Simulative design of predictive Longitudinal Controller (pLC)

apply & innovate

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The IfF is a member of the Automotive Research Centre Niedersachsen (NFF)
Structure

- Introduction
- Methodology
- Simulation
- Implementation in the vehicle
- Summary
Range of current sensors
Range of current sensors

- laserscanner
- electronic horizon
- multi-purpose camera
- radar-sensors

< 2000 m  < 200 m

prediction
Transmitter / receiver of EHR-data

Host unit

- Localization
- Digital map

EHR-data

EHR-reconstruction

Vehicle function

- Cruise control, ACC
- Gear box
- Operation strategy
Transmitter / receiver of EHR-data

- Localization
- Digital map
- EHR-data

Vehicle function
- Predictive longitudinal guide
- Gear box
- Operation strategy
Transmitter / receiver of EHR-data

host unit

localization

digital map

EHR-data

EHR-reconstruction

vehicle function

predictive longitudinal guide

in simulation

in the vehicle

GPS
Procedure

- identify situation-specific natural driving behavior
- find and create characteristic parameters
- model possible machine behavior
Procedure

- all relevant parameters for the description of the vehicle behavior (given or measured)
Procedure

• design a predictive longitudinal guide controller
• test and optimize (based on the determined target behaviour)
Procedure

- realization of the function in the vehicle
- based on the results of the simulation
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Modules for pLC

- driver analysis
- vehicle parameters
- simulation
- vehicle function
Modules for pLC

- driver analysis
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pLC
Using the big database

measured data > 1.2 Mio km

data editing

identification of customer behavior

statistical analysis of the data under consideration of 3F parameters

derivation of customer needs and potential analysis for new systems or technologies

issue-specific creation of representative 3F datasets for individual evaluations

driver analysis
Longitudinal control behavior of drivers

- road class: country road
- speed adjustment by the driver
- by road signs (bspw. speed signs or villages/towns)
- relevant vehicle signals:
  - velocity, acceleration (lateral/longitudinal), following distance, navigation data
Longitudinal control behavior of drivers

IfF - data tool

- data sets
  - search
  - and
  - selection

vehicle selection

- performance: 130 kW
- weight/power: 13,84 kg/kW
- drive: FWD
- driving time: 1525 h
- distance: 73046 km
Longitudinal control behavior of drivers

- **IfF - data tool**
  - data sets
  - search and selection

- **vehicle selection**
  - problem-specific 3F-data set
    - road class: country road
    - driving time: 188 h
    - distance: 11300 km

- **analysis**
  - maneuver
    - definition, filtering, search, preparation
Longitudinal control behavior of drivers

\[ \Delta v = \text{speed tolerance} \]

Vehicle speed

\[ v_{\text{start}} \rightarrow v_{\text{end}} \]

Approaching zone

Leaving zone

Acceleration

\[ a_{\text{max}} \]

\[ a_0 = 0 \]

Time [s] or distance [m]
Longitudinal control behavior of drivers

**driver analysis**

**filter options**

**tool**

**results**

---

**maneuver**

**accelerating**

- def. maneuver: 64
- 50 – 70 km/h: 64
- 50 – 100 km/h: 58
- 70 – 100 km/h: 170
- total: 302

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**analysis**

maneuver:

- definition, filtering, search, preparation

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vehicle speed

\[ v \]

\[ v_{\text{end}} \]

\[ \Delta v \]

\[ v_{\text{start}} \]

\[ \Delta v \]

approaching zone

leaving zone

acceleration

\[ a_{\max} \]

\[ a_0 = 0 \]

time [s] or distance [m]

\[ \Delta v = \text{speed tolerance} \]
Longitudinal control behavior of drivers

**Driver Analysis**

- **Maneuver**
  - Definition, filtering, search, preparation

**Diagram**

- Vehicle speed
  - $\Delta v$ (speed tolerance)
  - $v_{\text{start}}$, $v_{\text{end}}$
  - Approaching zone, leaving zone

