Preparing for the 4.0 Future: Industry strategies in anticipation of 4.0.

1. Introduction of TUM and AIS
2. Cyber Physical Production Systems/Industrie 4.0 – terms and challenges
3. Reconfiguration and data analytics in context of Industrie 4.0
4. Conclusion and Outlook

Univ.-Prof. Dr.-Ing. Birgit Vogel-Heuser
Full professor and Director of Institute – Automation and Information Systems (AIS)
Faculty of Mechanical Engineering
Technische Universität München

Member of EduNet
Introduction of Technische Universität München

Technische Universität München

- 37,343 students
- 13 faculties
- 3 Integrative Research Centers
- 6 Corporate Research Centers
- 12,490 female students
- 9,876 staff members
- 411 buildings
- ~ €1.1 billion invested in construction since 2001

Students by department

<table>
<thead>
<tr>
<th>Students by Department</th>
<th>Total</th>
<th>No. of female students</th>
<th>No. of international students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Engineering</td>
<td>5,313</td>
<td>760</td>
<td>1,175</td>
</tr>
</tbody>
</table>
Memberships

- Chair of VDI/VDE (Association of German Engineers) TC 5.15 “Multi-Agent Systems in Automation”
- Coordinator of CRC (Collaborative Research Center) 768 “Managing cycles in innovation processes”
- Co-Initiator of PP (Priority Programme) 1593 “Design for Future – Managed Software Evolution”

Scientific staff

- ca. 20 PhD students
- 9 technicians, trainees (software engineering)

Teaching

- Basics of Information Technology (1st and 2nd Sem., 8 ECTS)
- Modeling and Simulation (5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Automation I and II (from 5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Industrial Software-Development for Engineers I and II (from 5th Sem., 5 ECTS) plus Practical Training (4 ECTS)
- Development of Intelligent Distributed Embedded Systems in Mechatronics (from 5th Sem., 5 ECTS)
Overview of the functionality of our e-learning tool PIT

- Live evaluation
- Mobile application
- Direct feedback during lecture
- Alteration of the next lecture according to the students' demands
- Automated generation of statistics

Connection with...

- plant
- smartphone
- tablet

PIT

- lecture
- exam preparation
- homework
- exam preparation
- live polling

Connection with...

- plant
- IT-pool
- home pc

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Student‘s desktop view

Start/Stop functionality to upload the C code in the PIT PLC

PIT Server
Interface to FESTO industrial plant

Current I/O values

Current state of the state machine

Results of the C compiler, if compilation fails
PIT-based automation lab for ~1000 B.Sc. students: programming of production plants – software engineering on a real mechatronic system with actuators and sensors
Operation results of PIT

Since introduction in 2010: >5200 attendees at PIT

30,000 presence attestations in PIT with fully automated evaluation

In every summer term:

2970 plant operation hours with PIT control

29,000 successful plant launches

235,000 C programs compiled successfully (about 250 per student)

up to 25,000 clicks in a 6 hour time frame

We would be happy to share our experience!
Research Topics

Model-Driven Development

Intelligent Distributed Systems

Smart Information

Big Data in aPS

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Outline

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
- World wide 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)

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 product requirements, allow also structural changes
- Description of product and operating resources, e.g. ontology, for independent analysis, presentation, organisation and execution of a production process


21.08.2015
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Industrie 4.0 Interface for Machines and Plants

Description of the machine and its configuration:
- abilities (operations)
- units’ status (e.g. OMAC/PackML)
- relevant data points e.g. for tracking/tracing

- Process steps (recipe)
- parameters

14.0 Interface (TCP/IP)

CPPS Module
Plant’s representation within the CPPS network

Communication Module
Distribute messages

System management
Conditions of neighborhood, Plant’s structure

Whiteboard
Job offers, Job states

Process management
Information on the process or manufacturing (stages of production)

Control unit
Represents plant module, Scheduling for jobs

IEC 61131-3 control program

MES

IEC 61131
control program

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Motivation for agents on field level
KREAagentuse: SysML-based automation software development

Tool-Supported Development of Agents' Knowledge-base

PD: Redundancy Model
PD: Tolerance Model

Agent Models
Redundancy Model
Tolerance Model

Main Routine
Self-Aware Sensor Agent

Production Plant
Analytical Dependency

Real-Time Capable Fault Tolerant Software

Source: Frank et al. 2011, Schütz et al. 2012, DFG funded project KREAagentuse
Evaluation: Sensor failure

Sensor failure does not disrupt production process

Real sensor

Soft-sensor (virtual sensor)

Used value

Sensor value → Quality → [Wannagat 2010]
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Characteristics of Cyber-Physical Production Systems (CPPS) – Industrie 4.0

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- Data processing and integration for humans

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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)

e.g.

Automatic troubleshooting

Send status report
Self-adaptation of an automated production system

Agent Management System (AMS)
- agent directory
  - Agent A: Address A

Directory Facilitator (DF)
- service directory
  - Agent A: ability 1, ability 2

Message Transport System (MTS)
- message directory
  - Ability 1: message A, B, C, D, E

Peer2Peer Communication

Local Network or Internet

Agent A

Agent B

Customer-Agent

Service-Agent

Communication within CPPS

I4.0 Agent system

Agent Management System (AMS)
- Agent register
  - Agent A: Address A
  - Agent B: Address B

Directory Facilitator (DF)
- 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

Local area network or internet

Coordination-Agent

Customer-Agent

Plant Agent

Demonstrator A

CPPS A

e.g. C#
e.g. OPC

Demonstrator B

CPPS B

e.g. IEC 6113-3

Demonstrator C

CPPS C

e.g. C++
e.g. C++

Characteristics of Cyber-Physical Production Systems (CPPS) – Industrie 4.0

Data processing for humans

Assistance systems for Engineering

Data processing and integration for humans

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Overall Equipment Effectiveness (OEE)

