The Digital Twin – Physics-Based Modeling and Applications

MODPROD

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Systems and Control Innovation Lab (SCIL)

DLR

SCIL
SYSTEMS & CONTROL
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What is this “Digital Twin”?

CONTACT Software

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

ANSYS

“..integration of real-time operational data with all of an organization’s digital information for that specific product.”

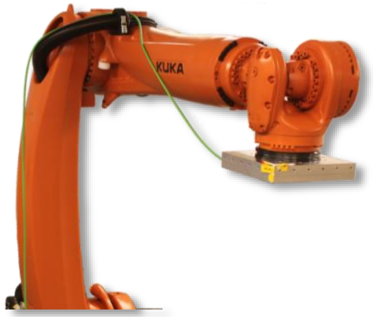
IBM

“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”

SIEMENS

“… 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. ”

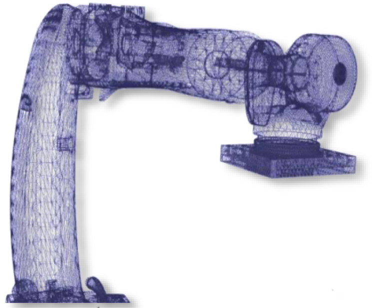
Cyclic Interaction between Product and Digital Twin



Product

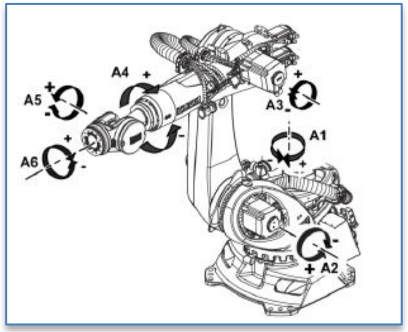
Adjustment, Interdependency

Knowledge gains Design process	Knowledge gains Production	Operational Data
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



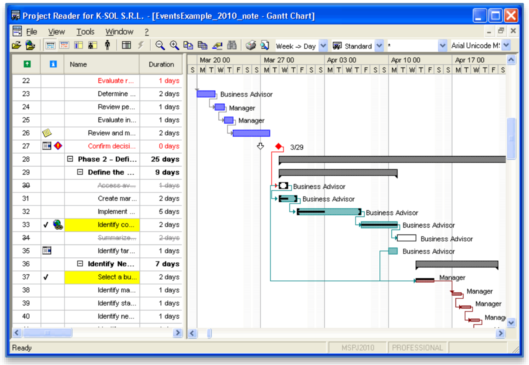
Digital Twin

The Digital Twin During the Design Phase (Generic Model)

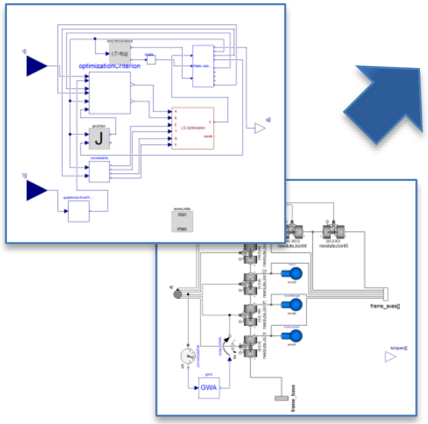


CAD Data and Dimensions

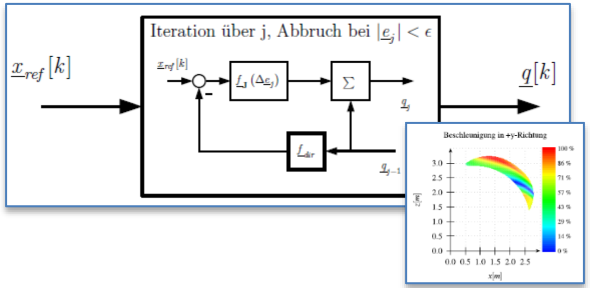
Digital Twin of the Product Concept (Virtual Product)



