Future Control System Architecture Enabling Industrie 4.0 / Smart Manufacturing

Service-oriented (Machine) Control Architecture in the Context of Smart Manufacturing

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How long did it take until Electricity significantly changed production?
1951: UNIVAC I, First Commercial Computer
1959: RW-300
Process Control System

1968: Modicon 084
First PLC

Source: Computer History Museum
Source: openautomation.de
New Technologies and Architectures

- **IoT:** Internet of Things
- **CPS:** Cyber Physical Systems
- ...

Source: AgendaCPS
New Paradigms: Industrie 4.0

1. Industrial revolution follows introduction of water- and steam-powered mechanical manufacturing facilities: End of 18th century
2. Industrial revolution follows introduction of electrically-powered mass production based on the division of labour: Start of 20th century
3. Industrial revolution uses electronics and IT to achieve further automation of manufacturing: Start of 1970s
4. Industrial revolution based on Cyber-Physical Systems: Today

Source: DFKI
And now?

"I keep six honest serving-men
(They taught me all I knew);
Their names are What and Why and When
And How and Where and Who."

Rudyard Kipling
Production Challenge: Highly Volatile Markets

Relative Production Index Germany

Source: German Federal Statistical Office, ifo Institute
Production Challenge: High Product Variety

Potential Approaches

Agile Manufacturing Systems
- Developed 1991 by Iacocca Institute
- Vision:
  - Production to Order
  - Lot/Batch size > 1 Unit
- Main Theme: Dynamic Reconfiguration
  - Physical Reconfiguration
  - Logical Reconfiguration
  - Not just Parametrization

Self-organizing Production: Holonic Manufacturing Systems
- Holonic → Cooperative distributed problem solving
- Distributed units (holons) with autonomous behavior to solve global problem
- Holons with a priori cooperation functionality
Goal: (Re-)Configuration on Process Module Level

- Break-up production cells in standardized production process modules (e.g., assembling, gripping, positioning, transport)
- Flexible combination and configuration of modules
Enabling Factors for Mutability

- Universality 11%
- Modularity 29%
- Scalability 14%
- Mobility 14%
- Compatibility 35%

[Source: Nyhuis, P. Wandlungsfähige Produktionssysteme: Heute die Industrie von morgen gestalten]
Service-Oriented Architecture (SOA)

Definition according to OASIS\(^1\):

„SOA is a paradigm for organizing and utilizing distributed capabilities that may be under the control of different ownership domains.“\(^2\)

1 Organization for the Advancement of Structured Information Standards
2 Reference Model for Service Oriented Architecture 1.0, Committee Specification 1, 2 August 2006
Experiences from Business IT

- Service Orientation is an important step but not enough
- Approaches for further decoupling of system parts
  - Technical decoupling through **Enterprise Service Bus** concept
  - Functional decoupling through **Complex Event Systems**

Quelle: IBM
Reference Architecture Industrie 4.0 (RAMI4.0)
Starting Point:
Batch Management according to ISA-88 / IEC 61512

Recipie A:
- Fill
- Heat
- Agitate
- Drain

Recipie B:
- Fill
- Heat
- Agitate
- Drain

Recipie C:
- Fill
- Heat
- Agitate

Recipie D:
- Fill
- Heat
- Agitate
- Drain

Unit 1:
- Fill
- Heat
- Agitate
- Drain
Decoupling of System Elements

- **ERP**
- **Station Registry**
- **MES**
- **Production Control**

Manufacturing Service Bus

- **PLC MPS Station**
- **MPS Modul**
- **FTS-Controller**
- **Robotino**
- **SPS MPS Station**
- **MPS Modul**

The diagram illustrates the decoupling of system elements in a future control system architecture enabling I4.0/Smart Manufacturing.
Modeling Production Resources
Example: Assembly Station

Module Slide
Module Pick & Place
Module Conveyor Belt
Interaction Points

Capabilities
* Transport
* Supply
* Assemble

Material Flow
Factory Model
Material Flow Modeling

- Material can flow between connected resources
- Direction of flow determined by types of two connected interaction points
- Automatic detection of Stations and Neighborhood

**Supply**
- Stack Magazine 1,2,3

**Pick & Place**
- Pick & Place Actuator
- Reversible Conveyor Belt

**Pick & Place**
- Pick & Place Actuator
- Reversible Conveyor Belt

**Sorting**
- Conveyor Belt
- Color Sensor
- Lever 1,2,3
- Slide 1,2,3
Automated Production Planning and Control

Product Plans

Shop Floor Topology and Capability Models
Bringing Modularity and Adaptivity into Production Cells

Source: Festo

Source: Festo
Communication Needs
OPC Unified Architecture IEC 62451

Standard defining a Service-oriented Communication Architecture
OPC UA Server Architecture

Application (e.g., control, sensor, Actuator)

OPC UA Server

Node

Node

Node

Node

Node

Node

Method

Progamm

OPC UA Address Space (Information Model)

