SIMPACK - A Tool for Off-Line and Real-Time Simulation

Real-Time for ECU Testing: State of the Art and Open Demands

SIMPACK - Code Export: A Newly Emerging Module for Real-Time Models

Application Example
### Single Source Data Management

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... to meet Real-Time World of ECUs

Functional Virtual Prototype
MBS-Model (1-2 ms)
- Wheels / Tyres
- Suspensions
- Steering System
- Chassis
- Brakes
- Driver
- Road
- ...

Actuators (0.5 ms)
- Hydraulics
- Electronics
- Pneumatics
- ...

Sensor Signals

Test Lab for ECUs

ETAS

HIL ECU

MIL Operator

SIL ECU-Code

ETAS
What does Real-Time Simulation mean to the FVP?

**Functional Virtual Prototype**

MBS-Model (1-2 ms)
- Wheels / Tyres
- Suspensions
- Steering System
- Chassis \( \dot{x} = f(x,u,t) \)
- Brakes \( y = g(x,u,t) \)
- Driver
- Road
- ...

Actuators (0.5 ms)
- Hydraulics
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- ...

- It always means „Co-Simulation“ with a fixed sample rate
- It means no “Jacobian” of Complete System
- It means within 0.5 - 2 ms: - at least one function evaluation
  - at least one integration step
  - one sensor evaluation
- Today it mostly means (semi) explicit Euler scheme for FVP
- Today it means ordinary differential equations
- Today it means non-stiff systems only
- Today it means no kinematic closed loops (DAEs)
- Today it means simple models
Approaches Today to Meet Requirements and Limitations

Approaches Today

- Hand coded, highly tuned, simple MBS models
- Representing kinematics of suspension by (multi-) dimensional look-up tables
- Adapting solver to topology and elements of each individual MBS
- Co-Simulation of MBS and/or actuator models
- Combination of methods

Limitations

- High implementation effort whenever system changes
- Low compatibility with existing off-line models for handling, ride, durability, ...
- Difficult process save parameterisation when using look-up tables
- Break in process line from off-line world to real-time world
- Nearly no flexible body support (stabiliser, leaf-spring, twist-beam axle, sub-frame)?
Open Demands

**fast at a fixed sample rate, stable, highly detailed, automatic, process save**

- Automatic generation of real-time models from existing FVPs using existing parameterisation, data pool and sub-structuring
- Process save model reduction techniques avoiding (multidimensional) look-up tables
- Library with different levels of detail for sub-systems like suspensions, steering systems, drive trains,
- Identification environment for finding the parameters of a reduced real-time model
- Account for flexible body components
- Real-time solvers for numerically stiff systems and differential algebraic systems
- Partial linearisation and multi-linear systems
- Stable and ease-of-use co-simulation of MBS and/or actuator models to support a multi-processor approach
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Application Example
**SIMPACK Symbolic Accelerator**

- Equations of Motion: $\dot{x} = f(x, u, t)$
- Sensor Equations: $y = g(x, u, t)$

**NUMERICAL CODES (SIMPACK, ADAMS, ...)**

**Step 0 (once): Load Model**

**Step 1 (once):**
Generate algorithm for $f$ and $g$ of an individual MBS
- eliminate all if, else, do, ... operations
- perform all 0, 1 and const. operations
- (perform partial linearisation)
- (perform additional model reductions)
- recursively check code for non-used statements
⇒ results in highly efficient code

**Step 2 (once):**
Compile and generate executable

**Step 3 (in each integration step):**
Evaluate **optimised** code for $f$ and $g$

**SIMPACK Symbolic Accelerator**

**Step 0 (once): Load Model**

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- (perform additional model reductions)
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⇒ results in highly efficient code

**Step 2 (once):**
Compile and generate executable

**Step 3 (in each integration step):**
Evaluate **generic** code for $f$ and $g$
SIMPACK Symbolic Accelerator - Fields of Application

- Reduce simulation time for
  SIMPACK- Virtual Test Lab (Parameter Variation, DoE, Batch)
  SIMPACK - Optimisation
How SIMPACK Code Export Works

Equations of Motion \[ \dot{x} = f(x,u,t) \]
Sensor Equations \[ y = g(x,u,t) \]

SIMPACK Symbolic Accelerator

**Step 0 (once):** Load Model

**Step 1 (once):**
Generate algorithm for \( f \) and \( g \) of an individual MBS
- eliminate all if, else, do, ... operations
- perform all 0, 1 and const. operations
- (perform partial linearisation)
- (perform additional model reductions)
- recursively check code for non-used statements

\[ \Rightarrow \] results in highly efficient code

SIMPACK Code Export

**Step 2 (once):**
- adapt dimensions to problem size
- resolve all SIMPACK dependencies
- export code to external simulation environment