Production Planning



Simulation Models

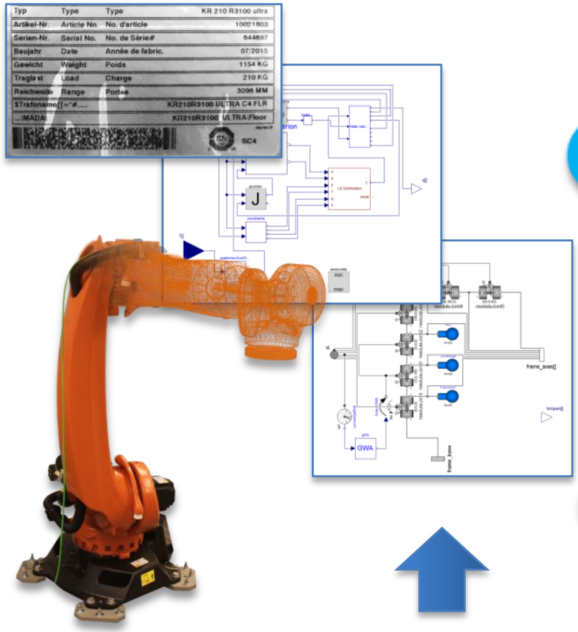


Control Concepts and Optimization of Default Parameters

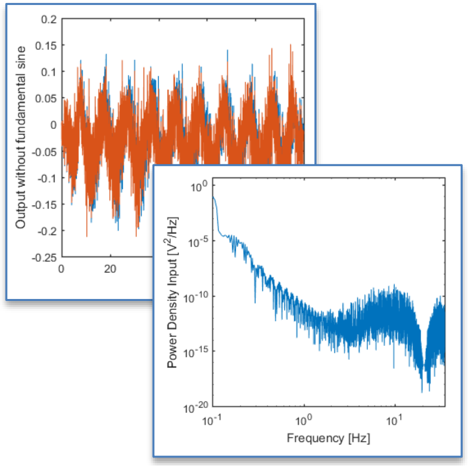
Logistics Planning

Individualization of Digital Twins with Data and Parameters

Operating Data and Usage Information



Wear and Consumption Information



Identified Parameters of the Real Product

Operational Environment

Maintenance History

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Interconnection

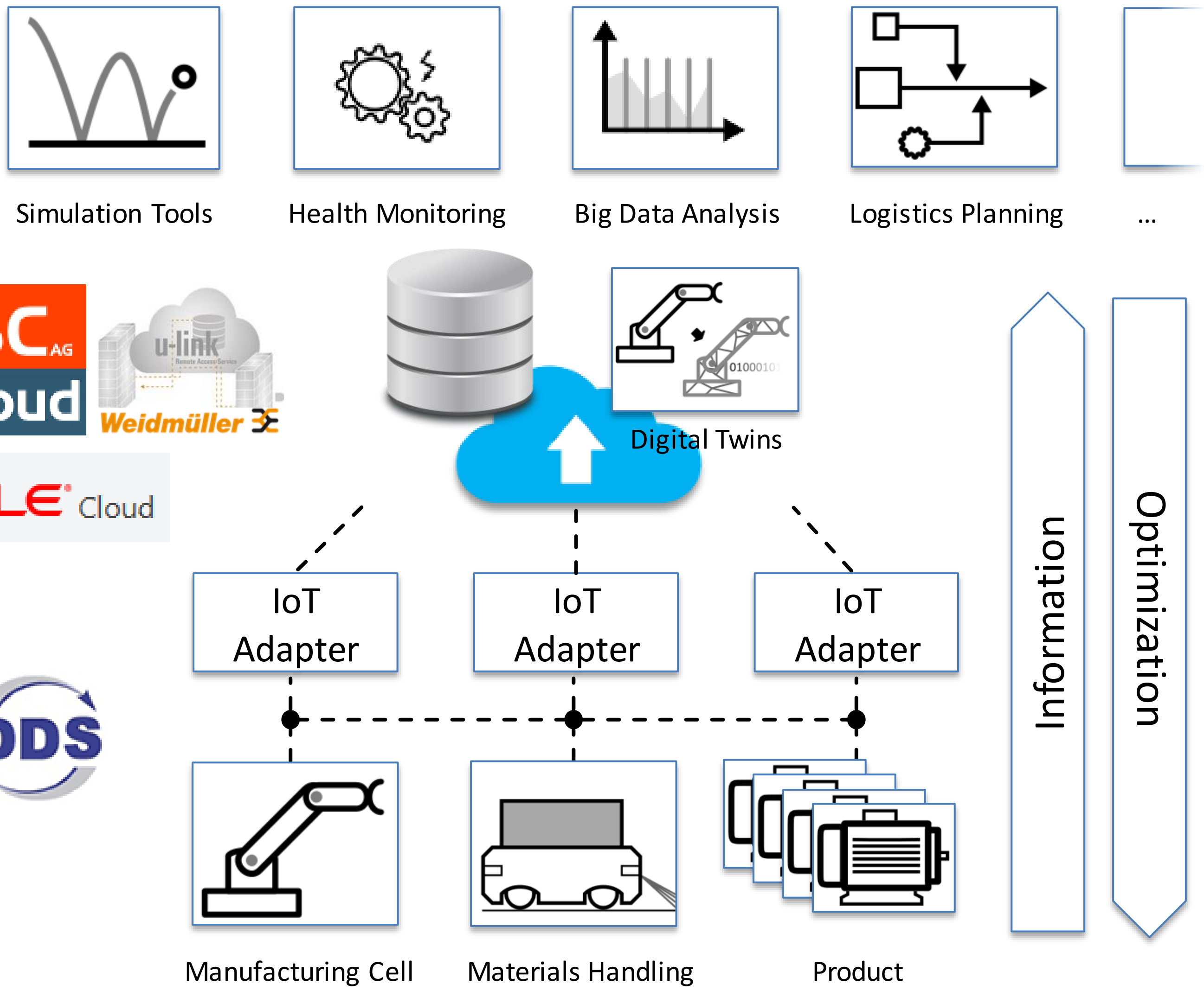
Analysis and Simulation Tools, Planning Software

Database and Data Management

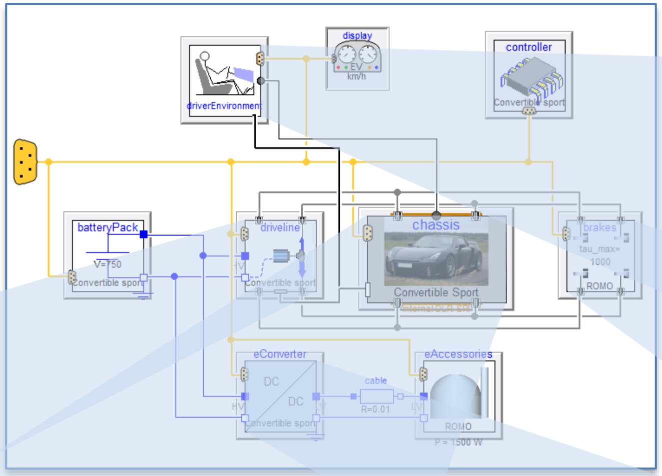
Secure Communication
Internet / Intranet

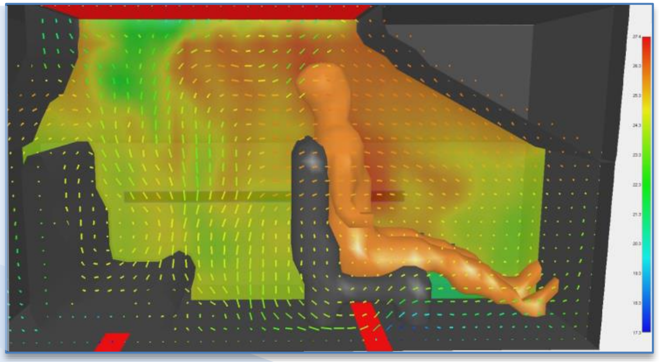
On-Site Communication Protocol
(Real-Time, Platform Independent)

