Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction On Highways

David Augustin, Opel Automobile GmbH
- MOTIVATION
- APPROACH
- LEARNING STAGE
- ESTIMATION STAGE
- APPLICATION
Motivation
Highly automated driving on highways

<table>
<thead>
<tr>
<th>HIGHLY AUTOMATED DRIVING FUNCTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SENSE</td>
</tr>
<tr>
<td><strong>Understand</strong></td>
</tr>
<tr>
<td>PLAN</td>
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<td>ACT</td>
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</tbody>
</table>

Ko-HAF – Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction On Highways

September 19th & 20th, 2018
Motivation
What is the driver's plan?
▪ MOTIVATION
▪ APPROACH
▪ LEARNING STAGE
▪ ESTIMATION STAGE
▪ APPLICATION
Approach

Typical Motion Patterns

Recorded trajectories of highway lane changes to the left.

Prototype trajectories of LCL maneuvers.
Approach
Block Diagram

Method
Constraints

Initialization and Stop Condition

Clustering

Data Basis

recorded and preprocessed environmental data

training set (70% of data, labeled)

test set (30% of data)

Prototype Generation

trajectory clusters

Evaluation

LEARNING STAGE

ESTIMATION STAGE

Prototype Generation

cluster prototypes

Estimation Method

maneuver estimate trajectory prediction

Feature Generation

feature vector

Maneuver / Trajectory Planning

environmental data

Feature Generation

Maneuver /
Trajectory Planning

LEARNING STAGE
▪ MOTIVATION
▪ APPROACH
▪ LEARNING STAGE
▪ ESTIMATION STAGE
▪ APPLICATION
Approach
Agglomerative Hierarchical Clustering

**Algorithm:** Basic agglomerative hierarchical clustering algorithm.

1: Compute proximity matrix
2: repeat
3: Merge closest two clusters
4: Update proximity matrix to reflect the proximity between the new cluster and the original clusters
5: until end condition.
Approach
Agglomerative Hierarchical Clustering

Dissimilarity measure: average Euclidean Distance

\[ \delta(d_i, d_j) = \left( \frac{1}{T} \int_{t=t_{\text{min}}}^{t_{\text{max}}} (d_i(t) - d_j(t))^2 dt \right)^{1/2} \]

- \[ t_{\text{min}} = \min(t_{0,i}, t_{0,j}) \]
- \[ t_{\text{max}} = \max(t_{0,i} + T_i, t_{0,j} + T_j) \]
- \[ T = t_{\text{max}} - t_{\text{min}} \]

Algorithm: Basic agglomerative hierarchical clustering algorithm

1: Compute dissimilarity matrix  
2: repeat  
3: Find closest two clusters  
4: if constraints are met  
5: Merge closest two clusters  
6: end  
7: Realign clusters  
8: Update dissimilarity matrix  
7: until end condition
Agglomerative hierarchical Clustering
Alignment by minimal pairwise dissimilarity
Agglomerative hierarchical Clustering

Min. pairwise dissimilarity and cohesion constraint

Prototype trajectories of LCL maneuvers.

Prototype trajectories of LCR maneuvers.
- MOTIVATION
- APPROACH
- LEARNING STAGE
- ESTIMATION STAGE
- APPLICATION
Estimation Stage
Find best match

Dissimilarity measure: average Mahalanobis distance

\[
\Delta(d_p, \mu_m) = \frac{1}{T_m} \int_{-T_m}^{0} \left( \frac{(d_p(t) - \mu_m(t + \tau_m))^2}{\sigma_m^2(t + \tau_m)} \right)^{1/2} dt
\]

\[
T_m = \min(T_{buffer}, \tau_m)
\]
Estimation Stage
Quadratic Gaussian Discriminant Analysis

Bayesian discriminant rule for each class $C_i$

$$D_i(f) = -\frac{1}{2} \ln |\Sigma_i| - \frac{1}{2} (f - \mu_i)^t \Sigma_i^{-1} (f - \mu_i) + \ln(p_i)$$

$$f = [d, \dot{d}]^T$$
Estimation Stage
Quadratic Gaussian Discriminant Analysis

Bayesian discriminant rule for each class $C_i$

$$D_i(\mathbf{f}) = -\frac{1}{2} \ln |\Sigma_i| - \frac{1}{2} (\mathbf{f} - \mu_i)^t \Sigma_i^{-1} (\mathbf{f} - \mu_i) + \ln(p_i)$$

$$\mathbf{f} = [d, \dot{d}, f_3, f_4]^T$$

$$f_3 = \Delta_{p,\text{LCR}} - \Delta_{p,\text{LCL}}$$

$$f_4 = \Delta_{v,\text{LCR}} - \Delta_{v,\text{LCL}}$$
▪ MOTIVATION
▪ APPROACH
▪ LEARNING STAGE
▪ ESTIMATION STAGE
▪ APPLICATION
Application

What is the driver's plan?
Application

Maneuver Detection
### Application

#### Results: Maneuver Detection

<table>
<thead>
<tr>
<th>Approach</th>
<th>$TPR$</th>
<th>$prc$</th>
<th>$F_1$</th>
<th>$\Delta T$ (s)</th>
<th>Misclassification</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td></td>
<td></td>
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<tr>
<td>LCL</td>
<td>0.95</td>
<td>1.0</td>
<td>0.976</td>
<td>1.65</td>
<td>0.16 0.09 0.23</td>
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<tr>
<td>LCR</td>
<td>0.87</td>
<td>0.97</td>
<td>0.916</td>
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<tr>
<td>D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCL</td>
<td>0.93</td>
<td>1.00</td>
<td>0.962</td>
<td>1.48</td>
<td>0.19 0.09 0.26</td>
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<tr>
<td>LCR</td>
<td>0.84</td>
<td>0.97</td>
<td>0.898</td>
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</tbody>
</table>

$\Delta T \triangleq$ average prediction time before a lane change event

A: Proposed approach.

D: Quadratic Gaussian Discriminant Analysis with feature vector $f = [d, \dot{d}]$
Application
Trajectory Prediction

Highway Test Run

Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction on Highways
David Augustin, Marius Hofmann and Ulrich Konigorski
Application

Results: Trajectory Prediction

![Graph showing mean absolute error vs prediction time intervals for LCL and LCR]

![Graph showing mean absolute error vs prediction time intervals for LCL and LCR]
Conclusion and Outlook

Proposed Approach

- Uncertainty-aware maneuver detection and trajectory prediction
- Trajectory alignment minimizing pairwise dissimilarity improves cluster quality
- Online-capability demonstrated

OUTLOOK

- Maneuver Prediction: Take interaction and topology of road into account
- Motion Prediction: Probabilistic selection of prototype trajectories
Thank you for your attention!

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