Fuzzy Architecture of Safety-Relevant Vehicle Systems

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1. Introduction
Automotive Active Safety Systems

1. Introduction

- Collision avoidance systems
- Autonomous cruise control
- Automated parking systems
- Automated highway systems
- Navigation systems

- Intelligent headlights
- Systems of night vision
- Human machine interface devices

- Active steering
- Anti-lock braking systems
- Traction control systems
- Electronic stability control
Identification of actual road situation
  road conditions, manoeuvre

Estimation of “Driver-Vehicle” processes
  safety limits, driver state

Vehicle dynamics forecasting
  changes in road conditions and safety limits

Knowledge acquisition
  self-learning, re-configuration of control strategy

Control results processing
  real safety limits, accuracy

Choice of optimal control
  controlling elements, dynamics of control actions

1. Introduction
Problem Statement

Road Parameters
Identification of surface and prediction of friction level

Vehicle Dynamics
Competing target factors: stability vs. handling vs. performance

Driver Parameters
Adaptation to emotional and physiological state of the driver
Search for Engineering-Reasonable Methods

- Variety of control tasks
- Coordination of vehicle control systems
- Unified open-architecture platform

Nonlinear and robust control

Statistical dynamics

Intelligent methods

- Neural networks
- Intelligent agents
- Genetic control
- Fuzzy sets

1. Introduction
2. Fuzzy Applications for Active Safety Control

Fuzzy Architecture of Safety-Relevant Vehicle Systems
Previous Works

• First discussions: Sugeno and Nishida (1985), Kiencke and Daiß (1994)

  Fuzzy Sets and Systems 16 (1985) 103-113
  North-Holland

  FUZZY CONTROL OF MODEL CAR

  M. SUGENO and M. NISHIDA

  Department of Systems Science, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama, 227 Japan

• State-of-the-art in automotive applications: 
  active suspension, brake pressure control, autonomous driving
Problems of Fuzzy Algorithms in Active Safety Control

- Vehicle model structure vs. fuzzy rule base dimension
  - Vehicle model: min. 19 DoF
  - Fuzzy controller: from 248 to 333 rules

- Parallel control on nonsimultaneous processes
  - Rapid response
    - Braking: 0.01… 1 min
    - Stability
  - Long-term processes
    - Optimal path routing
    - Driver adaptation
      - Several minutes, permanent observation

2. Fuzzy Applications for Active Safety Control
Principle of Alterably Fuzzy Computing: Preliminary Phase

- Control object formalization
- Basic fuzzy description of control object
- Control system synthesis
- Development of control algorithm

Expert Knowledge

Experimental Database

2. Fuzzy Applications for Active Safety Control
Principle of Alterably Fuzzy Computing: Operational Phase

Control Process

Mobile (Flash) database

Alteration of membership functions

Check point

Confluence of MF

Y

MF embedding

Modification of rule base

N

Y
Advantages of Alterably Fuzzy Computing for Active Safety Control

- No essential growth for the rule base in a fuzzy controller
- DoF-number of a control object is invariable
- No raise for the nonlinearity degree of a control system
- Acceptability both for the short-term and long-term dynamic processes
3. Road Parameters Identification and Monitoring
Uncertain Information in Tire-Road Models

- **Numerical Uncertainty**: What is the friction level for the actual surface?
- **Linguistic Uncertainty**: What the surface corresponds the actual friction level?
- The direct extended fuzzy statement
  “Tire-road friction coefficient around 0.1 conforms to ice”
- The indirect extended fuzzy statement
  “Tire-road friction coefficient on ice is around 0.1”
- The alterable fuzzy statement
  “Tire-road friction coefficient on ice is around 0.1 at the moment”
## Crisp and Uncertain Components of Tire Models

<table>
<thead>
<tr>
<th>Component</th>
<th>Crisp: friction grows both with the depth of pure micro- or macro-texture</th>
<th>Uncertain: the influence of mixed surface is difficult-to-define</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road texture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water film</td>
<td>Crisp: the water film reduces the friction coefficient in general</td>
<td>Uncertain: the effect of the water film depends on the velocity and road surface texture</td>
</tr>
<tr>
<td>Snow thickness</td>
<td>Uncertain: depending on level of snow compaction, the tire friction can be subject both to a firm surface and loose surface contact models</td>
<td></td>
</tr>
</tbody>
</table>
Cascade Fuzzy Architecture for Tire-road Friction Model

3. Road Parameters Identification and Monitoring

Friction coefficients: \( \mu_{\text{prim}} \) – primary; \( \mu_{\text{env}} \) – environmentally-corrected; \( \mu_{\text{act}} \) – actual

\( \kappa \) – microroofile; \( \lambda \) – macroprofile; \( Ab \) – albedo; \( T_c \) – road temperature; \( T_e \) – air temperature; \( \rho \) – moisture; \( i \) – rain intensity; \( \omega \) – wheel velocity; \( s \) – wheel slip; \( \alpha \) – sideslip; \( F_z \) – loading;
## Overcoming Uncertainty with Fuzzy Systems

