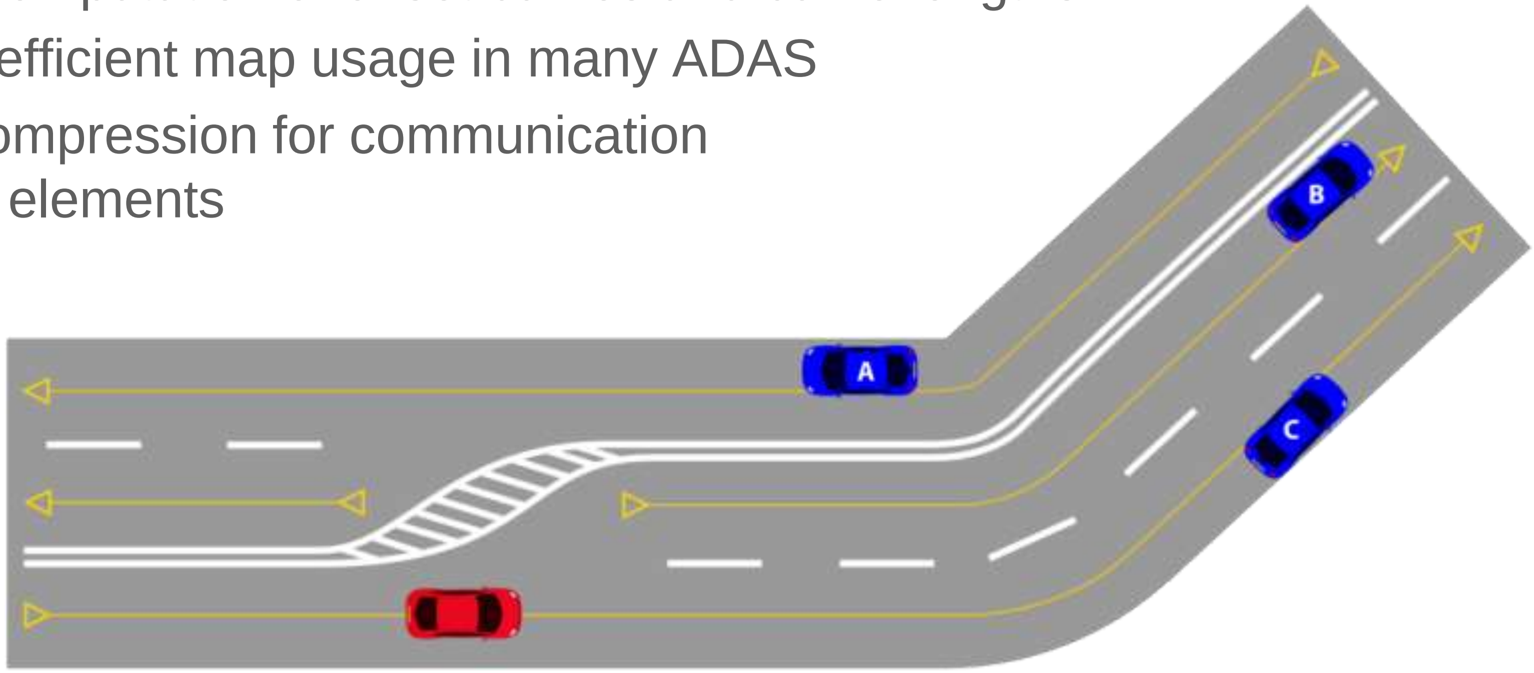
Evaluated and verified through independent high-precision reference measurements.



Summary

The proposed map model offers:

