Outline

1. CPPS and Industrie 4.0 in Germany
2. Agent technology to enable CPPS
3. Myjoghurt
   - Production changes due to malfunctions
   - New products
   - Maintenance support
4. xPick & Place unit plus COCOME an open I 4.0 demonstrator (PP 1593)
5. Metrics for CPPS and Industrie 4.0
6. Open Research issues

Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser
Full professor and head of Chair Automation and Information systems (AIS)
Faculty of mechanical engineering, Technische Universität München
41st IEEE IECON

Four stages of industrial revolution
Characteristics of Cyber-Physical Production Systems (CPPS) – Industrie 4.0

Data processing for humans
- Assistance systems for Engineering
- Data processing and integration for humans

Communication and data consistency
- Appropriation of necessary data for configuration, production, negotiation
- Worldwide distribution of data, high availability, access protection
- Data consistency about different "stakeholders" in different engineering phases and crafts
- Digital networks and interfaces for communication (between machine, human and plant, plant and plant)

Intelligent products and production units
- Production units with inherent capabilities
- Data analysis of process and alarm data and connection with engineering data
- Flexible production units, adaptable to modified product requirements, allow also structural changes
- Description of product and operating resources, e.g., ontology, for independent analysis, presentation, organization and execution of a production process


Reference Architecture for Industrie 4.0

Cyber Physical Production systems / Industry 4.0- challenges in research and industrial application)

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Properties of software agents

- Autonomy
- Encapsulation
- Goal orientation
- Reactivity, proactiveness
- Interaction / Social ability
-Persistenz

A technical agent is an encapsulated (hardware/software) entity with specified objectives. An agent endeavors to reach these objectives through its autonomous behavior, in interacting with its environment and with other agents.

Source: VDI-Standard 2653 Sheet 1, 2010
Technical Constraints of the Automation System

- Real-time requirements of aPS → hard real-time for the platform (PLC)
- Cyclic behavior of the platform (1µs – 1s)
- Classical PLC as well as Soft-PLC (PC-based) programmed in IEC 61131-3 Languages
- Increasing amount of IPC and C, C-derivatives
- Online change is mandatory

IEC 61131-3 Languages

- Sequential Function Chart
- Ladder Diagram
- Function Block Diagram

IEC 61131-3 Programming Languages

- Proprietary programming languages: Structured Text (ST), Ladder Diagram (LD), Instruction List (IL), Sequential Function Chart (SFC), Function Block Diagram (FBD)
- Upcoming: C

Fields of application

- Reaction time: 8 hours < x < 1 week
- Synchronized frequency: 1 hour < x < 1 day
- Any agent systems are applicable
- Programming languages: C++, C#, Java, …

- Reaction time: 1 hour < x < 1 day
- Synchronized frequency: 60 seconds < x < 1 day
- Any agent systems are applicable
- Programming languages: C++, C#, Java, …

- Reaction time: 1s < x < 60s
- Synchronized frequency: 1s < x < 60s
- Need for multi-agent systems
- IEC 61131, C++, C#, Java

- Reaction time: 10ms < x < 1s
- Synchronized frequency: 100 µs < x < 100ms
- Realtime Agents on RT-Java
- Mostly IEC 61131 and C

Compare: Lüder, A. Möglichkeiten und Grenzen Agentenbasierter Steuerungssysteme; 2006
Agents as Interfaces for Platform Industrie 4.0

**I4.0-service interface**
- I4.0-compliant
- Able to communicate actively

**Agent**
- Provides I4.0-compliant interface *upwards*
- Provides platform-compliant interface *downwards*
- Translates intelligently among interfaces

→ Embeds existing platforms in the I4.0-net
→ Enables migration of existing solutions

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Architecture models (reference architecture) for a category of aggregation/modules related to properties, capabilities, interfaces...

