Co-Simulation Platform Conneecting Chemistry and Powertrain Dynamics to Traffic Simulation

Project overview

LOGE GmbH & VKA RWTH Aachen

March 2020
Agenda

- Background
- Project goal
- Consortium
- Solution concept
- Development stages
- Implementation
- Project impact
- Progress
Background | Emission gap: reality vs laboratory

Since September 1, 2017, passenger car emissions have been measured under real conditions.

Source: Bosch

“normal driving” required, but coverage of 95%+ of EU driving expected. Considered as parameter of highest influence.

Solution: measurement- or simulation(virtual)-based vehicle calibration and optimisation for real driving conditions.

Background | Motivation for virtual calibration

Lower interest in developing new combustion systems, but high pressure on cost-effective product and process

Expensive development and calibration procedures that rely on measurements on engine/vehicle test benches

Simulation based front-loading enables cost reduction, efficiency increase and quality improvement

- **Computer Aided Engineering (CAE)** tools are used to reduce cost and time of powertrain development ECU calibration.
- **Hardware-in-the-Loop (HiL) / X-in-the-Loop (XiL)** platforms allow the integration of CAE tools in the powertrain development and ECU online calibration.
- Incorporation in the XiL platform **physical-based models** is essential to increase the accuracy of simulations and the acceptance of the novel HiL co-simulation model toolbox.
- The virtualization of test drives for **Real Driving Emissions (RDE)** requires a **holistic simulation approach**; to meet the requirements; incorporation of combustion → aftertreatment → powertrain → vehicle → driver → traffic; **multi-level co-simulation**

**Hardware-in-the-Loop (HiL) as a key for efficient development of environmentally friendly vehicle powertrains**
Project goal

- LOGE-RT engine software employing detailed chemistry for real-time emissions prediction for RDE applications of a compression ignition diesel engine
- Co-simulation of LOGE-RT – 0D physics-based model for Hardware-in-the-Loop based applications

Source: LOGE AB, VKA RWTH Aachen
Consortium

RWTH Aachen

ZIM Project Consortium

LOGE GmbH (Project Leader)

XiL Platform
Simulation framework for virtual prototyping/ECU calibration

LOGE-RT
Modelling of engine in-cylinder processes
Consortium | Team members

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Solution concept

Co-Simulation Model Domains:
- Combustion & Emissions
- Detailed Chemistry
- In-Cylinder
- Vehicle
- Transmission
- Engine
- Driver & Traffic

Model-in-the-Loop Hardware-in-the-Loop:
- MiL - FMI Interface
  - Engine
  - FMU
  - Simulation Environment
- HiL - ECU Hardware
  - HiL Simulation Environment

Application Assessment:
- Virtual Prototyping
- Virtual Powertrain Validation
- Virtual ECU Calibration
**Solution concept | Engine cylinder modelling**

**LOGE-RT based on SRM and 1D full engine model in GTP**

### XiL Platform

- **MiL - FMI Interface**
  - Engine
  - FMU
  - Simulation Environment

- **HiL - ECU Hardware**
  - HiL Simulation Environment

### HiL - ECU Hardware

- Virtual prototyping
- ECU calibration

#### Stochastic Reactor Model

- **Cl engine**
- Engine processes:
  - Piston motion
  - Fuel injection
  - Mixing
  - Chemistry
  - Heat transfer

#### Measured data for model development, training and validation

#### Model application to real driving cycle conditions such as WLTP

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**Norm. engine torque [%]**

-20
0
20
40
60
80
100
120

**Engine speed [U/min]**

500 1000 1500 2000 2500 3000 3500
Engine performance mapping using LOGE SRM

\[ \tau = f(k, C_i) \]

\( C_i \) - model constants,
\( k \) - turbulent kinetic energy

Mixing time (\( \tau \)) parameterisation
Towards real time driving cycle simulations

**LOGE SRM | Relation to other methods**

- **Tabulated chemistry**
  - Instead of using product species as indicators of the reaction progress, the evolution of the chemistry is parametrized with a progress variable \( C \) using chemical enthalpy \( h_{298} \):
    \[ C = h_{298} - h_{298,0} / (h_{298,\text{maxHR}} - h_{298,0}) \]
  - Detailed chemistry scheme is pre-compiled in a look-up table containing \( dc/dt \) source, molar mass of the mixture, polynomial coefficients, species to be monitored and emissions source terms; the look-up table parameters are pressure, unburned temperature, equivalence ratio and EGR

- Possibility to use complex fuel surrogates with no drawback on computational cost
- Advantages for full cycle simulations and control algorithms development and optimisation
HiL modeling approach using physics-based engine model

