Distributed Co-Simulation of Control Software and Process Plant using INTO-CPS

IFG Meeting

MAN Diesel & Turbo

Nicolai Pedersen

14-11-2017
• 2011: MAN become part of the VW Group

• MAN Diesel & Turbo world leader on low-speed diesel engines

• 50% of all world trade is powered by MAN Diesel & Turbo Engines

• 53,824 Employees World Wide
### Engines & Marine Systems
- Two-stroke and four-stroke engines for marine applications
- Propellers and complete marine propulsion systems
- Turbochargers

### Power Plants
- Two-stroke and four-stroke engines for stationary applications
- Diesel and gas power plants

### Turbomachinery
- Compressors, gas turbines and steam turbines
- Turnkey machinery trains
- Chemical reactors

### Service: MAN PrimeServ
Worldwide network of service hubs: 24/7 OEM service around the globe
Large Bore Engine Development Challenges

Increased Portfolio complexity

- **Emission Control**
  - SCR, EGR, SOX-Scrubbers
  - Increased thermodynamic complexity
  - Observer-based control

- **Dual Fuels**
  - Ethanol, Methanol, LNG,…,(Coal)
  - Increased Requirements for temporal execution

- **Auxiliary Systems**
  - Data sharing with other systems
  - Global vessel optimization

Cyber Physical System Complexity

- Control dynamics influencing physical dynamics and vice versa.
- Mixture of discrete and continues models
Embedded Control Software Simulation
Simulation of CPS

Software Application Environment
- C++ Environment
- Component Based Architecture
- Dynamic Simulation Environment (DSE)
  - ODE Solver
  - Higher Resolution Kernel
  - Model Library

Cross Compiler
- Build for Target (Embedded Core)
- Build for Simulation (x86)

Controlling the Clock for Temporal Execution
- BSP-Idle thread used as hook to schedule execution. (Clock ticks, Interrupts, Communication)

Manager Orchestrating Simulation
- Multiple Controllers (Multi-threaded)
- Implements FMI for orchestration of heterogeneous models and tools.
Exhaust Gas Recirculation Water Handling System (WHS)

- EGR exchange in-cylinder $O_2$ with $CO_2$ → decrease in combustion speed → lower peak temperatures during combustion → lower thermal $NO_x$

- Water Treatment System (WTS) Delivered by Alfa Laval

- WHS Control
  - Main objective: To regulate Level in Receiving tank
  - EGR Control Unit
    - State Machine for Start Stop and Operation
    - PI-Controller for Receiving Tank Level
Simulation and Verification Process

SIL Verification
- Engine Simulation Unit (ESU)
- DSE physical dynamics model of WHS
- EGR Control Unit (EGRCU)
- Complete EGRCU control software

HIL Verification
- Real embedded controllers
- Engine Model in ESU

Test Bed Verification
- Real embedded controllers & engine

Results
- Working PI-controller
- Water level overflow in Receiving Tank
Optimization of Development Process
Co-Simulation

Evaluation of Simulation Results

- Unhandled accumulation of water in Water Mist Catcher
- Incorrect state machine handling of operation Shutdown
- Preliminary study in MATLAB had been simplified when moving to DSE (C++)
- Test and Verification Cost approx.: XXX €

Platform & Architecture Challenge

- Control System 32-bit Linux
- 90% Organization tools 64-Bit Windows

Solution: Distributed Co-Simulation

Targeting Co-Simulation

1. Simulation of Control System In MATLAB
   - Redundancy in control model development
   - Physical Models still need to be converted to C++ for HIL testing

2. Enhancement of DSE Model.
   - Traditional Approach

3. Co-Simulation of Control System and MATLAB
Integrated Tool-chain for the model-based design of Cyber-Physical Systems

- From requirements to final realisations
- COE fully FMI 2.0 co-simulation compliant
- Supports multiple commercial tools
Distributed Co-Simulation

INTO-CPS COE Extension

Distributed Co-Simulation Orchestration Engine (COE)

- Multi-architecture and Platform Co-Simulation
  - Mixing 32- and 64-bit
  - Mixing Linux and Windows Processes

- Distributed Factory

- Java RMI
  - Cross Platform Communication
Distributed Co-Simulation
Process Plant and Control System Verification

Linux Host
- Distributed COE Daemon
- Control System FMU
- Shared Library with FMI API
- EGR Control Unit with WHS Control

Windows Host
- Master COE
- Code Generated MATLAB FMU
- WHS Physical Model

Results
- Higher fidelity model made it possible to develop a working state machine
- Stable Water level in Receiving Tank
Discussion & Future Work

Model Sharing between departments & OEMs
- Reduce development redundancy
- Closer collaboration with OEMs

Optimization of Development Cycle
- Rapid Prototyping
- Reduce test and verification Cost
- Limit pressure on HIL equipment and test bench

Diversity in Tool-Chain through Co-Simulation
- Use the tools most suited for the problem at hand

Future Applications & Products
- Engine Simulator for education purpose & Superintendent Assessment
- Model based fault diagnostics
- Root cause analysis

---

**Functional Mock-up Interface (FMI)**

- **Engine Dynamics** (MATLAB)
- **Engine Control System** (In-House Tool)
- **Auxiliary Systems** (GT-Suite)
- **Vessel Dynamics** (Modelica)
Do you have any questions?

Nicolai Pedersen
E-mail: nicolai.pedersen@man.eu
Phone: +45 33 85 20 12