Products / Plants

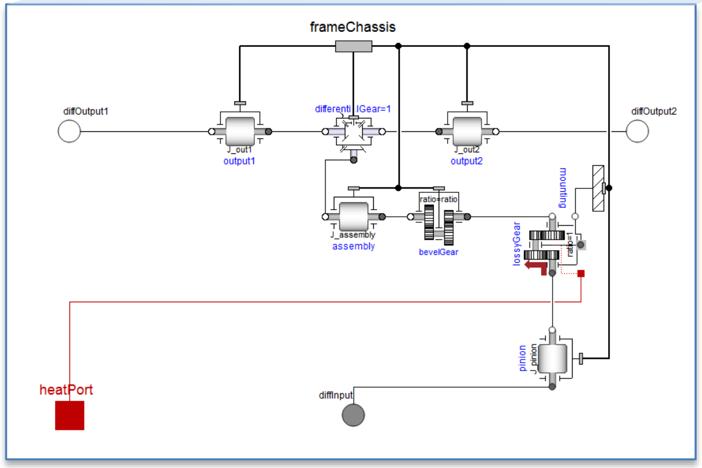


Physical Models – Core Components of the Digital Twin

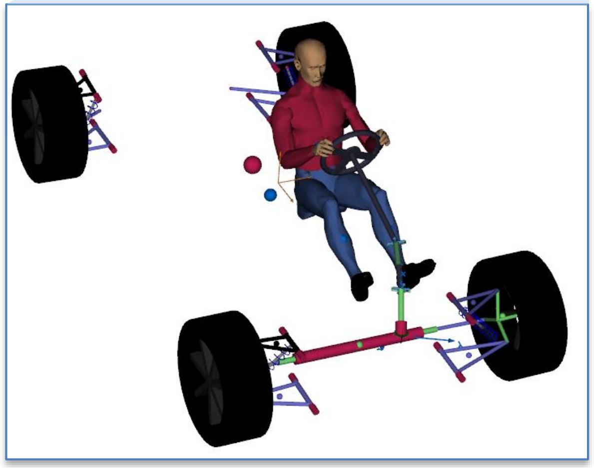




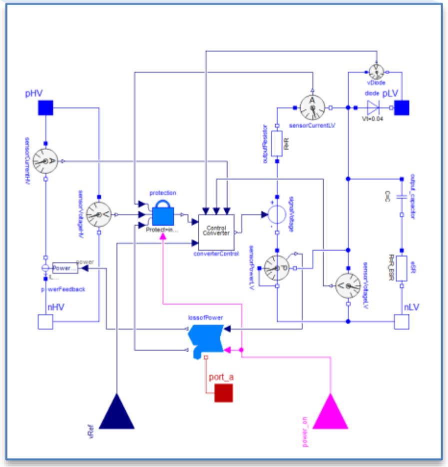
Fluid Dynamics



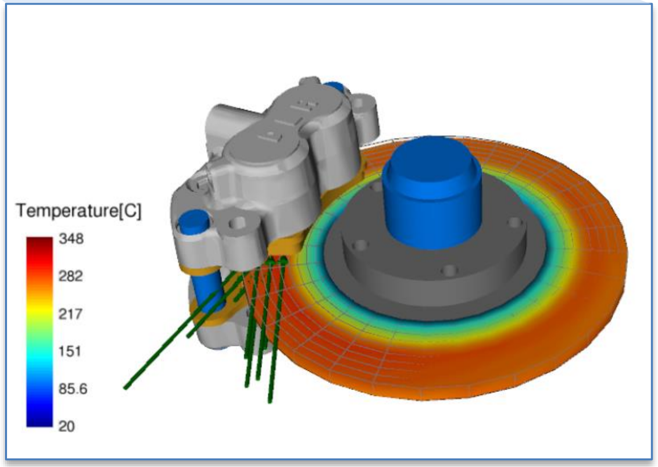
1-D Mechanics



3-D Mechanics

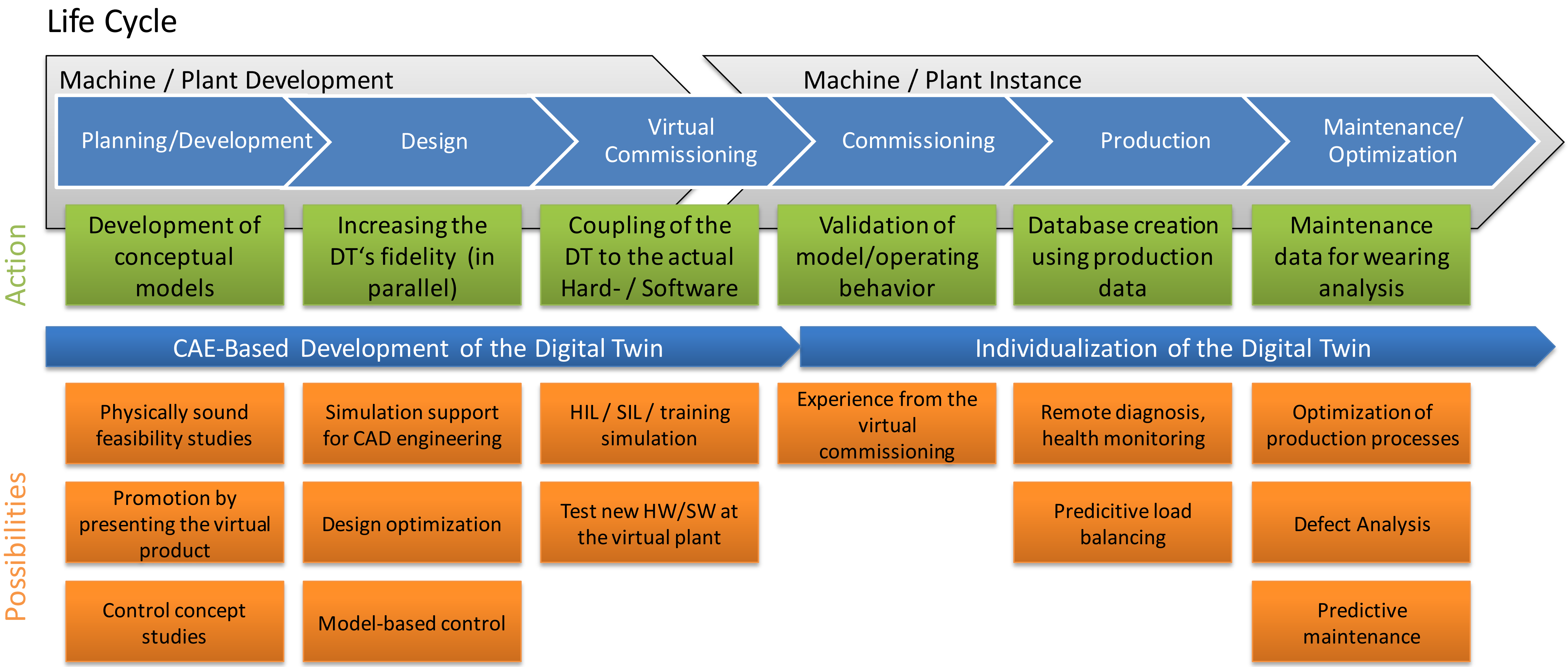


Electrics



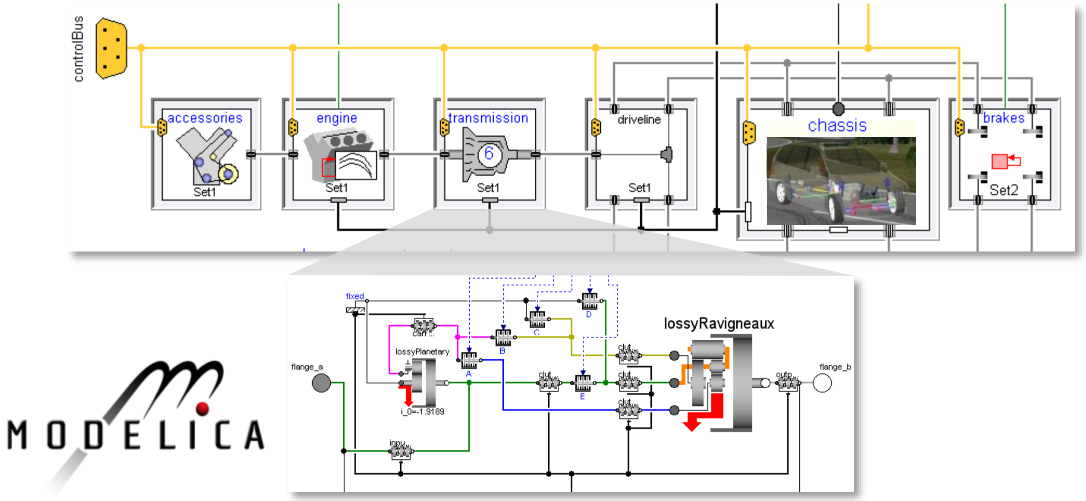
Thermodynamics