*Ongoing Development*
SIMPACK Code Export

Code Import e.g. MATLAB RTW

Code Export

Raw Data

Data

Parameter

Subsystems

Model

Data Base Level-3

Data Base Level-2

Input parameters

body marker, J, k

forces

MBS Substructure

Modell-1

time data
electric drive data
wheel rail contact, table
tracks & track excitation

data filters

Modell-2

Modell-3

parameters

overwrite Sub-Parameter

RTW

FEM/FEA

3d-CAD geometry

3d, 5d contact-surface

r(k) function table

measured w/o preproces

frequency-epic aperiod

Data Base Button Level
SIMPACK Code Export - Fields of Application

- Automatic generation of real-time models for ECU development and testing
- Automatic Generation of ETAS LabCar models
- Plug-in SIMPACK-model (and -solver) for MATLAB/Simulink
- Plug-in SIMPACK-model (and -solver) for ASCET-SD
- Plug-in SIMPACK-model (and -solver) for AMESIM
- Plug-in SIMPACK-model (and -solver) for any external simulation environment
- Archive simulation scenario independent of SIMPACK
Contribution of SIMPACK Code Export to Real-Time Models

- Automatic generation of real-time models from existing FVPs using existing parameterisation, data pool and sub-structuring
- Library with different levels of detail for sub-systems like suspensions, steering systems, drive trains
- Account for flexible body components
- Co-simulation of MBS and/or actuator models
- CPU-time reduction by partial linearisation
- CPU-time reduction by SIMPACK Symbolic Accelerator
- CPU-time reduction by model reduction techniques avoiding (multidimensional) look-up tables
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- Application Example
Application Example

**Full SIMPACK Vehicle Model:**

Based on sub-structure technique:

- Rear axle with full compliance
- Front axle with full compliance
- Chassis
- Steering System
- Pacejka Tyres
- Fully parameterised
- 10 sec sinusoidal steering manoeuvre
- 800 MHz Intel CPU
Application Example: Reduction of Rear Suspension

Full SIMPACK Model

- Upper Part
- Lower Part
- Link_1
- Link_2
- Link_3
- Link_4
- Link_5
- Wheel Carrier
- Wheel
- Dummy
- Chassis
- Spring
- Damper
- L: x, y, z
- Body
- Reference Frame
- Bodies
- Joints
- Constraints
- Force Elements
Application Example: Reduction of Rear Suspension

Reduced SIMPACK Model

- Reference Frame:
- Bodies: □
- Joints: ○
- Constraints: —
- Force Elements: \(\beta\)
Application Example: Full Model vs. Reduced Model

Full Model:
- number of bodies: 59
- number of force elements: 60
- number of 1. order states: 257
- real-time factor with stiff, DAE-Solver:
  - ODASRT: 1:5

Reduced Model:
- number of Bodies: 30
- number of Force Elements: 54
- number of 1. Order states: 64
- CPU-time with expl. Euler:
  - 1,5 msec: 1:0,5
  - CPU-time with SIMPACK Code Export, expl. Euler 1,5 msec: 1:0,2
Summary

✓ Model reduction techniques resulted in a speed-up by factor 10
✓ SIMPACK Symbolic Accelerator added a factor 3 in speed-up resulting in a real-time model
✓ Additional speed-up could be gained by partial linearisation
✓ Account for flexible body components possible
✓ Automatic generation of real-time models from existing FVPs by SIMPACK Code Export ensuring one data base for off-line and real-time simulation

Open Fields

• Real-time solvers for numerically stiff systems and differential algebraic systems
• Identification environment for finding the parameters of a reduced real-time model
• Stable co-simulation of MBS and/or actuator models to support a multi-processor approach
Full vs. Reduced Model

- Steering Angle
- Lateral Acceleration Full Model
- Lateral Acceleration Reduced Model

Graph showing the comparison between full and reduced model for steering angle and lateral acceleration over time [t in s].
Off-Line and On-Line: Different Worlds Today

Data Sources
- FE-Components e.g. Stabiliser Bar
- CAD-Data e.g. Geometry
- Measurements e.g. Air Resistance Suspension Kinematics Compliant Kin. Tyres...

Converter
- For Off Line
- For On Line

MBS Data Base
- Kinematics
- Handling
- Stability / Derailment
- Ride Comfort
- Noise / Vibration / Harshness
- Durability / Fatigue
- Safety / Impact

Real-Time Applications
- Real-Time Model Data

Real-Time Applications
- For Off Line
- For On Line

MBS Model
Off-Line and Real-Time: One World in Future

**Data Sources**
- FE-Components
  - e.g. Stabiliser Bar
- CAD-Data
  - e.g. Geometry
- Measurements
  - e.g. Air Resistance
  - Suspension
  - Kinematics
  - Compliant Kin.
  - Tyres
  - ...

**Converter**

**MBS Model**
- Kinematics
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Real-Time Model
Look-Up Tables for Suspension Kinematics

Virtual test with complex FVP of suspension

Real test with real suspension

Reduced virtual suspension represented by look-up tables

Kinematic hard points

SIMPACK Database

Kin. Look-up tables