Powertrain System Simulation

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Powertrain System Simulation

1. Vision
2. Concept
3. Implementation
   - Virtual Control Modules
   - Plant Models
   - Use Cases & Testing
4. Conclusions on Business Model
5. Summary
Integration and Completeness

Aim for completeness of the virtual approach for maximum impact!
To calibrate drivability (also) using a virtual vehicle the whole powertrain including all functional software and hardware components has to be digitalized.
SiL Platform for Powertrain System Simulation

Concept

Plant Models

Virtual xCUs

Co-Simulation

Engine
Transmission
Vehicle & Driveline
Battery
Electric Motor Inverter

Platform Functionality

Access Rights Management
Calibration Tool Interface
Test Automation
Auxiliary Code

ECU
TCU
CPC
BMS
Inverter ECU

CAN BUS

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Ingredients

Virtual Control Units (vXCUs)

Plant Models

Testing Use Cases
Completeness of powertrain software virtualization is crucial.
Creating Virtualized Control Units: Build Inhouse-SW for SiL (CPC, TCU)

Daimler / Inhouse

Modelling / Programming / (C-) Code-generation → SiL-Compiler → Preprocessed items (object files, SiL-specific) → „Linking“ (SiL-specific) → Virtual control unit

Inhouse Software: Direct usage on standard PC by tailored build process
Creating Virtualized Control Units: ChipSim for Multi-source xCU

Supplier

- Modelling / Programming / (C-) Code-generation
- Control-Unit Compiler
- Preprocessed items (xCU-specific)
- "Linking" (specific for xCU)
- Binary for target hardware
- ChipSim/Instruction Set Simulation

Daimler / Inhouse

- Modelling / Programming / (C-) Code-generation
- Control-Unit Compiler
- Preprocessed items (xCU-specific)

ChipSim: technology with attractive „one-size-fits-all“ attributes. Detailed at instruction set level.
Same Difference – It Does Matter How Much of the xCU Is Included!

Application Layer

Functional SW

Real Time Environment

Base SW

IO
Memory
Com Stack
Complex Device Drivers

AUTOSAR Libs

IO
MCal
Memory
Com Stack

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Same Difference – It Does Matter How Much of the xCU Is Included!
Completeness of powertrain software virtualization is crucial.
Ingredients

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Plant Models

Testing Use Cases
### Plant Models: Quality Levels – Example: Engine Model

<table>
<thead>
<tr>
<th>Quality level</th>
<th>Output e.g. engine</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
</table>
| **Advanced**  | torque, rpm, CO₂, thermal properties | Quality and accuracy comparable to production and vehicle-to-vehicle variation  
• Excellent transient response matching | DEM (discrete event models, crank-angle-based models) |
| **Functional** | torque, rpm, CO₂, thermal properties | Physical phenomenology covered  
• Qualitative evaluation, accuracy sufficient  
• Limited dynamic response (EUDC-dynamics)  
• Physical, empirical or semi-physical models | MVM (mean value models)  
[↓]  
Look-Up-Tables |
| **Basic**     | I/O supported, general system-behavior  
• Simple Look-up-models and physical approach | Functional model class (e.g. mean value models for engine) suitable for many applications |
Ingredients

Virtual Control Units (vXCUs)

Plant Models

Testing Use Cases
Use Case Matrix

Development Phase

Level of Plant Model

Advanced
Functional
Basic

Multi-xCU
Single xCU
SW-module(s)

w/o w/ measurements

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Example: Operating Strategy

Operating Strategy ICE/EM
- < 1 xCU / modules
- Look-up tables
- Update measurements

- Prediction
- Concept evaluation

Operating Strategy ICE/EM
- Multi-xCU (3+)
- MVM
- Measurements

- Simulation
- Optimization
- Calibration
- Testing
Example: Engine Speed Governor

