Digital Twin: how, where and why...

Digital Twin: la strada 4.0 per l’efficienza dei processi e la qualità dei prodotti
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Digital Twin: why

Virtual Factory

- Simulation of Production Line
- Analysis & Prediction
- Optimization

Real Factory

Network

Controlling

Sensing

Reconfiguration

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Digital Twin: where

BPMN

MES (ISA-95)

DIN 8580

<AutomationML/>

B2MML (ISA-95) Production Recipe

Plant Topology

Equipment Functionality

Vendor Specific Equipment

Objects Relations

Architecture & Processes

Machine 1 Contracts

Machine 2 Contracts

Machine 3 Contracts

Machine N Contracts

Verification & Synthesis

Digital Twin Executable Models

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DEFINING AND INTEGRATING MODELS
Business Process Model

**Activities**

- **Task**: A Task is a unit of work, the job to be performed.
- **Transaction**: A Transaction is a set of activities that logically belong together.
- **Event Sub-Process**: An Event Sub-Process is placed into a Process or Sub-Process. It is activated when its start event gets triggered and can interrupt the higher level process context or run in parallel (non-interrupting) depending on the start event.
- **Call Activity**: A Call Activity is a wrapper for a globally defined Sub-Process or Task that is reused in the current process.

**Gateways**

- Exclusive Gateway - without Marker
- Exclusive Gateway - with Marker
- Event-based Gateway
- Parallel Gateway
- Inclusive Gateway
- Complex Gateway
- Exclusive Event-based Gateway
- Parallel Event-based Gateway

**Swimlanes**

- **Pools and Lanes**: Pools and Lanes represent responsibilities for activities in a process.
- **Message**: The order of message exchanges can be specified by combining message flow and sequence flow.
- **Receive Task**: Others
- **Send Task**: Others
- **Message**: Receiving and sending messages.
- **Timer**: Others

**Others**

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ISA-95: Functional Hierarchy Levels description

**Level 4**

**Business Planning & Logistics**
- Plant Production Scheduling, Operational Management, etc

**Time Frame:**
- Months, weeks, days, shifts

**Level 3**

**Manufacturing**
- Operations & Control
- Dispatching Production, Detailed Production Scheduling, Reliability Assurance, ...

**Time Frame:**
- Shifts, hours, minutes, seconds

**Level 2,1,0**

**SCADA PLC**
- Batch Control
- Continuous Control
- Discrete Control

**Time Frame:**
- Months, weeks, days, shifts

**ERP**

**Time Frame:**
- Basic Plant Schedule- Production, material use, Delivery and Shipping

**MES**

**Time Frame:**
- To produce desired end-products. Maintaining records and optimizing the production process.
B2MML as a Solution

- **B2MML**: Business to Manufacturing Markup language
  - Implementation of ISA-95 in XML
  - XML elements which comprise information
  - Providing a generic / common / extendable platform
  - For data exchange between scheduling component and manufacturing environment
3.2.2.1. (DIN) 1.1.1.1.2.1. (Todd) **Drilling**
Drilling for making cylindrical hole

3.2.2.2. (DIN) 1.1.1.1.1.2. (Todd) **Boring**
Boring for enlarge drilling hole

3.2.2.3. (DIN) 1.1.1.1.2.2. (Todd) **Reaming**
Reaming for finishing hole or slightly remove material from hole

3.2.3. (DIN) **Milling**

3.2.5. (DIN) **Countersink**

3.3.1. (DIN) **Grinding with rotating tool**

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Simulation Infrastructure

- Several tools to model & simulate production lines (Siemens, FlexSim, Simio, Simul8 ecc..)
- Easy and really intuitive to use (Drag & Drop components from a library)

High level of abstraction  ➔  Fast simulation but... **Loss of details!**

Integration of

- Models/Contracts
- Temporal Series
- Real Equipment
Standards for Models Integration

• Model encapsulation
  – FMI Standard
  – OPC-UA

• Functional Mockup Interface (FMI)
  – Standard interface to exchange models

• OPC-UA
  – Machine to machine communication protocol for industrial automation
Automation Markup Language (AML)

- **AutomationML**
  - a neutral data format based on XML for the storage and exchange of plant engineering information
  - it is provided as open standard
  - to interconnect heterogeneous tools

- **Mapping from the AML domain to the OPC UA domain**
OPC-UA Server Design

1. Interface Definition (AutomationML)
2. AutomationML to OPC-UA Information Model
3. FMU Generation
4. FMU Integration in OPC-UA Server
OPC-UA Server for a Real Equipment

1. Interface Definition (AutomationML)
2. Equipment Classification (ISA-88/95)
3. OPC-UA Information Model Generation (Step 1 + Step 2)
BOX-IO

