Gasoline Engine Control Using Real Time 1-D Model Running in Rapid Prototyping ECU

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Agenda

• Introduction
• Engine Control Unit
• Real Time Engine Model
• MiL / SiL
• Testbed application
• Conclusions
Introduction - Motivation

• Emissions legislation is driving accuracy of Electronic Control Units
  – Mean value modelling approach is becoming insufficient

• Prove the concept of real time 1-D gas dynamics engine model based control
• Increase performance and robustness of engine control

• Demonstrate new approaches and help reduce the costs via integration of a real time
  1-D gas dynamics model into rapid prototyping ECU

• Engine control application development requires a complete vehicle system
  modelling to reduce the costs. This often leads to co-simulation of the most suitable
  SW tools
Introduction - future trends in advanced engine control algorithms development

- **MiL/SiL:** Integration of all vehicle modules and testing of control algorithms in the flexible physics-based modelling platform.

  Engine model can be represented by any SW tool that can be integrated into co-simulation.

- Advanced engine control algorithms

  Auto-generated binary is flashed into ECU for testing on the testbed and in vehicle.

- Integration of real time 1-D gas dynamics engine model into ECU is the future of advanced engine control algorithms development.
Introduction - advantages

- Running a real time 1-D gas dynamics model like WAVE-RT within ECU allows:
  - Improve quality and robustness of engine control performance
  - Improve On-Board Diagnostics and Condition Base Maintenance
  - Decrease engine costs by removing selected sensors
  - Meet future emissions limits

- Why?
  - WAVE-RT model is capable of calculating all crank resolved engine parameters.
  - WAVE-RT calculates parameters that are difficult and expensive to measure.
  - WAVE-RT calculates parameters that can be measured but does not suffer sensor life-time issues.
  - Some calculated parameters can be compared with measured parameters and the results can be used to check sensors functionality and/or to adapt the engine model/engine control strategy (e.g. adaptive control, model predictive control).

- Examples of possible controller development using this technology include:
  - Transient smoke limitation, knocking prediction
  - Cylinder to cylinder air/fuel ratio control
  - Transient EGR control
  - Closed-loop combustion analysis
  - Crank angle sensor prediction and O2 concentration sensing
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Ecu - rCube2: Hardware

- Ricardo has used its rapid prototyping ECU: rCube2
  - User ready rapid prototyping ECU based on AUTOSAR
  - Equipped with an additional modules

- Real time 1-D engine model is running in a module based on **ARM**-A9 quadcore where the model is running faster than real time and providing all requested parameters with a slight time advance

* ARM based module documentary picture credits: [www.fedevel.com](http://www.fedevel.com)
ECU – key features of rCube2:

- Modular platform with 2 Input/Output expansion modules
- Two 32 bit Infineon processors; Robust packaging for in-vehicle use
- LEMO® connectors; Compatible with 12 V and 24 V
- CAN, FlexRay, Ethernet, LIN, RS232
- Automotive specific inputs and outputs
- AUTOSAR with Simulink® integration
- OneClickBuild process from Simulink® interface
- XCP over Ethernet or CAN; Multi-rCube2 networking support
- Expansion module to run real time 1-D engine model (ARM platform based)

Suitable for various applications

- Engine control applications
- Transmission applications
- Hybrid & EV applications
- Telematics and multi-sensor data fusion applications
- Advanced control applications

And more...
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Real Time Engine Model – selected configuration

- Vehicle: VW Golf Mk6
- Engine: VW 1.4 litre TSI gasoline engine with turbocharger