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



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, ...)

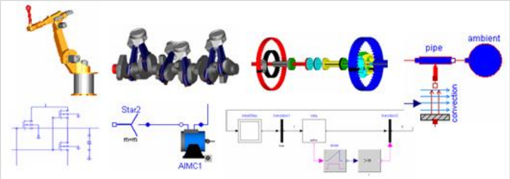
SR: Core developers of Modelica + FMI

Modelica Component Libraries

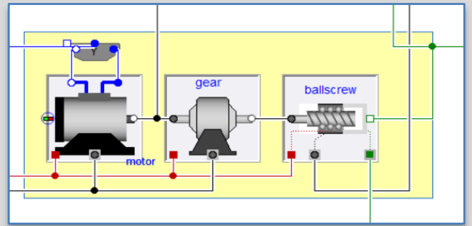
Reuse of Modeling Know-How

Free Open-Source Libraries (many more!)

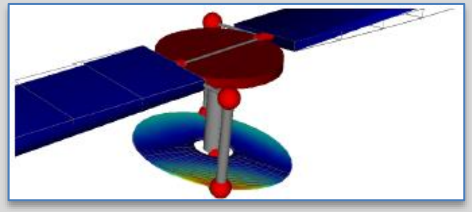
DLR In-House Libraries and Commercially Distributed Libraries