Intelligent products and production units
- Production units with inherent capabilities
- Data analysis of process and alarm data and connection with engineering data
- Flexible production units, adaptable to modified production requirements, allow also structural changes
- Description of product and operating resources, e.g. ontology, for independent analysis, presentation, organization and execution of a production process

Source:

Intelligent networked production systems – myJogurt how it all began

Website: http://www.ais.mw.tum.de/myjoghurt/
Procedure of production control

- Customer places order
- Splitting orders into sub-orders
- Collecting charges and deadlines for sub-orders of system
- Determine (new) schedule
- Contracting (new) sub-orders
- Production monitoring (operator and customer)
- Automatic troubleshooting
- Send status report

Models for classifying product, process and resource

- Formalised process description - VDI/VDE 3682

Gap/Weaknesses

- Is Automation ML “enough” for process and resource description and its variations and versions?
- “Rich” classification of not standardized or custom-specific products missing (more than UNSPSC necessary)

According to UNSPSC

- Product
  - Handling and Conditioning,
  - ... Packing materials
    - Bottles
      - Caps or Tops
        - Engraved lid

Communication within CPPS

I4.0 Agent system

- Agent Management System (AMS)
  - Agent register
    - Agent A: Address A
    - Agent B: Address B
  - Service register
    - Agent A: Ability 1, Ability 2
    - Agent B: Ability 2, Ability 3

Message Transport System (MTS)
- Message register (ACL)
  - Ability 1: Message A, B, C, D, E
  - Ability 2: Message X, Y, Z

Plant Agent
- Local area network or internet
  - Plant Agent
    - e.g. C#
  - Plant Agent
    - e.g. C++

Coordination Agent
- Coordination Agent

Customer Agent
- Customer Agent

Description of the plant and its configuration:
- Technical Resources (Units)
- Capabilities (Operations)
- Units’ status (e.g. PackML)
- Relevant Data points, e.g. for Tracking/Tracing

Intelligent Industrie 4.0 – Plant’s Agent System

- System Agent
  - Structure of the plant, arrangement of Resources
- Communication Module
  - Routing messages
- CPSS-Agent
  - Representation of the plant within the CPSS cluster
- Resource Agent
  - Represents plant module
  - Scheduling for jobs
- Process Agent
  - Execution and Supervision of the process or assembly
- Whiteboard
  - Job offers, job states

IEC 61131-3 Software Application
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Mapping technical system and process description by means of ontologies

Product description
- Name: White chocolate balls
- Viscosity: 2.5 Pa*s
- Yield strength: 20 Pa
- Diameter: 0.5 cm
- Aggregation state: solid

System description
- Name: Filler
- Acceptable viscosity: 1..3 Pa*s
- Acceptable yield strength: 10..30 Pa
- Acceptable diameter: 0.2..1 cm
- Functionality: separate single solid

Ontology
- Formal knowledge representation
- Provides the means to flexibly process knowledge
  → Basis to identify whether filler can manufacture yoghurts with white chocolate balls

Mapping of technical system's characteristics with requirements from product and production process by means of ontologies

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Overall Equipment Effectiveness (OEE)

Possible production time
Real production time
Possible production / quality
Possible production / quality
Real output / performance
Losses due to changing tools, batches...
Losses due to unplanned shutdowns
Losses due to rework, defective goods...

Availability losses
Power losses
Quality losses
effectiveness loss

Possible production time
Real production time
Possible production / quality
Real production / quality
Possible production / quality
Real product / quality
Real output / performance
Losses due to changing tools, batches...
Losses due to unplanned shutdowns
Losses due to rework, defective goods...

