Online Localization and Fusion via Vehicle Sensor and Backend HD Map Data

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Outline

- Localization on HD Maps
  - Motivation
  - Localization through Graph Optimization
  - Application

- Online Fusion of Vehicle Sensor and HD Map Data
  - Motivation, Aims, and Contribution
  - Fusion Challenges
  - High-Level Road Model Fusion
  - Fusion Summary
Motivation I

Traffic sign detection

Lane detection

Velocity
Orientation
Global position

Online Localization and Fusion via Vehicle Sensor and Backend HD Map Data
Motivation II

- More comfortable, foresightful driving
- Increased safety and efficiency
- ... through data exchange

- decelerate?
- hazard flasher?
- handover?
Motivation II

Online Localization and Fusion via Vehicle Sensor and Backend HD Map Data
Single-Shot Measurements

- Detect lanes
- Align lanes with map

✓ Done ... best solution?

Pose measurement (position + orientation)
Data Fusion – Uncertainty

Sensor has high uncertainty.

Sensor has low uncertainty.
Fusion algorithm requirement:

- Robust against outliers and short-term sensor outage
- Resolve ambiguities
- Model optimization problem instead of Bayes Filter
Graph-Based Optimization

Optimize:
- Mahalanobis distance to sensor measurements
- Allow but penalize sensor outage
- Constrain parameters

\[
\begin{align*}
M_{m,i} & \quad P_i \\
M_{m,i+2} & \quad P_{i+2} \\
M_{g,i+1} & \quad P_{i+1}
\end{align*}
\]
Map Upload

Upload-frame (optimized using pose-graph)

Server

Mainz Wiesbaden

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Online Localization and Fusion via Vehicle Sensor and Backend HD Map Data
Application: Explanation

- Front camera lane detections
- Estimated vehicle pose
- Optimized poses “↑”
- Rear camera lane detections
- Digital map from server
- Matched lanes
**Poster:** Außenbereich, Zelt.

**Paper:** M. Harr, J. Janosovits, S. Wirges, and C. Stiller.  
*Fast and Robust Vehicle Pose Estimation by Optimizing Multiple Pose Graphs.*  
In 21th International Conference on Information Fusion, 2018.
Poster: Außenbereich, Zelt.


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  - Fusion Challenges
  - High-Level Road Model Fusion
  - Fusion Summary
Automated driving functions need a consistent and robust representation of the driving environment (= environment model) for proper behavior planning and decision making.

Adequate fusion of vehicle sensor and backend HD map data for additional i) redundancy, ii) accuracy, and iii) range of the environment model.

Motivation, Aims, and Contribution
Motivation, Aims, and Contribution

- The **road model** is a bird's-eye view representation of
  - the road/lane **geometry**,
  - the road/lane **topology**, and
  - traffic-rule related **attributes**.
- The road model can either be derived from
  - sensor data (→ **sensor-based road model**) or
  - digital map data (→ **map-based road model**).
- **Contribution**: Presentation of a general **High-Level Road Model Fusion** concept to infer **lane-specific traffic rules** by combining
  - regulatory traffic elements,
  - lane geometry, and
  - backend HD map data.
Fusion Challenges

- Coping with incomplete, uncertain, and inconsistent information sources.
- Adequate consideration of i) spatial, ii) existence, and iii) attribute uncertainties.

- Ko-HAF result: Unified uncertainty representation across all partners.
- The online road model fusion should take these uncertainties into account without „thresholding“.
High-Level Road Model Fusion

Sensor-Based Information Fusion

- Regulatory Traffic Elements (Traffic Signs, Traffic Lights, ...)
- Road/Lane Geometry
- Position Relation Determination
- Logical Lane Assignment
- Attribute Fusion and Inference

Map-Based Information Fusion

- Map-Based Road Model
- Attribute Association
- Attribute Fusion and Inference

Traffic Regulation Knowledge

Road Model (Sensor-Based)

Road Model (Fused Attributes)

Situation Knowledge
High-Level Road Model Fusion
Position Relation Determination

- Determination of **probabilistic position relations** between lanes and regulatory traffic elements.
- Consideration of spatial and existence uncertainties.
- **Method:** Monte Carlo

\[
\begin{align*}
p \text{ (TS1 is right of Lane 1)} &= 0.7 \\
p \text{ (TS1 is above Lane 1)} &= 0.2 \\
p \text{ (TS1 is above Lane 2)} &= 0.05 \\
p \text{ (TS1 is above Lane 3)} &= 0 \\
p \text{ (TS1 is left of Lane 3)} &= 0 \\
p \text{ (TS1 is elsewhere)} &= 0.05
\end{align*}
\]
High-Level Road Model Fusion

Sensor-Based Information Fusion
- Regulatory Traffic Elements (Traffic Signs, Traffic Lights, …)
- Road/Lane Geometry
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Map-Based Information Fusion
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Traffic Regulation Knowledge

Road Model (Sensor-Based)

Situation Knowledge

Road Model (Fused Attributes)
Inference of logical lane assignments, i.e. which regulatory traffic element is valid for which lane.