- Deceleration
  - $a_0 = 0$
  - $a_{\text{min}}$
  - Time [s] or distance [m]

**Equations**

- $\Delta v = \text{speed tolerance}$

**Results**
Longitudinal control behavior of drivers

**maneuver**

**braking**

- def. maneuver : 
  - 70 – 50 km/h : 64
  - 100 – 50 km/h : 43
  - 100 – 70 km/h : 180
- total : 287

**analysis**

- definition, filtering, search, preparation
Acceleration maneuvers (e.g. 70-100 km/h)
Acceleration maneuvers (e.g. 70-100 km/h)
Braking maneuvers (e.g. 100-70 km/h)
Braking maneuvers (e.g. 100-70 km/h)

![Graph showing braking maneuvers with velocity and acceleration over distance.]
Modules for pLC

vehicle parameters

coefficient of rolling resistance
rotational inertia factor
weight
drag coefficient
...
objective: create the curve of roll to standstill to predict the vehicle behavior

roll/coast behavior of the vehicle

<table>
<thead>
<tr>
<th>Gear</th>
<th>Roll to standstill</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Eco</td>
<td></td>
</tr>
</tbody>
</table>

vehicle parameters
Modules for pLC

Simulation

Road digitalization for the simulation

description (altitude, latitude, longitude) via GPS

Analysis of the measurement system:

Quality comparison of GPS systems (GPS, AGPS, SRTM (NASA))

Toolchain:

1. Reference run on target routes
2. Converting the GPS data for using in CarMaker 5.x
3. Detailed modeling of the track incl. related attributes
AGPS is very accurate, high reproducibility → \( \Delta h_{\text{Error}} < \pm 1 \text{ m} \)

• GPS too inaccurate, high variations in the measurement and the number of repetitions, not reproducible → \( \Delta h_{\text{Error}} = \sim \pm 15 \text{ m} \)

• AGPS is very accurate, high reproducibility → \( \Delta h_{\text{Error}} < \pm 1 \text{ m} \)
Modules for pLC simulation

element for the toolchain

Geodata

CarMaker Road Preview
Structure

Introduction

Methodology

Simulation

Implementation in the vehicle

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Module: Simulation for pLC

- coast/roll behaviour
- driving resistance
  - roll resistance
  - grade resistance
  - air resistance

EHR-creation

environment attributes

environment detec.

- curve detection
- target speed for the curve
- zones with speed limits
Block: predicate coast to a stop

calculate the distance based on the traction equation

\[ Z = F_L + F_R + F_{St} + F_B \quad \text{mit} \quad Z = 0 \]

equation of motion

\[ \ddot{x} = -\frac{c_w \cdot A \cdot \rho}{2 \cdot \lambda \cdot m} \cdot \dot{x}^2 - \frac{g}{\lambda} \left( f_R \cdot \cos \alpha + \sin \alpha \right) \]

calculation method

\[ x(t) = \dot{x} \cdot dt + x(t - 1) \]

---

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Block: predicate coast to a stop

calculate the distance based on the traction equation

\[ Z = F_L + F_R + F_{St} + F_B \quad \text{mit} \quad Z = 0 \]
Simulated coasting due to attribute change

![Diagram showing coast curve 1 and coast curve 2 with points for beginning coasting marked.](image)

- Coast curve 1 starts at 110 km/h and decreases to 70 km/h.
- Coast curve 2 starts at 110 km/h and decreases to 70 km/h.
- Point 1 for beginning coasting is at 1000 m.
- Point 2 for beginning coasting is at 2500 m.