Scenario: Information aggregation for maintenance
HMI with AR and touchscreen

- Mobile devices with touchscreen
- Augmented Reality supports optimization and maintenance of industrial plants

Shift supervisor undertakes role of mechanic
- Red-green color blindness
- Preferred voice control

Shift supervisor undertakes role of operator
- Shift supervisor
- Mechanic
- Operator

Source: Lehrstuhl für Automatisierung und Informationsysteme, TU München
Information aggregation for maintenance (2)

Role shift supervisor undertakes role of mechanic
- Red-green color blindness
- Preferred voice control

Role shift supervisor undertakes role of operator
- mechanic
- operator

Challenge
- Prediction of critical situations based on analysis of process data and alarm sequences
- recommendations for operator

Approach
- Pattern analysis, statistical approaches and Clustering

Context

Project: #SmartData2015 / Data Mining in process industry

- Bundle detailed knowledge of processes and plants and include in analysis
- Data logistics
  - Secure provision and transport
  - Secure storage
- Aggregation and analysis of data
  - Aggregation of data specific to processes and plants with historical data
  - Identification of unknown correlations in data → make implicit knowledge explicit
  - Integration of field device manufacturers for improving field devices
- Data use
  - Application of the analytical findings to plant families throughout the company
  - Supporting the operating personnel in engineering, process management, servicing and maintenance
Outline

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Joined Industrie 4.0 Demonstrator DFG - PP 1593 phase II

http://www.dfg-spp1593.de
### Sequential evolution scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Enabler</th>
<th>Context</th>
<th>Platform</th>
<th>Software</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc0</td>
<td>Green field: pick and place unit</td>
<td>Increasing transportation throughput of work pieces</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc1</td>
<td>Y-shaped ramp</td>
<td>Increasing capacity of output storage</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc2</td>
<td>Inductive sensor for metal detection</td>
<td>Two different products are processed</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc3</td>
<td>Stamp unit added</td>
<td>One product has to be labeled</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc4</td>
<td>Replace crane sensors</td>
<td>Decreasing failure due to sensor pollution</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc4b</td>
<td>Microswitches still in charge and spatial shifted crane sensors</td>
<td>Reliability: redundancy for positioning sensors</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc5</td>
<td>Optimized crane behavior by using stamp as buffer</td>
<td>Increasing throughput of work pieces</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc6</td>
<td>Additional mechanical buffer; higher crane optimization</td>
<td>Due to third product two different logistical locations are processed and labeled</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc7</td>
<td>Light sensor installed for plastic WP detection</td>
<td>Different processes for metal (strong) and plastic (light)</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc8</td>
<td>Different pressure profiles at stamp</td>
<td>Transportation of WPs for logistic optimization</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc9</td>
<td>Replace ramp with conveyor including one ramp</td>
<td>Increasing collection locations</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc10</td>
<td>Additional ramps at conveyor</td>
<td>Different logistical locations</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc11</td>
<td>Defined sorting of work pieces for (similar for each ramp)</td>
<td>Special sorting that every sorting location has the same WP order</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc12</td>
<td>Analog sensor for crane positioning</td>
<td>Increasing the precision of the crane</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td>Sc12f</td>
<td>Incremental encoder for crane positioning</td>
<td>EMC resistance due to electromagnetic influences</td>
<td>A</td>
<td>C</td>
<td>P</td>
</tr>
</tbody>
</table>

**Legend:**
- A: Added
- M: Modified
- -: not available at this evolution time
- o: no changes
- C: Context
- P: Platform
- S: Software

**Sources:**

### Self healing PPU - fault handling @ belt pushers

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Additional functionality</th>
<th>Required sensors and software</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sc12f</td>
<td>Additional sensor for fault detection, isolation, and handling</td>
<td>x 0 x</td>
<td>Additional sensors and software required, automatic mode enlarged</td>
<td></td>
</tr>
</tbody>
</table>

- **Binary Sensors** for discrete front and back position detection
- **Additional analogue sensor** to detect exact position of pusher and redundancy for binary sensors
- Result: work piece jam → self healing mode
### Overview of the xPPU (Pick and Place Unit)

- Stepwise evolution covers mechanical, electrical and software changes (sequential and parallel)
- Backward compatibility to older PPU versions

### Changes on model level (software)

#### Alarm104
- f1(In)
- f2(In)
- f(In)
- Sens_Transducer
- Fault
- FB_Fault_Handling
- g(In)
- MaximumTime
- TimeFault
- FB_Monitoring_Sc12f
- PressureFault