Message Management

Monitored Item

Subscription

Request from OPC UA Client

Response to OPC UA Client

Subscription from OPC UA Client

Notification of OPC UA Client
VDMA represents the broad manufacturer industry
Many companies are on the way to Industrie 4.0

- Agricultural Machinery
- Air Conditioning and Ventilation
- Air Pollution Control
- Air-handling Technology
- Building Control and Management
- Cleaning Systems
- Compressors, Compressed Air and Vacuum Technology
- Construction Equipment and Building Material Machines
- Drying Technology
- Electrical Automation
- Electronics, Micro and Nano Technologies
- Engine Systems for Power and Heat Generation
- Engines and Systems
- Fire Fighting Equipment
  - Fluid Power
  - Food Processing Machinery and Packaging Machinery
  - Foundry Machinery
  - Gas Welding
  - Hydro Power
  - Integrated Assembly Solutions
- Large Industrial Plant Manufacturing
- Lifts and Escalators
- Machine Tools and Manufacturing Systems
- Machine Vision
- Materials Handling and Intralogistics
- Measuring and Testing Technology
- Metallurgical Plants and Rolling Mills
- Metallurgy
- Micro Technologies
- Mining
- Plastics and Rubber Machinery
- Power Systems
- Power Transmission Engineering
- Precision Tools
- Printing and Paper Technology
- Process Plant and Equipment
- Productronic
- Pumps + Systems
- Refrigeration and Heat Pump Technology
- Robotics
- Robotics + Automation
- Security Systems
- Software
- Surface Treatment Technology
- Textile Care, Fabric and Leather Technology
- Textile Machinery
- Thermal Turbines and Power Plants
- Thermo Process Technology
- Valves
- Waste Treatment and Recycling
- Wind Energy
- Woodworking Machinery
Problem: Software Development Effort

„... increases the software-engineering portion of the overall Manufacturing costs of a machine: Starting from currently 50% share for electronics and software the share will rise in 2020 up to 80%.“

translated from IEE 01-2006

„We have so far mastered most topics and could save up to 70% of the engineering effort. What makes us still problems is the software effort.

translated from SPS Magazin 08-2012
IEC 61499

Domain-specific Modelling language for Distributed Industrial Process Measurement and Control Systems
Background IEC 61499

1990
Holonic Manufacturing

Self-organizing production through autonomous cooperative modules

Resulting Requirements:
• Flexibility
• Adaptivity
• Distribution

1992
IEC 61131-3

Goal: “Harmonizing PLC programming“

• Core element: Function Block
• Definition of 5 Languages
• Sequential Execution
• Targeting central strongly coupled systems

2005
IEC 61499

Goal: “Architecture for distributed industrial process measurement and control systems“

• Extended function block model
• Equal participants in the distributed system
• Basic support for dynamic reconfiguration
Core Element: Function Block

- Function Blocks extended with event interface
- Pure **event-driven** execution model
- Data types based on **IEC 61131-3**
- Focus on **encapsulation** and **reuse**
- No global or directly addressed variables
- Hardware access with special function block type: **Service Interface Function Block**
IEC 61499 Application Model

- Function Blocks instances
- Event connections
- Data connections
System Model

- Devices
- Process/Machine
- Communication infrastructure
Distribution Model

System Model:
- Devices
- Process/Machine
- Communications Infrastructure

Controlled Process/Machine

Application Model

Device 1
Device 2
Device 3
Device 4
Device 5

Application 1
App. 2
Application 3
Device Specific Adjustments and Parameters

Application Model

Device 1

Device 2

Network Interface

Process Interface

First Experiences:
Service-oriented Machine Control with
IEC 61499 and OPC UA

fortiss GmbH
An-Institut Technische Universität München
• Open source solution for **IEC 61499**
  - Founded 2007
  - Since 2015 Eclipse project
• Main components
  - Development Environment: **4diac-ide**
  - Device abstracting run-time environment: **4diac-rte**
    - Increasing device support, several PLCs
    - Integrated IoT and industrial communication
• Open Source License
  - Eclipse Public License
  - Allows usage in products and proprietary extensions
Integration of OPC UA with 4diac

OPC UA Server (http://open62541.org/)

OPC UA Address Space (Information Model)

FORTE OPC UA Connection

IEC 61499 Application Part

FORTE

FB 1

FB 2

FB 3

FB 4

FB 5

OPC UA SIFB

OPC UA

Client

Node

Node

Node

Node

Node

Node
Modelling of Services in IEC 61499
Application Structure Follows Mechatronic Structure
Outlook: IAS OPC UA Demonstrator

See it live at automatica
Optimize your Production
Outlook: OPC UA over Time Sensitive Networking Ethernet Extension
**Outlook:** Interconnecting Engineering Models and Use them during Run-Time
Are we there yet?

Don’t wait for all of the standards to be completed before moving to Smart Manufacturing

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