Software System Test
- Multi-xCU (3+)
- Open loop
  - xCUs communicate

Integration Test
- 1 xCU
- Open loop
  - SW and Comstack according to spec

Module Test
- < 1 xCU / Module
- Open loop
  - Module according to spec

Closed Loop
- 1 xCU
- MVM

Development Phase

Powertrain System Test
- Multi-xCU (3+)
- MVM
- HW/Messungen
  - Concept validated
  - Response of engine and transmission

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Ingredients

Virtual Control Units (vXCUs)

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Testing Use Cases
In addition to unrestricted driving, various test types can be implemented which - when used repeatedly - can be triggered automatically.
Test Automation

Automated Tests, e.g.:
- Drivability
- Air path
- WLTC
- Durability

New Software (virtualized)

New Dataset

dataset management

Trigger

SiL

Test

Analyze

Release

ok?

yes

no
Test automation enables permanent evaluation of the development progress and supports continuous improvement of software and calibration.
Aspects for Assessing a Software-in-the-Loop Environment

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness</td>
<td>Completeness is more important than specific level of detail</td>
</tr>
<tr>
<td></td>
<td>No limitations, no pitfalls, interactive operation</td>
</tr>
<tr>
<td>Open Models</td>
<td>Open models vs. blackbox</td>
</tr>
<tr>
<td></td>
<td>One task → one tool for measurement, calibration and diagnosis</td>
</tr>
<tr>
<td>Focus on Physics</td>
<td>Physical phenomena more important than accuracy</td>
</tr>
<tr>
<td></td>
<td>Rights Management (DRM) – Content defines value</td>
</tr>
<tr>
<td>Flexible Licensing</td>
<td>Royalty-free models</td>
</tr>
<tr>
<td></td>
<td>Pure Software – always available &amp; highly scalable</td>
</tr>
<tr>
<td>Modularity and Extendability</td>
<td>Intuitive interfaces, standardized exchange formats</td>
</tr>
<tr>
<td></td>
<td>A simple user interface increases acceptance</td>
</tr>
</tbody>
</table>

- Unrestricted Driving
- Standard tools
- Access Rights
- “To-go”-Flexibility
- User-friendly
Conclusions on Business Model

Control Modules

• The vXCU is part of the delivery and part of the business model OEM - supplier
• Technology for XCUs with software from multiple sources available
• The virtual XCU must be available before the real one or the software

➤ If it has software, it has a virtual control module

Plant Models

• Supply of plant models which are required for the completeness of the SiL (e.g. battery, starter/alternator) or the required parameters
• The plant model must be available before the real component

➤ The plant model is the first development ressource
Conclusions on Business Model

Exchange Format

• Plant models and vXCU should not be restricted to a tool-specific format
• Exchange between multiple model owners required
• Enabler for completeness of SiL

> Independence from target platforms by means of exchange formats

Standards

• Strong alignment to standards, both "external" (e. g. FMU) and "internal" (e. g. for open and standardized software architecture AutoSAR)

> „Comply on standards, compete on implementation“
Conclusions on Business Model

**Skills**

- Development on virtual vehicles becomes an integral part of every development discipline
- Simulation provides the modeling skills but not (all) the simulation results
- Skill set part of the training-on-the-job for professionals or the academic education

- Additional skills for virtual development

**Engineering Tools**

- Tools to analyze and post process test results to be activated by generic test automation and reporting

- Compatible with both, real and virtual test environment and process
Summary

• The goal is to use a virtual vehicle for development where it is suitable.
• For powertrain development, e.g. for drivability calibration, this requires that all control units and powertrain subsystems are virtualized. Completeness of the system is crucial - hence, powertrain system simulation.
• The key technology is the Software-in-the-Loop approach for digitalizing control systems.
• The virtualized control modules are integrated with powertrain plant models using a co-simulation tool.
• The SiL-platform provides engineers with the complete application software for the ECUs and all relevant powertrain models. It is used for software development, calibration and simulation tasks.
• The virtual platform catalyzes automated testing.
• The option of integrating powertrain system simulation into development project has an impact on the cooperation of OEMs, suppliers and engineering companies.
Thank You for Your Attention!