**Possible production time**

- Real production time

**Losses due to unplanned shutdowns**

**Theoretical output / performance**

- Real output / performance

**Losses due to changing tools, batches...**

**Possible production / quality**

- Real production / quality

**Losses due to rework, defective goods...**

**Availability losses**

**Power losses**

**Quality losses**

**effectiveness loss**

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Scenario: Information aggregation for maintenance
HMI with AR and touchscreen

- Mobile devices with touchscreen
- Augmented Reality supports optimization and maintenance of industrial plants
Information aggregation for maintenance (1)

- shift supervisor
  - Red-green color blindness
  - Preferred voice control
- role
  - shift supervisor
  - mechanic
  - operator

Context

Source: Lehrstuhl für Automatisierung und Informationssysteme, TU München

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Information aggregation for maintenance (2)

**Context**

**shift supervisor**
- Red-green color blindness
- Preferred voice control

**role**
- shift supervisor
- 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
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Robot Integrated Agent Network (RIAN)

1. Storage
2. Laser simulation
3. Injection molding
4. Engraving-laser
5. Packaging

Halle B4
Halle A4
Halle A5
CPPS architecture based on multi agent system

CPPS Compound (Multi-Agent System)

CPPS Cloud (Infrastructure)

CPPS Agent Management System
- Agent A: Adresse A
- Agent B: Adresse B

CPPS Message Transport System
- Agent A, Message A
- Agent 3, Message D

CPPS Directory Facilitator
- Agent A: Cap1, Cap2
- Agent B: Cap2, Cap3

Coordination Agent

Customer Agent

PLC Interface

Robot Interface

MAS ITF

CommAgent

SysAgent

ProcAgent

MAS ITF

CommAgent

SysAgent

ProcAgent

Operator

„Smart Device“

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

Plant Agent
- Module Agent 1
- Module Agent n

CPPS A (Linux)

CPPS B (Fanuc-OS)

CPPS C (Fanuc-OS)

CPPS D (PLC)

CPPS E (Linux)

Prod. System Reis

FANUC

Prod. System Fanuc-SGM

Prod. System Fanuc Laser

Prod. System Beckhoff/ AIS

Robot System AIS

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Lessons Learned – Industry 4.0: agent-based migration

Definition of messages between agents:
- Detailed process description necessary
- Iterative proceeding necessary
- Successful application of model-based message development

Implementation:
- Connection between heterogeneous platforms could be instantiated by agent system
- High importance of infrastructure/restrictions of the network
- Detailed planning of integration

Mobile transport robots:
- Separation into real-time and non-real-time communication
- Low data load facilitates fast data exchange via the Internet
- Provide for automatic dialing into networks and reconfiguration

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Open demonstrator for evolution Pick & Place Unit (PPU)
Deliverables from PPU – for each evolution step

16 SysML models with evolutionary changes

PLC implementations

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

Technical Documentations

16 PLC implementations each

Based on plcUML

Classical IEC61131

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

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

<table>
<thead>
<tr>
<th>Sc12f</th>
<th>Additional functionality self-healing machine and diagnosis</th>
<th>x</th>
<th>0</th>
<th>x</th>
<th>Additional sensors and software required, automatic mode enlarged</th>
</tr>
</thead>
</table>

**Sc12f: Additional Sensor for Fault Detection, Isolation and Handling**

- **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

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fault handling @ belt pushers

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 [V]</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>310</td>
<td>B1.1</td>
<td>pusher is extended</td>
<td>pusher</td>
<td>reed switch DI</td>
<td>24V</td>
<td>mand.</td>
</tr>
<tr>
<td>310</td>
<td>B1.4</td>
<td>position of pusher</td>
<td>pusher</td>
<td>distance sensor AI</td>
<td>24V</td>
<td>SHM</td>
</tr>
<tr>
<td>300</td>
<td>B1</td>
<td>pressure sensor</td>
<td>valve node</td>
<td>pneum. meas. AI</td>
<td>0-24V</td>
<td>SHM</td>
</tr>
</tbody>
</table>

Changes on code level (software)

FB_Monitoring_Sc12

- MaximumTime
- Sens_Slide

FB_Fault_Handling

- TimeFault
- Alarm104

FB_Monitoring_Sc12f

- Sens_Transducer,
- Sens_Pressure

TransducerFault

PressureFault

Alarm201

Scenario Sc12

Alarm201

FB_Monitoring_Sc12f

Scenario Sc12f

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Industrie 4.0 - puzzle pieces

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Intelligent products and production units

Data analysis of process and alarm data and connection with engineering data

Production units with inherent capabilities

Flexible production units, adaptable to modified product requirements, allow also structural changes

Legend: online offline

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Summary and Outlook

• Industrie 4.0 demands new concepts for automation software during engineering (software development) and during runtime

• Changes during runtime are mandatory for Industrie 4.0
• Reconfiguration of production processes for customized products
• Compensation of sensor faults to increase the availability of aPS
• Self-Healing Mode for smart diagnosis and maintenance

➢ Metrics have to be developed for benchmarking Industrie 4.0 compliant aPS

• Open demonstrator for software evolution of an aPS at the PPU
• Joined demonstrator Myjoghurt is open for cooperation

• @education – e-learning environment with automatic evaluation of programs, Boolean algebra, simulation interfaces for PPU

http://i40d.ais.mw.tum.de

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Selected Related Publications