### Changes on component list/sensor level (context)

<table>
<thead>
<tr>
<th>Group</th>
<th>Device</th>
<th>Function</th>
<th>Location</th>
<th>Device/Signal type</th>
<th>P. supply</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>310</td>
<td>B1.1</td>
<td>pusher is extended</td>
<td>pusher</td>
<td>read switch DI 24V</td>
<td>mand.</td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>B1.4</td>
<td>position of pusher</td>
<td>pusher</td>
<td>distance sensor AI 24V</td>
<td>SHM</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>B1</td>
<td>pressure sensor</td>
<td>valve node</td>
<td>pneumat. meas. AI</td>
<td>0-24V</td>
<td>SHM</td>
</tr>
</tbody>
</table>

### Changes on code level (software)

#### FB_Monitoring_Sc12
- FB_Fault_Handling
- Run
- Sens_Slide
- Sens_Pressure
- TimeFault
- FB_Monitoring_Sc12f
- PressureFault
Deliverables from PPU – for each evolution step

16 SysML models with evolutionary changes

Technical Documentations

PLC implementations

Especially for project Pythia:
- 45 different IEC 61131-3 Projects
- graphical and textual programming languages

16 PLC implementations each

Based on plcUML

Classical IEC61131

https://mediatum.ub.tum.de/node?id=1208973

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Proposed metrics – adaptivity coverage and realization effort

Fault Coverage Metrics

Adaptivity Metrics for automated Production Systems

Real-time Capabilities Metrics

BECAI: Basic Event Coverage Adaptivity Index
BENCAI: Basic Event Not Coverage Adaptivity Index
FLCAI: Fault Level Coverage Adaptivity Index
plcDFAI: PLC-cycles to detect faults
plcIFAI: PLC-cycles to isolate faults
plcSTSAI: PLC-cycles to switch to soft sensor
plcFCLAI: PLC fault compensation latency

Sc12f: Additional Sensor for Fault Detection, Isolation and Handling

Fault Coverage – Basic Event Coverage (level 1)

Fault tree based fault detection

level 2

leakage in pipe

OR

compressor failure

level 1

&

&

p1

p2

p3

p1

p4

< 4 bar

U_{comp} = 230 V

switch_{comp} = 1

< 4 bar

U_{comp} = 0 V

Measured Basic Events to detect symptoms of a fault

• values that
  • are measured (grey) or
  • need to be measured (white) to detect level 2 fault
• BECAI - coverage of values that are measured (c) related to all basic events (b)

\[ BECAI = \frac{\sum_{i=1}^{c} \epsilon(0,1)}{\sum_{i=1}^{b}} \]
Results for Fault Level Coverage Adaptivity Index (level 2)

Fault Coverage

- indicates a ratio of adaptivity concerning fault robustness of a plant (level 2)
- Fault Level Coverage Adaptivity Index (FLCAI) is used with cf-covered faults and ef-all existing faults

Fault Level Cover age Adaptivity Index

\[ FLCAI = \frac{\sum_{i=1}^{n} cf_i}{\sum_{i=1}^{n} ef_i} \]

\[ \text{cf} = 0.167 \quad \text{ef} = 16.7\% \]

Industry 4.0 - puzzle pieces - open research issues

- Data processing for humans
- Architecture models
- Intelligent products and production units
- Reconfiguration, recovery, restart of production units
- Data analysis of process and alarm data and connection with engineering data
- Description of product (classification and ontologies) – consistency checking

- Metrics have to be adapted / further developed for benchmarking aPS designs and operation behavior regarding Industry 4.0
- Open demonstrators are required to benchmark methods, technologies and approaches for dynamic reconfiguration, restart/recovery and data analysis
Selected Related Publications


Thank you for your attention.

Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser
Full professor and head of Chair Automation and Information Systems (AIS)
Faculty of mechanical engineering, Technische Universität München