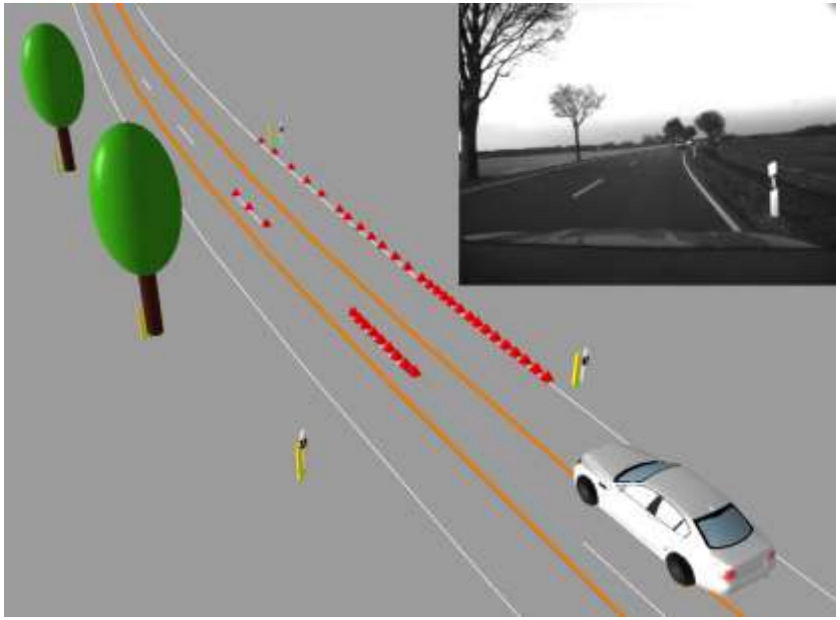
- 2D and 3D representation of roads and lanes
- Approximation with preset (and therefore controlled) accuracy
- Exact computation of offset curves and curve lengths
- Highly efficient map usage in many ADAS
- High compression for communication of map elements



Vehicle Self-Localization

Landmark based localization

Association of **landmarks** (road markings, traffic signs, trees) with elements of a **high-precision digital map** in order to estimate the vehicle's position and orientation

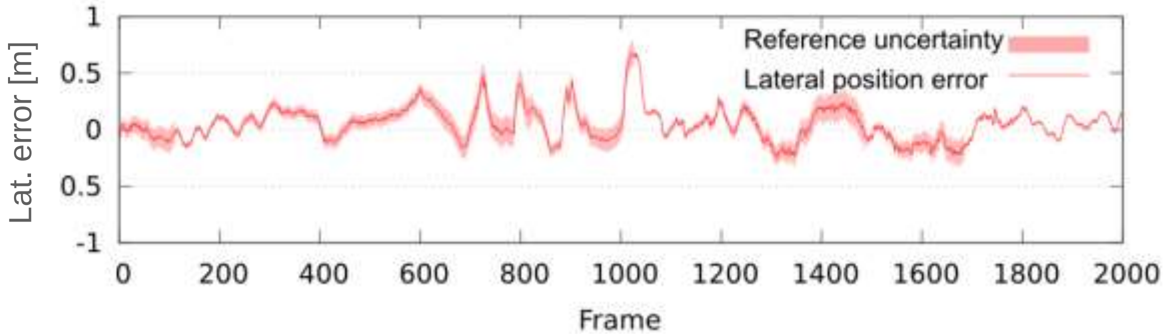


System model and state estimation

- **System state at time t_k:** $\mathbf{x}_k = \begin{pmatrix} x_k \\ y_k \\ \varphi_k \\ v_k \\ \dot{\varphi}_k \\ \beta_k \end{pmatrix} = \begin{pmatrix} \text{Position x} \\ \text{Position y} \\ \text{Orientation} \\ \text{Velocity} \\ \text{Yaw rate} \\ \text{Slip angle} \end{pmatrix}$

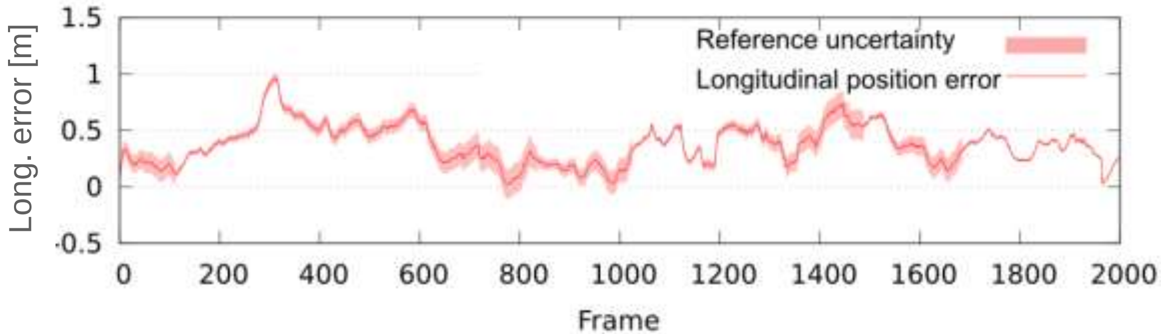
- **Dynamic model (CTRV)**:
- **Observation models**:
  - GPS (initialization)
  - Point landmarks
  - Continuous landmarks
- **Sequential Monte Carlo method** with M particles
- **Prototype fitting** to solve the landmark association problem