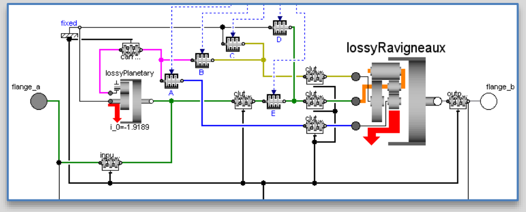
Modelica Standard Library



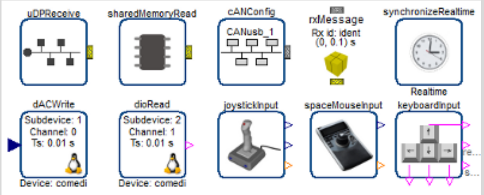
Actuator Library



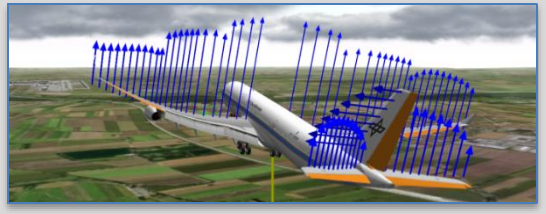
Flexible Bodies Library



Powertrain Library

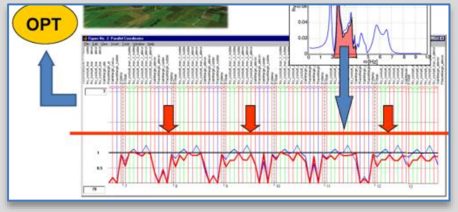


Modelica_DeviceDrivers



FlightDynamics Library

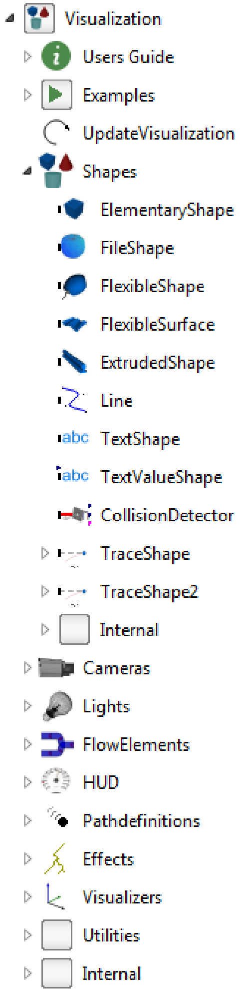
EWITAC Library



Optimization Library

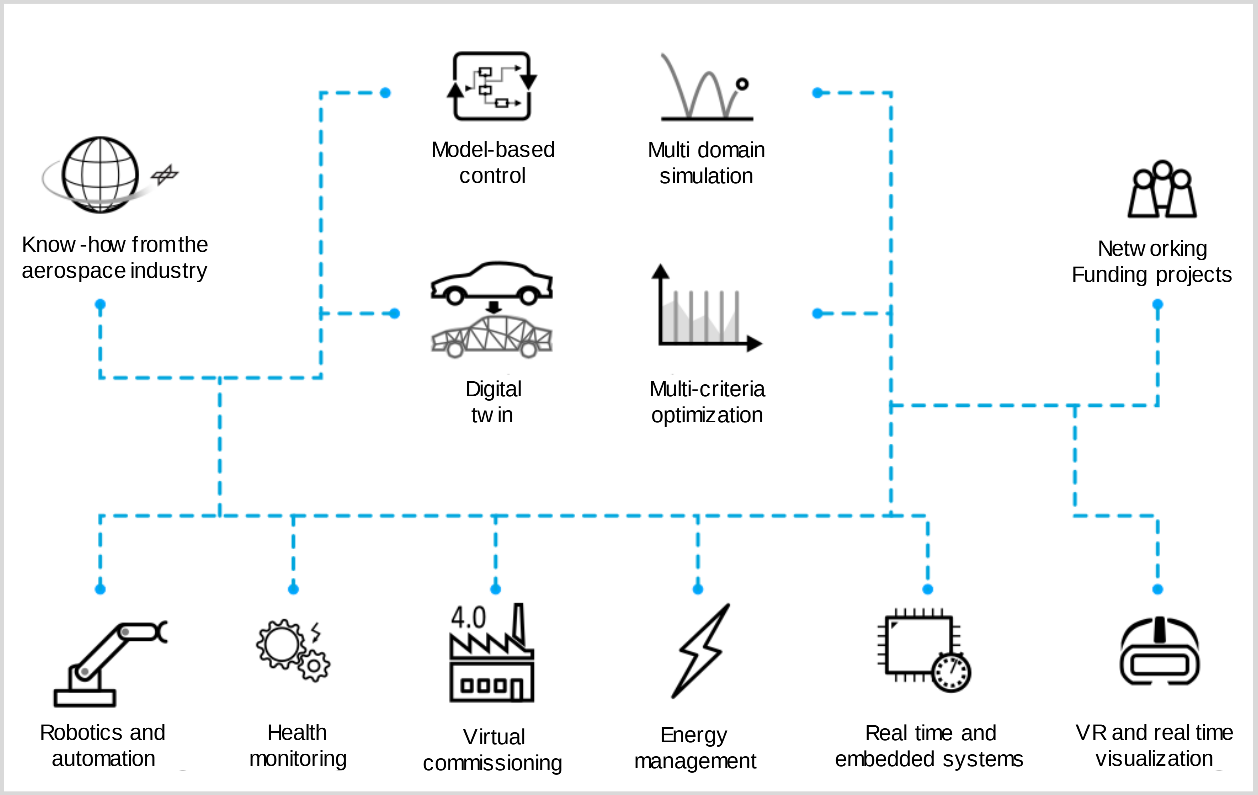
Technology Development: Model-Integrated Visualization

- Model-integrated visualization for complex physical simulations
- Visualization of multi-body, flexible-body, thermal, and fluid systems
- From planetary scale→ 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)

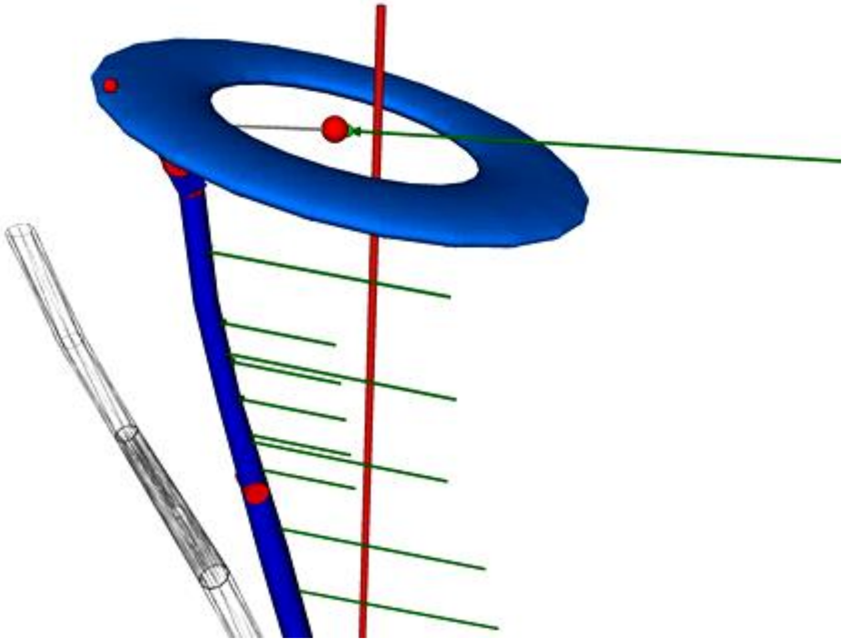
- Part of the Institute of System Dynamics and Control
- **Innovation Lab** for the technology transfer in **SMEs** and **start-ups** with focus on:
  - **Control technology**
  - **Modelling**
  - **Simulation**
  - **Optimization**
  - **Digitalization**
- Following application examples were implemented at the lab/institute, most of them together with industry partners