<table>
<thead>
<tr>
<th>Fuzzy system</th>
<th>Numerical uncertainty</th>
<th>Linguistic uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>„Texture“</td>
<td>Deviations of road friction caused by surface wear or slight wetness</td>
<td>Limited differentiations between texture-related road types (asphalt, concrete, etc.)</td>
</tr>
<tr>
<td>„Environment“</td>
<td>Deviations of road friction caused by external environmental factors</td>
<td>Wide linguistic range of surface interpretation, incl. snow, ice, and various grades of wetness</td>
</tr>
<tr>
<td>„Dynamics“</td>
<td>Supporting the accuracy of tire-road friction computing based on vehicle dynamics models</td>
<td>—</td>
</tr>
</tbody>
</table>
Handling the Tire-road Friction Uncertainty

Essence of linguistic classification:

Criterion to choice a corresponding tire-surface contact model for vehicle control algorithms

Different contact models within same numerical intervals
Practical Application: ITS Concept

3. Road Parameters Identification and Monitoring
Practical Application: Examples

3. Road Parameters Identification and Monitoring
### Practical Application: Case Study

<table>
<thead>
<tr>
<th>Air temperature $T_e$, °C</th>
<th>Rain / snow intensity $lg i$, mm/min</th>
<th>Previous road type and $\mu_{prim}$ value</th>
<th>Expected surface type and $\mu_{env}$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>1</td>
<td>Asphalt concrete, 0.82</td>
<td>Highly wet asphalt concrete, 0.378</td>
</tr>
<tr>
<td>-15</td>
<td>-2</td>
<td>Asphalt concrete, 0.82</td>
<td>Asphalt concrete, 0.698</td>
</tr>
<tr>
<td>-5</td>
<td>-2</td>
<td>Snow, 0.2</td>
<td>Snow by frost, 0.25</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Slightly wet asphalt, 0.76</td>
<td>Highly wet asphalt, 0.401</td>
</tr>
</tbody>
</table>
4. Vehicle Dynamics Control
Background of Vehicle Dynamics Control

- Concurrent target criteria
- Fixed set of actuating systems
- Uncertain attributes

- Performance
- Safety
- Powertrain
- Brakes
- Suspension
- Steering
- Reconstruction of force fields
Background of Vehicle Dynamics Control

Slide 25

4. Vehicle Dynamics Control

- Vehicle sideslip angle
- Yaw rate
- Lateral acceleration

Multi-parameter control

Combined control

Single-parameter control

- Lateral acceleration $a_y$
  - Error
  - Rate
- Yaw rate $\Omega$
  - Gain
  - Damping
- Vehicle sideslip angle $\alpha$
  - Error
  - Rate
Structure of Vehicle Dynamics Control System

- Estimator of Velocities
- Reference Yaw Rate
- Sideslip angle
- Fuzzy Reference Signal
- Wheel Control Selector

Wheel Slip Controller
- Wheel Slip
- Fuzzy Slip Threshold

Three-phase Algorithm
- Pressure build-up
- Pressure relief
- Pressure hold on

Pressure Control Unit (ESC)

4. Vehicle Dynamics Control
Verification of VDC Architecture

Hardware-In-the-Loop & On-road testing

Control prototyping: MATLAB / Stateflow
Hardware control: dSpace AutoBox
Real components: Brakes, Control units, sensors

4. Vehicle Dynamics Control
Case Study 1: Braking with Surface Changing

Fuzzy monitoring: asphalt
Fuzzy identification: friction drop
New linguistic attribute: loose snow

Maximal slip (front / rear) 0.493 / 0.489
Average slip (front / rear) 0.247 / 0.245

4. Vehicle Dynamics Control
Case Study 2: Sine-Steer Manoeuvre

Turning on loose snow at the constant velocity 60 km/h

Maximal yaw rate, rad/ sec
0.464 (w/o control)
0.344 (with control)

Maximal sideslip, deg
4.716 (w/o control)
0.878 (with control)
5. Conclusions and Future Works
Conclusions

• Fuzzy methods give flexible and reasonable tooling for designing automotive active safety systems

• Alterable fuzzy computing enhances the control quality both for the short-term and long-term processes without the complication of control system

• Cascade fuzzy architecture allows a rapid prototyping of systems for the road surface identification

• Integration of nonlinear and fuzzy control methods increases the performance and advantages the overcoming numerical and linguistic uncertainties by vehicle dynamics control
Challenge 1: Driver Modeling

**Fuzzy input**
- Steering actions
- Braking actions
- Position in seat
- Face movements

**Fuzzy output**

**Physiological classification**
- Relaxed
- Tired
- Strained
- Cheerful

**Emotional accentuation**
- Labile
- Pedantic
- Asthenic
- Anxious ...

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5. Conclusions and Future Works
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