The Digital Twin – Physics-Based Modeling and Applications
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What is this “Digital Twin”?

“... the virtual representation of devices in the field for product and process improvements”

“... a virtual representation of a physical product or process, used to understand and predict the physical counterpart’s performance characteristics. Digital twins are used throughout the product lifecycle to simulate, predict, and optimize the product and production system before investing in physical prototypes and assets.”

“A digital twin is a virtual representation of a physical object or system across its lifecycle, using real-time data to enable understanding, learning and reasoning”
Cyclic Interaction between Product and Digital Twin

Product

Knowledge gains
Design process

Knowledge gains
Production

Operational Data

Digital Twin

Adjustment, Interdependency

CAD Design
Detailed Design Data

Production Data
Logistics Data
Design Validation

Process and Control
Data
Service & Maintenance

Basic geometry
Simulation Models
Feasibility Studies
Analysis of Details

Production Model
Logistics Planning
Design Adjustments

Defect Analysis
Optimal Operating
Strategy

Virtual Design

Production and Logistics
Simulation and Planning

Operations Optimization
Error Diagnostics

Design

Phase

Production

Phase

Service

Phase

Adjustment,
The Digital Twin During the Design Phase (Generic Model)

- CAD Data and Dimensions
- Digital Twin of the Product Concept (Virtual Product)
- Simulation Models
- Control Concepts and Optimization of Default Parameters
- Production Planning
- Logistics Planning
Individualization of Digital Twins with Data and Parameters

Operating Data and Usage Information

Identified Parameters of the Real Product

Operational Environment

Maintenance History

Wear and Consumption Information
Interconnection

- Analysis and Simulation Tools, Planning Software
- Database and Data Management
- Secure Communication
  - Internet / Intranet
- On-Site Communication Protocol
  - (Real-Time, Platform Independent)
- Products / Plants

Simulation Tools
Health Monitoring
Big Data Analysis
Logistics Planning

Digital Twin

IoT Adapter
Manufacturing Cell

IoT Adapter
Materials Handling

IoT Adapter
Product

Digital Twins

OPC UA
DDS
Physical Models – Core Components of the Digital Twin

1-D Mechanics

3-D Mechanics

Electrics

Thermodynamics

Fluid Dynamics
Applications for Model-Based Digital Twins in the Product Life Cycle

**Life Cycle**

<table>
<thead>
<tr>
<th>Machine / Plant Development</th>
<th>Machine / Plant Instance</th>
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</thead>
<tbody>
<tr>
<td>Planning/Development</td>
<td>Commissioning</td>
</tr>
<tr>
<td>Design</td>
<td>Production</td>
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<tr>
<td>Virtual Commissioning</td>
<td>Maintenance/Optimization</td>
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- **Action**
  - Development of conceptual models
  - Increasing the DT’s fidelity (in parallel)
  - Coupling of the DT to the actual Hard- / Software
  - Validation of model/operating behavior
  - Database creation using production data
  - Maintenance data for wearing analysis

- **CAE-Based Development of the Digital Twin**
  - Physically sound feasibility studies
  - Simulation support for CAD engineering
  - HIL / SIL / training simulation

- **Possibilities**
  - Promotion by presenting the virtual product
  - Design optimization
  - Test new HW/SW at the virtual plant
  - Experience from the virtual commissioning
  - Remote diagnosis, health monitoring
  - Optimization of production processes
  - Predictive load balancing
  - Defect Analysis
  - Predictive maintenance

- **Individualization of the Digital Twin**
  - Control concept studies
  - Model-based control
Methods and Tools for Multi-Domain Physical Models
Modelica and FMI — Open Standards for Systems Modeling

Standard for modeling the dynamical behaviour of complex technical systems (mechanical, electrical, hydraulic, ..., components)

Modelica model can be created and simulated by Dymola, Maplesim, OpenModelica, ...

Standard for exchanging models and for co-simulation
Supports IP protection

Wide support:
> 100 simulation tools (Dymola, Simulink, ...)

SR: Core developers of Modelica + FMI
Modelica Component Libraries

Reuse of Modeling Know-How

Free Open-Source Libraries (many more!)

- Modelica Standard Library
- Modelica_DeviceDrivers

DLR In-House Libraries and Commercially Distributed Libraries

- Actuator Library
- Flexible Bodies Library
- Powertrain Library
- FlightDynamics Library
- EWITAC Library
- Optimization Library
Technology Development: Model-Integrated Visualization

- Model-integrated visualization for complex physical simulations
- Visualization of multi-body, flexible-body, thermal, and fluid systems
- From planetary scale to Precision mechanics scale using the same visualization/simulation
- Multi-monitor, stereo, VR support
- Commercial tool (DLR Visualization Library), further development at the SCIL
The System and Control Innovation Lab (SCIL)

- Part of the Institute of System Dynamics and Control
- **Innovation Lab** for the technology transfer in **SMEs** and **start-ups** with focus on:
  - Control technology
  - Modelling
  - Simulation
  - Optimization
  - Digitalization
- Following application examples were implemented at the lab/institute, most of them together with industry partners
Application Examples for the Digital Twin – Design Phase
Architectural Art
Feasibility study for the Futurium in Berlin (Streicher Group)
Control concept studies

Example: Terramechanics Robotics Locomotion Lab (TROLL)

- Design of the force-torque controller
- Analysis of the closed-loop stability (dead time, sampling rate)
Model-based control

Controller based on digital twin

Optimal trajectory planning
Elasticity compensation
Model-based control
Drilling rig simulator (Streicher Group)

- Complete model of kinematics, actuators, sensors
- Connection to original PLC systems
- Identical HMI / operating elements
- Virtual windows for the visualization of the operating elements
- Functioning as training simulator or virtual test environment
Virtual commissioning

Operator Training
Application Examples for the Digital Twin – Operating Phase
Health Monitoring

Model-based health monitoring of electromechanical actuators

- Model-based sensor data processing of the actuator sensors
- No additional sensors required
- Detection of damages in bearings, gearboxs, wheel-rail contacts...

Diagram:
- Actuator model
- Linearized actuator model
- Kalman filter
- Fault criterion
- Measurement
- Data selection
- Spectrum analysis over position
- Fault frequencies
- Spectra selection
- Nominal amplitudes
- Spectra selection
- Analysis and Decision
- Averaging
Defect analysis

Higher maintenance effort as expected

→ Model-based analysis shows strong vibrations due to seat rollover
→ Modification of the flange mountings of the seats results in reduced vibration excitation
Optimization of Production Processes

Energy efficiency improvements using model-based trajectory optimization

Non-optimized energy consumption:
1804 Wh
Cycle time: 50.6 s

Optimized energy consumption:
1697 Wh
Cycle time: 51.8 s

Energy savings: 6.0%
Time increase: 2.3%
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Thank you for your attention.

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