Support of automobile transmission development with co-simulation of vehicle and driver behaviour at virtual driving tests

Michael Matthäi, Christian Petschaelis
ZF Friedrichshafen AG
Agenda

- Motivation
- Where do we come from? What should the journey be like?
- Structure of the Co-Simulation
- Demo video
- Measurements and analyses of the Co-Simulation environment
- Summary
Thinkable uses of the SiL-co-simulation at ZF

- Load collective
- Predictive Control
- Driving strategy
- Design of new developments
Load collective data for the transmission

Measurement Load collective data

Analysis of:
• the number of the gear shifts
• the type of the gear shifts
• the quality of the gear shifts

The gear shifts depend on:
• the environment (course of curve, slope, weather conditions)
• driver (slow, normal, aggressive)
• loading of the vehicle (with trailer, loaded, empty)
## Motivation for the SiL Co-Simulation environment

<table>
<thead>
<tr>
<th></th>
<th>Vehicle</th>
<th>HiL test bench</th>
<th>SiL test bench</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behaviour of the driver</td>
<td>✓</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Vehicle characteristics</td>
<td>✓</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Environment</td>
<td>✓</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Availability</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Time for tests</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
</tr>
<tr>
<td>Danger for tester</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Agenda

- Motivation
- Where do we come from? What should the journey be like?
- Structure of the Co-Simulation
- Demo video
- Measurements and analyses of the Co-Simulation environment
- Summary

Driver controller

- Controller retraces speed profile
- No route information
- Fitful pedaling action
- Type of driver just via speed profile
- Test approach based on events
- Controller shall retrace the real route
- Different types of drivers have to be installed
Structure of the SiL test environment

- **Vehicle**
  - Transmission
  - Hydraulics
  - Engine
  - Driver controller

- **Environment**
  - Memory area
  - Control elements

- **3D Environment**
  - Road
  - Traffic
  - Driver controller
  - Components of the vehicle

- **Measuring software (external)**

**Test object:** Transmission software
SoftCar
(ZF-Friedrichshafen)
SoftCar im V-Model

Requirements Elicitation

System Requirements Analysis

System Architectural Design

Software Requirements Analysis

Software Design

Software Construction

Software Test

System Test

System integration & Integration Test

Software integration & Integration Test

Validation

Prototype

Integration Test

Hardware-in-the-Loop

Software-in-the-Loop

Model-in-the-Loop

CarMaker (IPG)

Vehicle (Simulink) (ZF-Friedrichshafen)

Agenda

- Motivation
- Where do we come from? What should the journey be like?
- Structure of the Co-Simulation
- Demo video
- Measurements and analyses of the Co-Simulation environment
- Summary
Modification of the vehicle for the SiL Co-Simulation

- Single-track model
- Acceleration only in direction x
- No slip

- Multitrack model
- Acceleration in direction x, y, z
- Slip at the wheels
Complete SiL-Co-Simulations Environment

- Vehicle
- Hardware Simulation
- Environment
- APO-Client (Application Online)
- 3D Environment
- Control unit emulation
- Measuring software (external)

TCP/IP
Reference macro of SoftCar
Operating principle of the APO-Client

- Hands over end flag
- Hands over calculated values from CarMaker

SoftCar

- Triggers APO
- Provides required values

APO-Client

- Demands for...
- Hands over calculated values after request

CarMaker

- Triggers CarMaker
- Hands over increment
- Hands over required values from SC

APO-Client
## Agenda

- **Motivation**
- **Where do we come from? What should the journey be like?**
- **Structure of the Co-Simulation**
- **Demo video**
- **Measurements and analyses of the Co-Simulation environment**
- **Summary**
Simulation (Route and Vehicle)

- **Vehicle:**
  - Audi Q5 Hybrid
  - System capacity: 245hp = 180kW (155kW engine + 40kW electric motor)

- **Route:**
  - Deggenhausertal
  - Distance ~13km
  - Country road with small towns
  - Difference in altitude ~230m
  - Maximum slope ~10%
## Agenda

- Motivation
- Where do we come from? What should the journey be like?
- Structure of the Co-Simulation
- Demo video
- Measurements and analyses of the Co-Simulation environment
- Summary
## Simulation (Types of drivers)

<table>
<thead>
<tr>
<th>Names / Characteristics</th>
<th>Hudson Hornet (Doc) „The Grandpa“</th>
<th>Sally „Average Joe“</th>
<th>Lightning McQueen „Racer“</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum speed</td>
<td>100 km/h</td>
<td>150 km/h</td>
<td>300 km/h</td>
</tr>
<tr>
<td>Acceleration</td>
<td>low (~2 m/s²)</td>
<td>normal (~4 m/s²)</td>
<td>large (~6 m/s²)</td>
</tr>
<tr>
<td>Pedal changing time</td>
<td>slow (~1s)</td>
<td>normal (~0,5s)</td>
<td>fast (~0,25s)</td>
</tr>
<tr>
<td>Cut a corner</td>
<td>not at all</td>
<td>rarely</td>
<td>all</td>
</tr>
</tbody>
</table>

Quelle: [http://www.pixarcars.tv](http://www.pixarcars.tv)
Analysis of the SiL Simulation
(Number of gear shifts)

Analysis of the gear shifts

Mean values

Error < 5%

Agenda

- Motivation
- Where do we come from? What should the journey be like?
- Structure of the Co-Simulation
- Demo video
- Measurements and analyses of the Co-Simulation environment
- Summary
Summary

- The Co-Simulation works and delivers results which are close to reality
- Simulations in x-fold real-time (till 8-fold on office PC)
- Comparable simulation by real transmission software with real application data

- The types of drivers have to be adjusted to the real driver
  - The type of driver has great influence on the gear shifts
- APO-Client and CarMaker have to be reprogrammed on interrupt
  - Better performance
Thank you very much for your attention!