SW Development for Powertrain Control of a Research Plug-in Hybrid

Mubin Bhai
Powertrain Solutions
MBtech Group GmbH & Co. KgaA
Agenda

- Introduction
- DE-REX powertrain concept
- SW structure requirements, specifications and architecture
- Collaborated SW development
- Modular concept
- Monitoring and safety concept
- MIL simulation of a shift sequence
- Summary and outlook
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Cooperation project

- Public funding by the Federal Ministry for Economic Affairs and Energy, Germany
- Funding amount: approx. 2.5 m. €
- Consortium partners:
Timeline

2015
Configuration & Basic Design

2016
SW Development
Electrical & Mech. Integration

2017
Testing, Optimization & Validation
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DE-REX powertrain concept

Two parallel 2-speed subtransmissions
- High efficiency due to load shifting
- High starting torque and high maximum speed
- No frictional elements in transmission
  Actuation
- No reverse gear required
- No synchronization mechanism required

Two small electric machines
- No interruptions of traction force during shifting
- High efficiency of small machines at low loads

Range-Extender
- Parallel and series hybrid modes
Modes of the DE-REX powertrain

- Electric Driving
- Powersplit
- Operating Point Shift
- Series Hybrid
- Parallel hybrid
Location of powertrain components

Driving direction

HV-Verkabelung in Richtung Fahrzeugheck (PDU, Batterie,...)

2x Brusa-LE

Motorhaube

EM1

EM2

Driving direction

VKM

LE
Topology and Central Rapid Prototyping Controller

- DCDC Converter
- EM2
- EM1
- BMS
- On-Board Loader

- HV CAN
- LIN
- Chasis CAN
- Powertrain CAN
- Engine Control Unit
  - Position Sensors
  - Oil Temp. Sensor
  - Speed Sensor
  - Accelerator Pedal

- Electronic ignition Switch
- Electrical Power Steering
- ABS / ESP
- Shifter
- ...

- Coolin Actuators
- Private CAN
- Shift Motor Controller

Matlab Automotive Conference, 21 September 2016, Stuttgart
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SW structure requirements

- Clear partitioning based on system components
- Portability on rapid prototyping platform (minimal focus on data/data type management)
- Compatibility with existing development environment (Matlab-Simulink)
- Reusability
- Agility
- Traceability of faults
- Fast integration (multiple SW developers)
SW functional specifications

- Graphical method to describe SW Specifications in UML
- Linking of UML to Simulink also possible in the future
SW architecture

Input

Signal Input
- Reception of Input Signals
- CAN & LIN
  - CRC calculation
  - Alive counter
- HW Signals
  - Conversion to physical values
  - Electrical Diag.

Signal Preparation
- Interface to core SW
- CAN & LIN
  - SNV Check
- HW Signals
  - Sensor diag.
  - Filtering

Input Preparation MIL
- Routing of MIL Signals to core SW

HW

MIL
SW Architecture

Core SW

<table>
<thead>
<tr>
<th>Current states</th>
<th>Target states</th>
<th>Control</th>
<th>Monitoring/ Evaluation</th>
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</thead>
<tbody>
<tr>
<td>Brake</td>
<td>Operation strategy</td>
<td>Traction Torque</td>
<td>Plausibilisation</td>
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<tr>
<td>Gear</td>
<td>Shift process</td>
<td>Synchr. Speed</td>
<td>Failure manager</td>
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<tr>
<td>Wheel torque</td>
<td>Engine Start</td>
<td>HV Current</td>
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<tr>
<td>Shifter</td>
<td>Torque coordination</td>
<td>Cooling temp.</td>
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<tr>
<td>Shift Actuators</td>
<td>HV strategy</td>
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<tr>
<td>Battery</td>
<td>Sep. clutch</td>
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<tr>
<td>Traction E-Motors</td>
<td>Traction Torque</td>
<td>Shift Actuator</td>
<td></td>
</tr>
<tr>
<td>Inverters</td>
<td>Synchr. Speed</td>
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<tr>
<td>DC-DC Converter</td>
<td>HV Current</td>
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<tr>
<td>On board Charger</td>
<td>Cooling temp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cooling flowrates</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Control

Monitoring/ Evaluation

Plausibilisation
Failure manager
Failure reaction
Signal switching
SW Architecture

Output

Output Preparation
- Switching between automatic & manual o/p
- Generation CAN Signals
- Generation Signal structure

Signal Output
- Transfer of Signals to dSPACE RTI Blocks
- Generation of CRC
- Generation alive counter

Output Preparation MIL
- Routing of Signals to MIL

HW

MIL
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Collaborated SW development

Versionmanagement → SVN Server

User Y ↓

Change Request

Trac System

→

Upload of Libs and Test Modules to SVN server

Modultest

Model-Construction

User X

→

Change Request
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Modular Concept

- Clear definition of Modules according to component and function in SW
- Enables pin pointing generation of a signal / state or an error
- Library links enable the developer to work in a test environment
- Library structures allows availability of a functional MIL environment to all users
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Monitoring Concept

• Limited number of prototype components demand a robust monitoring and component / driver safety concept
• Following safety targets were identified for the powertrain
  – Avoidance of unwanted acceleration
  – Avoidance of starting in wrong direction
• 2 level Monitoring Concept was implemented to achieve the targets
Safety concept for transmission components

Powertrain & Transmission plant modeling in Simscape

- Aim to build the plant model in Simscape was to inject sensor errors in the control loop
- Plant could be modelled quite close to the actual powertrain
- Following situations could be successfully tested with the corresponding safety functions
  - Overheating of transmission components
  - Overvoltage/ overcurrent at shift motors
  - Permanent torque output of the shift motor at v=0
  - Jamming of dog clutch teeth
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MIL simulation for a shift sequence (NEDC cycle)
Shift sequence explained

1-2 Shift
Transmission 1

0-1 Shift
Transmission 2
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Outlook and Summary

- SW structure / architecture for the research plug-in hybrid was developed in Simulink
- Degree of complexity not applicable for series applications but good enough for a proof of concept application
- Can be reused for similar projects in the future
- Concrete test-bench and car results available next year
- SW structure / architecture will be analyzed retrospectively with the test bench and demo car results
- Potential to further development /adaptation for series applications
Thank you for your Attention!

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DE-REX Powertrain Concept

**Electric Machines**
- Permanent magnet synchronous motors
- $P_{EM,max} = 48 \text{ kW}$

**Combustion Engine**
- 3-cylinder turbo charged engine
- $P_{ICE,max} = 65 \text{ kW}$
Potentials and advantages

- Highest efficiency in pure electric driving modes
- High range in parallel Range-Extender operating modes
- Good driving performance
- High driving comfort
- Potentials for reducing costs
HV Configuration

Front

- PE EM1
- PE EM2
- EAC

Boot

- OBL
- PDU
- DCDC-C.
- HV-Battery

$P_{EM,max} = 48 \text{ kW}$

$P_{EM,max} = 48 \text{ kW}$
DE-REX Powertrain Concept

Transmission

- Coaxial layout with common usage of the gear wheels for both subtransmissions
- Tooth couplings/dog clutches without synchroniser rings
- Shifting system based on AMT-technology
- Integrated parking lock function
Core SW specification in UML
Torque Path

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