- The engine model is calibrated using steady-state engine mapping from the test bench
- Achieved cycle NOx emission target ±10% set during the project begin
- Effort for HiL system set-up
  - Depending upon the verified inputs (hardware information, measurement data, ECU, rest bus simulation, etc.) required for the HiL set-up

Validation of the HiL simulation results for the engine-out NOx emission

Source: Virtual Real driving environment and emissions: a road towards XiL-based digitalization of the powertrain calibration, International Conference on Calibration Methods and Automotive Data Analytics May 21–22, 2019, Berlin

Relevant publications
Development stages | Overview

### GTP-LOGE model
- First release
- Platform development for MiL

### Update to GTP model
- **M1: Cross check GTP-SRM**

### Testing co-sim on MiL
- **M2: Cross check GTP-SRM**

### Testing co-sim on HiL

### Specification
- **VKA & LOGE**
  - GTP-SRM v1; initial calibration; focus on the external cylinder module
  - Models development, refinement and validation

- **VKA**
  - GTP-SRM v2; LOGE-RT integration in the MiL platform; S-function

- **LOGE**
  - LOGE-RT refinement in co-sim
  - Work on FMI

- **Applications; driving cycle on the HiL**
### Development stages | Work packages

<table>
<thead>
<tr>
<th>Specification</th>
<th>WP1</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Test engine, Fuel specification, Operating points selection, RDE application case, Input- and output for co-sim; ...</td>
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<table>
<thead>
<tr>
<th>MiL platform</th>
<th>WP2</th>
<th>Real-time engine model</th>
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<tbody>
<tr>
<td>Powertrain models extension and for RT applications</td>
<td>Modelling updates: 0D turbulence, vaporization, heat transfer</td>
<td></td>
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<tr>
<td>MiL integration, simulation and validation</td>
<td>Optimizations of sub-models (time and accuracy)</td>
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<td>LOGE-RT on the MiL platform</td>
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<thead>
<tr>
<th>HiL platform</th>
<th>WP3</th>
<th>Real-time tabulated chemistry</th>
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</thead>
<tbody>
<tr>
<td>Driver and environment model adaptations for RT compilation</td>
<td>Interpolation method for tabulated chemistry</td>
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<tr>
<td>RT capability of all models considering HiL specification</td>
<td>Automated calibration of emission parameters</td>
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<tr>
<td>Integration of LOGE-RT on the HiL platform</td>
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<thead>
<tr>
<th>Functional-Mockup Interface</th>
<th>WP4</th>
<th>Functional-Mockup Interface</th>
</tr>
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<tbody>
<tr>
<td>HiL simulation and validation</td>
<td>FMI programming and validation</td>
<td></td>
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<tr>
<td>Driving cycle on the HiL platform</td>
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<thead>
<tr>
<th>Management</th>
<th>WP5</th>
<th>Management</th>
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<tbody>
<tr>
<td>Meetings, Workshops, Conferences, Reports, Advertising, Market introduction, ...</td>
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Implementation strategy

"We already start advertising and showing results during the project increasing the impact of the project results"

"We inform our customers about the project and keep them involved to increase their interest"

"There is a high interest in this technology in different application fields"

Project kick-off Oct 2019

LOGE-RT & HiL RDE application 2021

Project end Sep 2021

LOGE-RT software market introduction 2021 - 2025

OEMs, Tier 1 in application field of Virtual vehicle calibration
- Function development
- Hybrid & electrification
- Automotive software development

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### Impact of the Project

Strategies for knowledge transfer to improve the impact of the CONNECDT project:

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Time frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal meetings</td>
<td>During the personal meetings with customers, OEMs and Tier 1 the project partners will present non-confidential results.</td>
<td>During and after the project</td>
</tr>
<tr>
<td>Workshops</td>
<td>The project partners will organize workshops with customers, OEMs and Tier 1 to discuss the project results and progress.</td>
<td>During the project</td>
</tr>
<tr>
<td>Conferences</td>
<td>The project partners will attend international conferences for scientific and industrial organization to present and discuss the latest project results.</td>
<td>During and after the project</td>
</tr>
<tr>
<td>Publications</td>
<td>The project partners will publish the project results in international journals.</td>
<td>During and after the project</td>
</tr>
<tr>
<td>Graduates</td>
<td>Graduates who are working on the project and get a new position in the industry could promote the project results.</td>
<td>After the project</td>
</tr>
<tr>
<td>Website</td>
<td>The website contains a description of the project, its goals, the project partners, recent news and publications.</td>
<td>During and after the project</td>
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