Positioning results

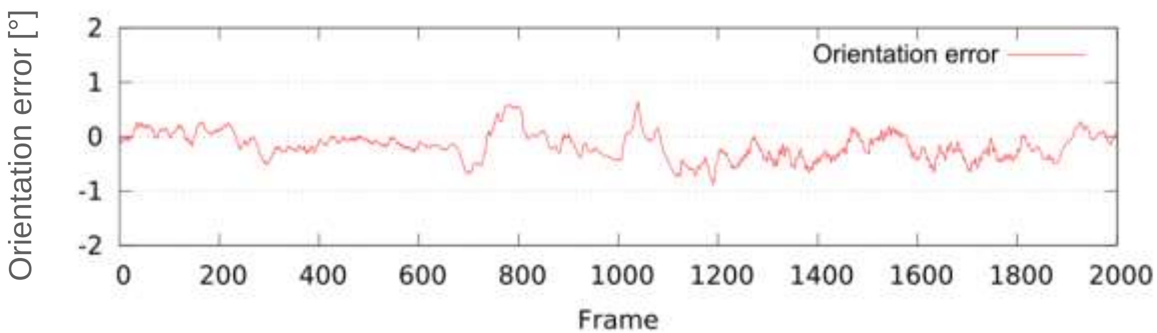


Mean and standard deviation of absolute errors:

$\mu = 0{,}12\text{m} \quad \sigma = 0{,}10m$



$\mu = 0{,}38m \quad \sigma = 0{,}17m$

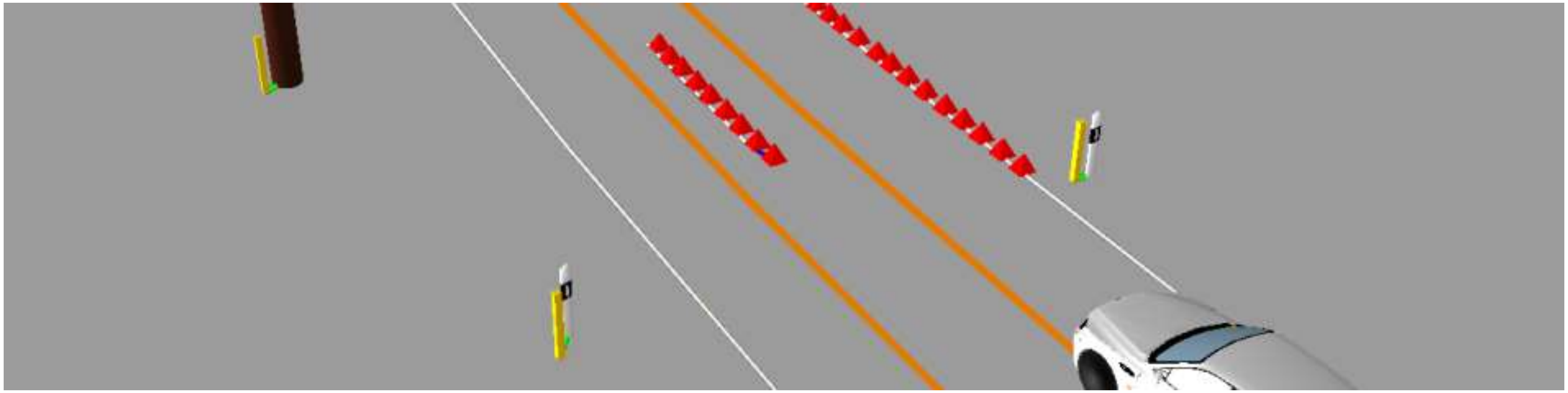


$\mu = 0{,}25° \qquad \sigma = 0{,}18°$

Summary

The proposed localization strategy offers:

- **Global positioning accuracy < 1m**
- **Global orientation accuracy < 1°**
- Full **real-time capability**: cycle time < 10ms
- Positioning strategy benefits extensively from the positive properties of the **arc spline map model**



Forschungsinitiative Ko-FAS

Demonstration

Ko-PER

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Generation of high precision maps

FORWISS, University of Passau

UNIVERSITÄT PASSAU

SICK Sensor Intelligence.

BMW Group Forschung und Technik

Gefördert durch:

Bundesministerium für Wirtschaft und Technologie

aufgrund eines Beschlusses des Deutschen Bundestages

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Thank you for your attention!