<table>
<thead>
<tr>
<th>Engine parameters</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>Manufacturer:</td>
<td>VW (EURO 5)</td>
</tr>
<tr>
<td>Type:</td>
<td>EA211, 1.4 litre TSI</td>
</tr>
<tr>
<td>Engine code:</td>
<td>CHPA</td>
</tr>
<tr>
<td>Max. power:</td>
<td>103 kW / 4500 - 6000 rpm</td>
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<tr>
<td>Max. torque:</td>
<td>250Nm / 1500 - 3500 rpm</td>
</tr>
<tr>
<td>Number of cylinders:</td>
<td>4 cylinders, inline</td>
</tr>
<tr>
<td>Stroke volume:</td>
<td>1.395 litre</td>
</tr>
<tr>
<td>Injection, Ignition system:</td>
<td>BOSCH Motronic ME 17</td>
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<tr>
<td>Fuel:</td>
<td>gasoline</td>
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<tr>
<td>Bore:</td>
<td>74.5 mm</td>
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<tr>
<td>Stroke:</td>
<td>80 mm</td>
</tr>
<tr>
<td>Compression ratio:</td>
<td>10.5</td>
</tr>
<tr>
<td>Valves per Cylinder:</td>
<td>4</td>
</tr>
<tr>
<td>Firing order:</td>
<td>1 – 3 – 4 – 2</td>
</tr>
</tbody>
</table>
The WAVE-RT model is created from a pre-existing, validated WAVE (standard 1-D gas dynamics software) model which covers, in detail, modelling of individual cylinders, real engine geometry, boosting system, etc.

Good match between measured data vs. WAVE vs. WAVE-RT
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MiL / SiL

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Vehicle model – driveline part

- Before works on testbed the algorithms are checked in complete vehicle simulation

Co-simulation block:
Engine model and engine control strategy
Control strategy - entire overview

- Engine control application is developed in MATLAB/Simulink while WAVE-RT offers precise real-time engine modelling and IGNITE models the rest of vehicle functionality

- Blocks A - N
  - Individual modules of engine control strategy, e.g. input manager, ignition, injection, rail pressure, output manager
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Set up

- rCube2, containing the control strategy with WAVE-RT model, completely manages the engine in its entire operating range.

- Testing on testbed - work in progress
WAVE-RT monitor: 2 examples

- The optional WAVE-RT monitor allows a user to display various engine parameters of running WAVE-RT model from rCube2

Motoring mode
Fuel consumption: 0 kg/h

Part load mode (accelerator pedal position = 90 pct)
Start of main injection #1/2/3: -298/-205/-116 deg
Start of ignition: 6 deg
Fuel consumption: 17.4 kg/h
Example of available estimated parameters in ECU

- rCube2 has been used to run VW engine in steady state and transient drive cycles
- WLTC has been chosen for transient testing

Estimated WAVE-RT parameters are easily used in engine control strategy.
Advantages

- Real time 1-D engine model provides more detailed information in comparison to data from a common sensor and mean value engine approach:

![Intake manifold pressure graph](image)

![Knocking in cylinder #1-4 graph](image)
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**Conclusions**
Summary

- This work shows a unique solution presenting the implementation and use of a real time 1-D gas dynamics model for gasoline engine within a rapid prototyping ECU extended by automotive grade ARM-A9 processor.

- The testbed implementation shows promise for improving system performance and engine on-board diagnostics as well as decreasing engine costs by removing selected sensors and meet future emissions limits.

- Examples of possible controller development using this technology include knocking prediction, transient smoke limitation, cylinder to cylinder air/fuel ratio control, transient EGR control, closed-loop combustion analysis, crank angle sensor prediction, O2 concentration sensing, and condition base maintenance.

- This technology can be used on any combustion engine, e.g. genset or diesel engines (see next slide).
Diesel Engine Control Using Real Time 1-D Engine Model Running in Rapid Prototyping ECU

• WAVE-RT model is running real time within the rCube2 engine management system. Advantages have been demonstrated for smoke limitation control, and sensorless control of boost pressure.
• Results have been presented at SAE and VPC conferences.

Schematic overview of smoke limitation engine control strategy

Type: IVECO, F4AE0682C – turbocharger diesel with intercooler
Max. power: 194 kW / 2500 rpm
Max. torque: 930 Nm
Number of cylinders: 6 cylinders, inline
Stroke volume: 5.9 litre
Fuel injection system: HPCR electronic (Common Rail)
VGT (instead of the original wastegate) was chosen for the advanced ECU implementation

Conclusion:
Up to 5.5 % smoke improvement in WHTC drive cycle
Conclusion

Thank you for your attention

Do you have any questions?

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