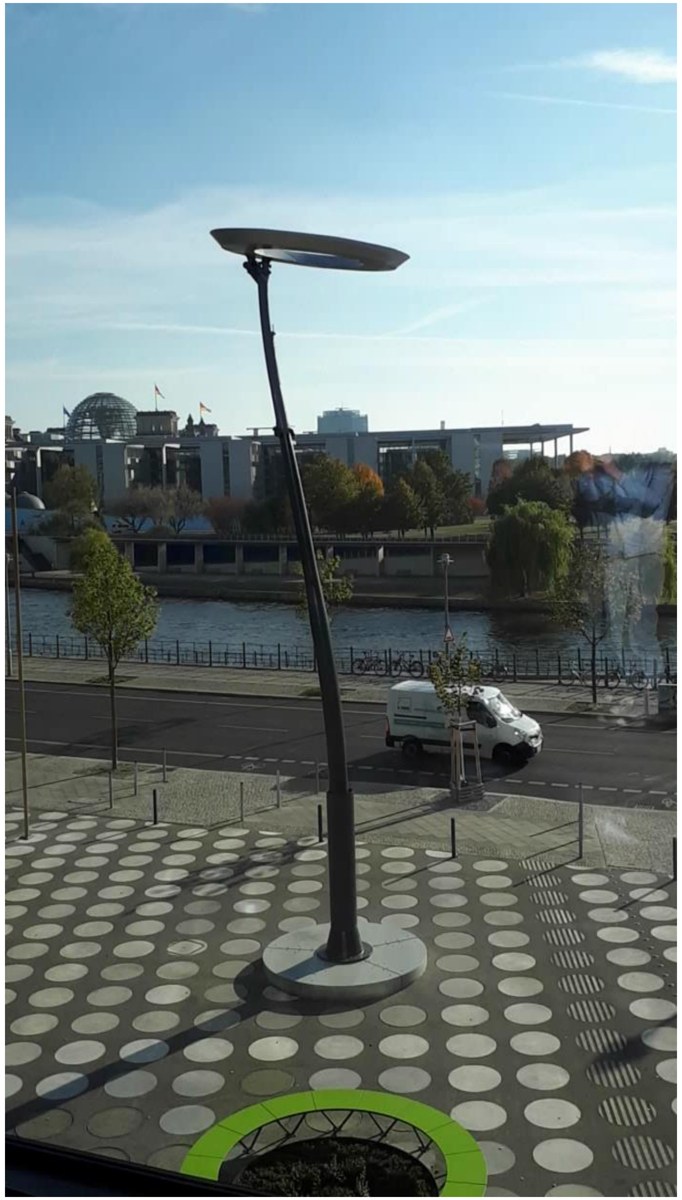


Application Examples for the Digital Twin – Design Phase

Planning/Development

Feasibility Studies





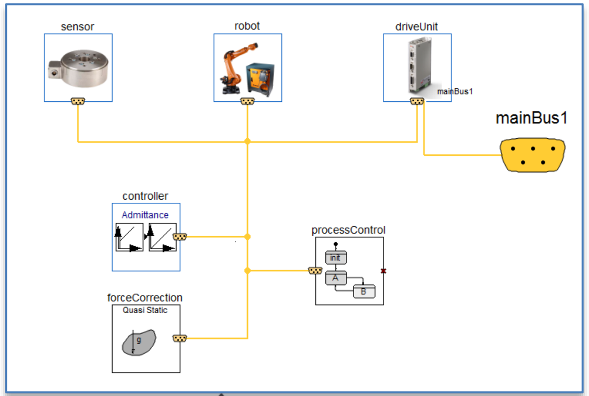
Architectural Art
Feasibility study for the Futurium in Berlin (Streicher Group)

Planning/Development

Control concept studies

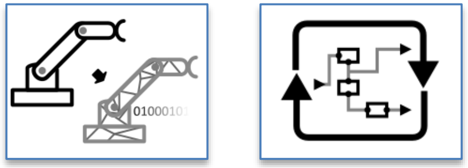
Example: Terramechanics Robotics Locomotion Lab (TROLL)