- BOX-IO is a data aggregator
  - it can be connected to nodes that can be sensors and actuators
- The «heart» of BOX-IO software is eLSE
- eLSE is composed of three parts:
  - Frontend Layer for interaction with the application and the site for example
  - Data model Layer for modeling data
  - Backend Layer for interacting directly with the devices
- The three levels can communicate with each other
BOX-IO as a Link to Cloud

- It can be placed in the plant as an advanced equipment
- At different levels of the automation hierarchy
FROM CONTRACT TO MODELS
Machine library of A/G contracts

Machine: 1

Actions from DIN Taxonomy: 2

Elementary actions: 3

A/G Contracts Library: 4

DIN Taxonomy

Machine Capabilities

Action1  Action2  ...  ActionN

Assumptions

Guarantees

Plant Environment

Machine Behaviours (Actions)

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Library example: Milling machine

Machine: 1

Actions from DIN Taxonomy: 2

Elementary actions: 3

A/G Contracts Library: 4

Machine library

- Drilling A/G Contract
- Boring A/G Contract
- Reaming A/G Contract
- Milling A/G Contract
- Countersink A/G Contract
- Broaching A/G Contract

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Simulation example of a Production Line
FROM TEMPORAL-SERIES TO MODELS
Black-box Discovery of the Control Algorithm

- Main steps are:
  - Export the dataset
  - Build of the trained classifier
  - Implement in system
  - Optimize the classifier
  - Generate the code
Export dataset

- Use Simulation Data Inspector
  - Observe the interested signals
  - Export and save them in the Matlab workspace
  - Export the data in a CSV-file
Build the trained classifier

Manual method

**Statistics and Machine Learning Toolbox**

- Import Dataset
- Build the various classifiers with their confusion matrix
- Compare the confusion matrices graphically
- Or calculate accuracy, precision and recall and choose the best classifier

Automatic method

**Classification Learner App**

- Import dataset
- Try it on all types of classifiers
- Choose the best classifier

NEW CONTROLLER

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Implementation in the system

- Put the classifiers in
  - **M-function** blocks
  - **S-function** blocks

- Simulating the same result is obtained with the M-functions
- The S-function is **faster** than M-function

```matlab
function OPEN_CLOSE = fcn(u1, u2, ...)
persistent mdl;
if isempty(mdl)
    mdl = loadCompactModel('my_classifier.mat');
end
OPEN_CLOSE = int8(predict(mdl,[u1, u2, ...]));
end
```
Code generation

- From M-file to C-file
  - MATLAB Coder
  - Simulink Coder

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```

classifyX.m
BOX-IO-based Implementation
BOX-1O

HTTP
WEBSOCKET
MQTT
RULE ENGINE
ZIGBEE
MODBUS
OPC-UA
CONTROLLER (CLASSIFIER)

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EXEMPLIFICATION ON THE ICE LABORATORY
ICE Laboratory - Where

Location available starting from the end of July 2019
ICE Laboratory - System Architecture

Enterprise Resource Planning (ERP)  |  Cloud Application  |  UniVR Comp. Platform

Manufacturing Execution System (MES)

SCADA

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Physical Laboratory

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ICE Laboratory – Digital Twin Focus
ICE Laboratory – Robots and Devices
ICE Laboratory – Sensors/Cloud Architecture

UniVR Computational Platform

Cloud Application (MindSphere)

Digital Twin Tecnomatix Plant Simulation

OT Networks

Fiber Network

IT/OT Gateway

Cloud Gateway

OT Networks

PLC

OPC UA Module

Industrial Wireless

Controller

IloT machinery

Legacy Machinery

IoT Sensors

Mobile Robots

Tracking System

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UniVR Computational Platform

Composed of two kind of nodes managed by **OpenStack**

- **HPC node**
  - *CentOS 7* available to end-user
  - *Slurm* workload manager
    - *launch/schedule* tasks with specific HW resources
  - *Not supported* by all applications

- **Cloud node**
  - dedicated to host *Virtual Machines*
  - a running VM *meets loose real time* requirements
  - less *processing power* if compared with *HPC*
Industrial Advisory Board (IAB) - Opportunities

• A group composed of more than 35 companies
• Established for Computer Engineering for Industry 4.0 project

• Companies are actively participating in our project by
  – suggesting ICE lab components
  – giving opinions over the new Master’s Degree
  – developing new teaching modules to train students, employees, customers
  – getting the annual research reports over Industry 4.0 technologies
  – testing new technologies on the ICE lab after its construction
Industrial Advisory Board (IAB) - Composition

• IAB contains companies of different categories:

  – Industrial Automation
  – Software House
  – Buildings
  – Media and Communications
  – Engineering
  – System Integrator
  – Automation
  – IT consulting
  – Manufacturing
  – Food and Beverage
  – IT Hardware