Consideration of soft position relation evidences and traffic regulation knowledge.

Method: Bayesian Networks
High-Level Road Model Fusion
Logical Lane Assignment

- Example: Simple **Bayesian network** for logical lane assignments of speed limit signs.

- Traffic regulation knowledge is encoded in **conditional probability tables**.
- Logical lane assignments are inferred (estimated) via **causal reasoning**.
- Inference via **junction tree algorithm** for arbitrary discrete, multiply-connected networks.
High-Level Road Model Fusion

Sensor-Based Information Fusion
- Regulatory Traffic Elements (Traffic Signs, Traffic Lights, ...)
- Road/Lane Geometry

Map-Based Information Fusion
- Map-Based Road Model

Traffic Regulation Knowledge

Position Relation Determination
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Attribute Fusion and Inference

Road Model (Sensor-Based)

Attribute Association
Attribute Fusion and Inference

Situation Knowledge

Road Model (Fused Attributes)
High-Level Road Model Fusion
Attribute Fusion and Inference

- Attribute fusion and inference of hidden attribute state ranges of non-observed lanes.
- Consideration of
  - logical lane assignments,
  - traffic regulation knowledge,
  - attribute uncertainties.
- **Method:** Dempster-Shafer
High-Level Road Model Fusion
Attribute Fusion and Inference

- Generation of sensor-based and map-based Basic Belief Assignments (BBAs).
- Lane-specific belief mass fusion to recursively update a Dempster-Shafer knowledge base of traffic rule knowledge.
- Dempster's rule of combination as fusion operator for stochastic constraint combination.
High-Level Road Model Fusion
Attribute Fusion and Inference

- Correction of false classifications.
- Inference of hidden speed limit state ranges.

- However, there are situations in which backend map data becomes vital.
High-Level Road Model Fusion

Sensor-Based Information Fusion
- Regulatory Traffic Elements (Traffic Signs, Traffic Lights, …)
- Road/Lane Geometry
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Map-Based Information Fusion
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Traffic Regulation Knowledge

Road Model (Sensor-Based)

Road Model (Fused Attributes)

Situation Knowledge
Map-based BBAs are generated from **backend map data**.
Fusion performed the same way as with sensor-based BBAs.
Output either in form of
- **support** and **plausibility** functions or
- **probability mass functions** including **information conflicts**.
High-Level Road Model Fusion
Attribute Fusion and Inference

- Map-based BBAs are set up from
  - map speed limit attributes with attribute uncertainty provided by backend map,
  - map-based situation classes (autobahn, inner city, ...).

- Map-based speed limits are adapted depending on uncertain situation knowledge, e.g.
  - Dempster-Shafer map mass discounting in case of detected variable message signs.
  - Dempster-Shafer map mass discounting according to detected construction sites.
High-Level Road Model Fusion
Attribute Fusion and Inference – Speed Limit Fusion Examples

- Correct fusion result in construction sites despite outdated map speed limits by using situation knowledge.
- Correct fusion result on the autobahn despite wrong speed limit sign associations by using situation knowledge.

→ Situation-adaptive fusion of vehicle sensor and backend map data leads to more accurate environment models and resolves unjustified fusion conflicts.
High-Level Road Model Fusion

Traffic Regulation Knowledge

Sensor-Based Information Fusion
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Road Model (Sensor-Based)
Road Model (Fused Attributes)

Situation Knowledge
Fusion Summary

- Presentation of a road model fusion concept for traffic rule inference, which
  - takes different kinds of uncertainties into account,
  - allows the seamless integration of multiple information sources,
  - uses traffic regulation knowledge for Bayesian network-based logical lane assignments,
  - incorporates situation knowledge within a Dempster-Shafer-based attribute fusion, and
  - permits plausibility checks between digital map content and sensor-inferred lane attributes.
- Exemplary concept demonstration and implementation for the task of multi-lane speed limit inference, but usable for other lane-specific attribute fusion tasks, e.g.
  - lane marker type fusion, no passing zone fusion, traffic light state fusion, dynamic backend event fusion (e.g. broken down vehicles), lane turn direction fusion, etc.

Further details: „Schreier, M. et al.: „A High-Level Road Model Information Fusion Framework and its Application to Multi-Lane Speed Limit Inference“, IEEE Intelligent Vehicles Symposium 2017, June 2017, Redondo Beach, CA, USA."
Thank you
for your attention!

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