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

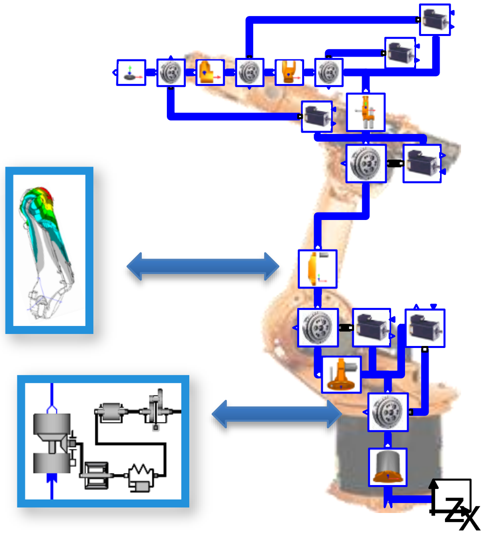


Design

Model-based control



Controller based on digital twin



Optimal trajectory planning

Elasticity compensation

Model-based control

Virtual commissioning

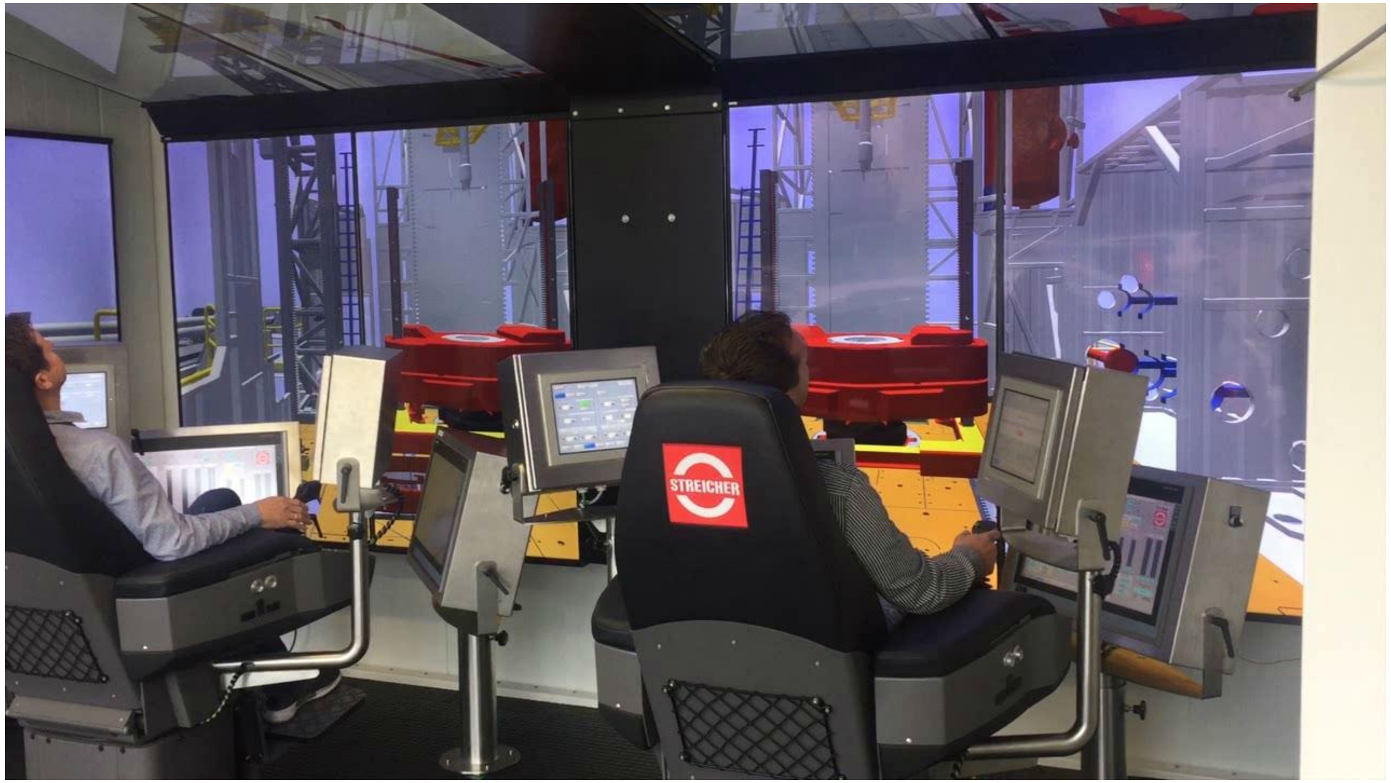
HIL / SIL / Training Simulations

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



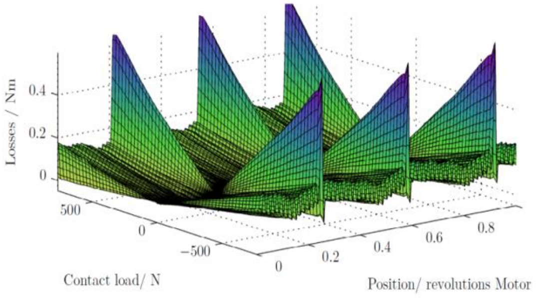
Application Examples for the Digital Twin – Operating Phase

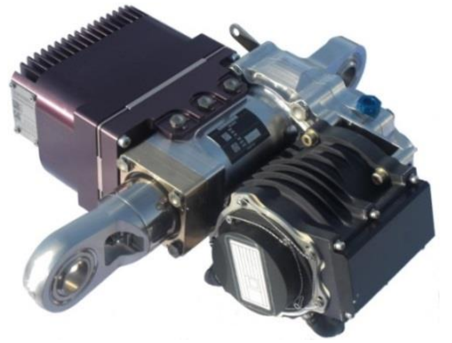
Production

Health Monitoring

Model-based health monitoring of electromechanical actuators

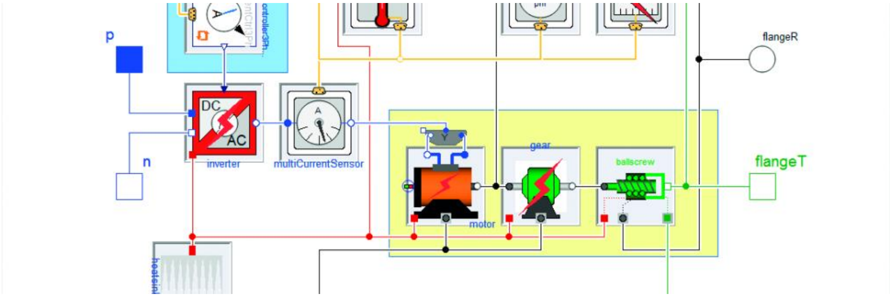
- Model-based sensor data processing of the actuator sensors
- No additional sensors required
- Detection of damages in bearings, gearboxes, wheel-rail contacts…





LIEBHERR

Actuator model → Linearized actuator model
Measurement → Kalman filter
Linearized actuator model → Kalman filter → Fault criterion



Fault criterion → Data selection → Spectrum analysis over position → Averaging → Analysis and Decision

