Multi-disciplinary simulation of Cyber-Physical Systems – The OpenCPS approach

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Akos Horvath (IQL)
Internet of Things

Cyberphysical systems

Digital Industries/Industrial Internet
- GE

CityNext
- Microsoft

Industry 4.0
- H2020

Smart home

Connected Society
- EU-ECSEL

Smart city, smart grid
- IBM

Networked Society
- Ericsson

(Global Situation Awareness)
- Saab
Perspectives of IoT

User

Applications addressing real-world / everyday problems embedded in a natural/human environment:

Well-known

- Cities, buildings, Energy grids, Healthcare, sport, etc.

“Cyber Physical Systems”

- Transportation, defence, espionage, building security, etc.

Engineer
Short Overview

- Duration 3 years, December 2015 to December 2018
- 4 countries: Sweden, France, Finland, Hungary
- Current status: 46.5 person-years, 6.5 M€, 18 partners
Consortium Overview
Industrial Domains & Applications

Sweden
- Equa Simulation
- Ericsson
- KTH
- Linköping University
- Saab
- SICS East
- Siemens Industrial Turbomachinery
- SKF

France
- CEA LIST
- EDF
- ESI Group
- Inria
- RTE
- Sherpa Engineering
- SIREHNA

Finland
- VTT

Hungary
- IncQuery Labs
- ELTE-Soft

Red = Project Leader
Green = National Coordinator
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**OpenCPS**

- **Energy & Power plants**
- **Aeronautics**
- **Bearings**
- **Automotive**
- **Communications technology**
- **Naval**
- **Buildings & infrastructure**

Red = Project Leader
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Top 3 Key Innovation Areas
Targeted Innovations

- **FMI run-time and master simulation framework including UML/Modelica Interoperability**
  
  Scalable, reliable co-simulation of discrete-time software parts with continuous-time physical processes, designed for handling large numbers of events.

  Integration of the UML and Modelica domains utilizing the FMI standard.

  Open source FMI Master Simulation Tool.

- **State Machine and Real-Time Debugging & Validation**
  
  Industry-strength support for advanced state-machine modeling and debugging.

  Several levels: limited debugging of connected black-box FMUs, full debugging capabilities for components for which the model source code is available.

- **Efficient Multi-Core Simulation**
  
  Improved compilation and simulation capabilities for large models.

  Several levels: coarse-grained, running whole simulations and/or FMUs in parallel, to more fine-grained by parallelization of equation models and algorithmic code inside model components.
Validation of project results in a **wide range of advanced industrial demonstrators!**
Industrial demonstrators

Building

Aeronautics

Mechanics

Naval

EQUA

Saab AB

SKF

Sirehna

Power plant

Gaz turbines

Automotive

EDF

Siemens TU

Sherpa
Industrial demonstrators

- **Building**: EQUA
- **Aeronautics**: Saab AB
- **Mechanics**: SKF
- **Naval**: Sirehna

**Power plant**: EDF
**Gaz turbines**: Siemens TU
**Automotive**: Sherpa
Industrial Use Case
Saab Aeronautics
MODELING DOMAINS

Usage, Needs, Architecture

Control
\[ f(t) \rightarrow L(s) \]

G(s)

F(.)

Information

Class G
Prop
GetSpe
Class H
Number

MMI Virtual

Models of information objects, needs, services

Structure

F

Physical systems

Embedded

Electronics Optinics

Models of physical objects

Model Integration and System Simulation
MODEL integration and system simulation

Training System Requirements

- Prototyping Tools and Simulators
- Software Development MYSIM
- Hardware Rigs
- System Simulator

Flight Test

Aircraft Software

Prototype Demonstrations and Evaluation

Mission Trainer

Software models and tools
• **FMI-based co-simulation of Aircraft Vehicle Systems**
  - Models of physical systems
  - Models of control software
  - Models of functional monitoring
  - Models of human physiology

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**Industrial Use Case**

**Saab Aeronautics**

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System schematics of an aircraft Environmental Control System (ECS)
Industrial Use Case
Saab Aeronautics

Boundary Conditions
- Flight mission (Mach, altitude,...)
- Pressure, Temp., Humidity with altitude
- Sun radiation, Sun position.
- Pressure, Temperature, Humidity change over horizontal distance
- Non standard atmospheres model?
- Time varying heat loads from e.g. 6015076

Geometry Data

Model description [language/tool origin]

Functional Mock-up Unit (FMU)
Physical connection
Information signal

FMI master simulation environment

Engine [Modelica]
Sample model of an aircraft engine bleed pressure, temperature.

ECS Control System [Simulink]
Control system model, takes sensor signals as input, sends control signals to a number of electrically actuated valves in the ECS.

Aircraft Environmental Control System (ECS) [Modelica]
Model of the aircraft environmental control system, including realistic provision of cockpit comfort air.

Cockpit Model [Matlab]
Simulate the temperature, pressure and humidity of the cockpit air depending on the inputs from the ECS system and the pilots physiological performance.

Flight Management System [CtUML]
Model providing the pilot with alerts, warnings, and suggested actions depending on current aircraft state.

Pilot Physiological Model [Matlab]
Simulate human (pilots) body temperatures depending on personal or automatically set cockpit environmental aircraft data.

Pilot Psychological Model [UML]
Model which simulate the psychological behavior and reactions of the pilot depending on the environmental comfort.
Industrial Use Case
Saab Aeronautics

- More efficient processes for **model export & integration** supporting continuous model validation and improvement
  - Early validation of system safety and security
  - Supporting large-scale system simulator development

- Model based development has shown to increase the system knowledge and **errors are found in an earlier stage**
  - Simulation of system including both continuous and discrete event models

- **Modelling as a means for communication** has a great potential for development of complex systems
  - Both internally and externally with partners and subcontractors
Conclusion
Current Status of OpenCPS

- Industry grade benchmark models developed
- First prototype of run-time integrating FMI and UML
- Prototype implementations for real-time synchronization and clocked synchronous library
- Extensive testing/development of the Transmission Line Method (TLM) connection to Modelica tools
- Prototyping method for simulation of connected and mutually dependent FMUs

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