Geschwindigkeit [km/h] vs. Weg [m]
Module: Simulation for pLC

- EHR-creation
- coast/roll behaviour
- driving resistance
  - roll resistance
  - grade resistance
  - air resistance
- environment attributes
- environment detec.
  - curve detection
  - target speed for the curve
  - zones with speed limits
Block: control on the driving environment

environment attributes

- $\Delta$ distance to target attribute
- $\Delta$ speed to target attribute
- curve target speed
- speed limit

driver

- desired speed

distance control

- $\Delta$ distance to target attribute
- $\Delta$ speed to target attribute

acceleration control

- distance: required acceleration
- choose and set the desired acceleration
- speed: required acceleration

Speed control

- curve target speed
- speed limit
- desired speed
Block: control on the driving environment

**distance control**

\[ \Delta \text{distance to target attribute} \]

\[ \Delta \text{speed to target attribute} \]

\[ v_{\text{Kurve\_Ziel}} = \sqrt{\rho_{\text{Kurve}} \cdot \ddot{y}_{\text{Grenz}}} \]
Block: control on the driving environment

**distance control**

$\Delta$ distance to target attribute

$\Delta$ speed to target attribute

Approaching speed limit change

\[
\begin{align*}
S_{\text{vehicle}} & \rightarrow \pm \\
S_{\text{speed limit}} & \\
V_{\text{vehicle}} & \rightarrow \pm \\
V_{\text{speed limit}} & \\
\Delta S_{\text{speed limit}} & \\
\Delta V_{\text{speed limit}} & \\
\end{align*}
\]
Simulated control on road attributes

Parameter curve 1
- $\rho = 30\ m$
- $v_{\text{target speed}} = 38\ km/h$

$\ddot{y}_{\text{limit}} = 3.5\ m/s^2$
Simulated control on road attributes

Parameter curve 1
- $\rho = 30$ m
- $v_{\text{target speed}} = 38$ km/h

$\dot{y}_{\text{limit}} = 3.5 \frac{m}{s^2}$
Simulated control on road attributes

Parameter curve 2
- \( \rho = 100 \) m
- \( v_{\text{target speed}} = 68 \) km/h

\[ \ddot{y}_{\text{limit}} = 3.5 \frac{m}{s^2} \]

\[ y \dot{\dot{y}} = \frac{2\text{limit}}{5,3 s} \]

Velocity [\( \text{km/h} \)]

Distance [\( \text{m} \)]
Simulated control on road attributes

Parameter speed limit

- $v_{\text{Tempolimit\_Ziel}} = 50 \text{ km/h}$
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Vehicle adaptation

Packages & options

driver assistance systems:
- ACC, AEB, LKA, Navigation High

TiLo

measuring technology

dSpace Autobox, vehicle computer,
2xCAN-Interfaces, 2xCANlogs, camera,
high frequency A-GPS, datalogger,
independent power supply management,
ADMA (optional)
Vehicle adaptation

implemented test functions

self-developed, fully adjustable
ACC, AEB and LKA controllers

TiLo
Database in the vehicle

**TiLo**

**navi-messages**

informations about roads segments regarding:
- road geometry
- attributs

**EHR-reconstruction**

**ECU**

**navigation computer**
- digital map
- integrated database for additional road informations
EHR-reconstruction in the vehicle

- EHR-reconstruction
- e.g. lower saxony (location Harz)
- online computation in vehicle
- based on real measurement data

source image: wikipedia (left; Okertalsperre) ; google (right; maps)
Gliederung

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Acceleration maneuvers (e.g. 70-100 km/h)

Module: Simulation for pLC

Vehicle adaptation

Packages & options

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ACC, AEB, LKA, Navigation High

measuring technology

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independent power supply management,
ADMA (optional)
Prospects

**development goals**

- suitable controller structure
- optimization algorithms
- link between objective criteria, optimization and simulation function
- adaptation and adjustment of the data quality in the navigation system to the simulation
Prospects

vehicle function

development goals

• import the controller function from the simulation into the autobox
• function tests
• HMI concepts
• studies with experimentee

source image: google (right; maps)
Thank you for your attention

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