Fault frequencies → Spectra selection → Averaging
Fault frequencies → Nominal amplitudes → Spectra selection → Analysis and Decision

Maintenance/Optimization

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

Maintenance/Optimization

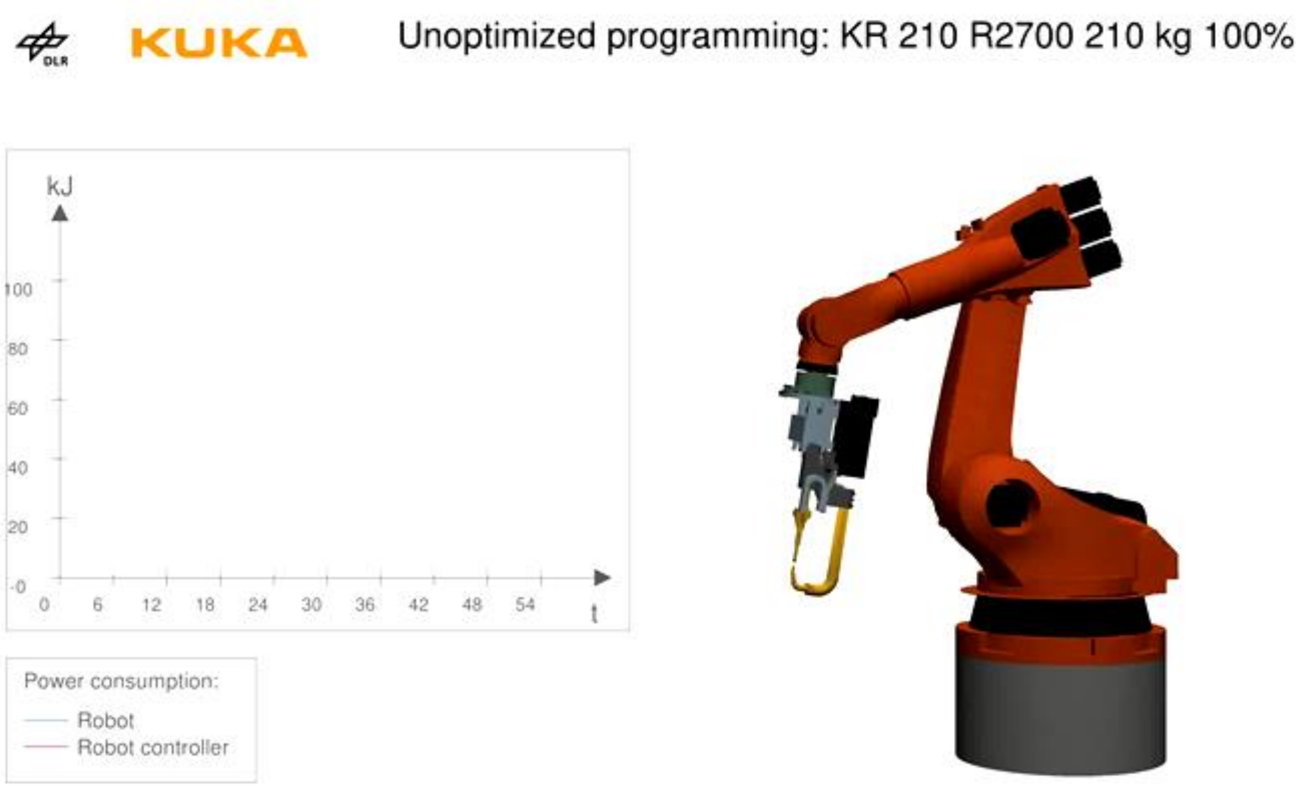
Optimization of Production Processes

Energy efficiency improvements using model-based trajectory optimization

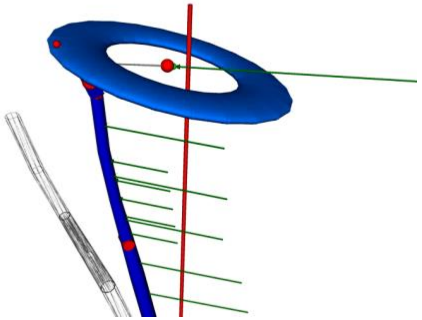
Non-optimized energy consumption:
1804 Wh
Cycle time: 50.6 s

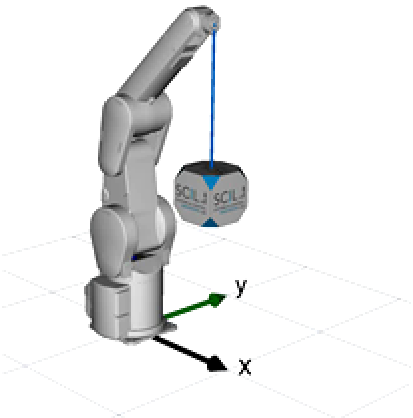
Optimized energy consumption:
1697 Wh
Cycle time: 51.8 s

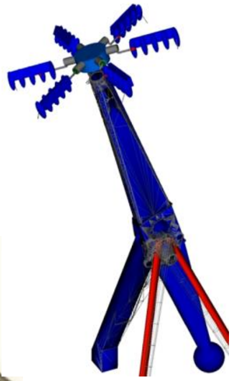
Energy savings: 6.0%
Time increase: 2.3 %



The Digital Twin – Physics-Based Modeling and Applications







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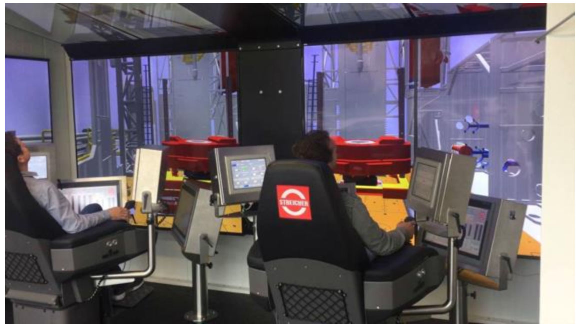

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