Industrie 4.0: Cyber-Physical Production Systems for Mass Customization

Professor Wolfgang Wahlster
CEO of DFKI

Saarbrücken, Kaiserslautern, Bremen, Berlin
Phone: +49 (681) 85775-5252
Email: wahlster@dfki.de
WWW: http://www.dfki.de/~wahlster
Towards Intelligent Environments based on the Internet of Things and Services

5) Intelligent Environments
4) Embedded Computers
3) Smart Phone
2) PC, Notebook
1) Central Computer

1 Computer, Many Users
1 Computer, 1 User
Many Computers, 1 User

90% of all computers are embedded
Future Project Industrie 4.0 of German Chancellor Dr. Angela Merkel

Evolution from Embedded Systems to Cyber-Physical Systems

- Internet of Things
- Intelligent Environments/Smart Spaces
  - Digital City
- Cyber-Physical Systems
  - Smart Factory, Smart Grid
- Networked Embedded Systems
  - Intelligent Street Crossing
- Embedded Systems
  - Airbag

National Roadmap

Embedded Systems

Cyber-Physical Systems

Agenda
From Industrie 1.0 to Industrie 4.0: Towards the 4th Industrial Revolution

1. Industrial Revolution through introduction of mechanical production facilities powered by water and steam - End of 18th Century

2. Industrial Revolution through introduction of mass production based on the division of labour powered by electrical energy - Start of 20th Century

3. Industrial Revolution through Introduction of electronics and IT for a further automation of production - Start of 70ies

4. Industrial Revolution based on Cyber-Physical Production Systems - today

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After an Initial Publication in 2011 the Term „Industrie 4.0“ was Propagated Exponentially

According to GENIOS Data Base of Publications in Germany
The Internet of Things in the Smart Factory: A Network of Intelligent Objects

- Capturing Context Information
- Digital Product Memories
- M2M Communication Between Intelligent Objects
- Context-sensitive and Location-Based Smart Services
- Cross-linking of Assets and Products in the Factory Internet
- Trusted Cloud
Socio-Economic Drivers of Industrie 4.0

- Lack of Skilled Workforce
- Aging Society Later Retirement
- Volatile Markets and Cost Reduction Pressure
- Dynamic Value Chain Networks
- Shorter Product Lifecycles
- Increasing Product Variability
- Resource-Efficient and Clean Urban Production
- Batch Size 1, Mass Customization Low-volume High-mixture Factories

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Outline of the Talk

1. The Birth of Industrie 4.0

2. Mass Customization based on Cyber-physical Production Systems

3. Semantic Technologies for Plug&Produce

4. Industrial Assistance Systems for the Next Generation of Factory Workers

5. Hybrid Team Work between Humans and Robots

6. Conclusion
Industrial production is the backbone of Germany’s economic performance:
- jobs direct: 7.7 Million, indirect: 7.1 Million, every second job
- more than als 158 € Billion trade surplus from export of industrial products
- (export: machine tool industry, automotive industry)

Disruptive Paradigm Shift in Production based on the Future Internet

1. M2M and All-IP Factories are shifting from central MES to decentralized item-level production control
2. The embedded digital product memory tells the machines, which production services are needed for a particular emerging product.
3. Green and urban production based on cyber-physical production systems
4. Apps for software-defined products and smart product services

Germany is preparing the 4th Industrial Revolution based on the Internet of Things, Cyber-physical Production Systems, and the Internet of Services in Real industry.
The Role of Software for Industrie 4.0

today (Industrie 3.0):

Machine plus Software

tomorrow (Industrie 4.0):

ICT as Innovation Motor No. 1 and Advanced Manufacturing

Software plus Machine
Industrie 4.0: The Fourth Industrial Revolution
Digital Production with Batch Size 1

Internet of Services
Using Internet portals to configure and order a personalized product

Future Project:

Smart Shop:
Innovative Retail Software

Make to Order
Tailored production: 566 billion variants of custom-mixed cereals from:

Smart Factory:
Innovative Factory Software

Internet of Things
Active Product Memories
Service-based manufacturing control based on CPSS

Future Project:
Mass Customization of Perfumes and their Packaging

- Customer can create her own perfume from millions of possibilities via a web portal
- Smart Factory can produce 36,000 Unique Perfume Packages per day
- 24 hours after the order via the Internet has been completed the individualized product is ready for shipment.

Since the customer of an individualized product, that she has designed by herself, does not accept long delivery times, the product should be produced close to the customer → advantage for local European production industry.
The costumers can design their own short shoes using an App.

Since the customer wants to receive his personalized product on the next day or faster, long logistic chains from low-wage countries are no longer acceptable in the era of mass customization.

Thus, adidas decided to open various "speedfactories" for personalized shoes in Germany close to the customer, using Cyber-physical production systems (CPPS).
From Manual Production via Mass Production to Mass Customization

“People can have the Model T in any color – so long as it's black.”

Henry Ford (1913)

Based on: The Global Manufacturing Revolution; sources: Ford, beetleworld.net, bmw.de, dw.de
Onshoring in Industrie 4.0 versus Offshoring in Industrie 3.0

- High-wage Countries
- Industrie 4.0
- Mass Customization
- Short and Mobile Chains to Consumers in Europe
- Small Networked Smart Factories

Offshoring

- Low-wage Countries
- Industrie 2.0 - 3.0
- Mass Production
- Long and Complex Logistic Chains to Consumers in Europe
- Big Traditional Factories

For example: sport shoes, clothes, kitchens, appliances, consumer electronics, toys, bikes…
Products with Integrated Dynamic Digital Storage, Sensing, and Wireless Communication Capabilities

⇒ The product as an information container
  - The product carries information across the complete supply chain and its lifecycle.

⇒ The product as an agent
  - The product affects its environment

⇒ The product as an observer
  - The product monitors itself and its environment
The Semantic Product Memory Is Continuously Updated and Serves as a Lifelog of the History of an Individual Product

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Smart Services Based on Active Digital Product Memories

- Controls its own production process
- Software environment for active product memories
- Enable intelligent logistics and distribution systems
- Enable smart services for end customers
- Deutsche Sparkassen Direct Insurance: Dynamic insurance premiums based on driver behaviour
- 7x4 Pharma - Blister: Prevents wrong dosing
- Smarter Socks from BLACKSOCKS: easy sock pairing

Cyber-physical systems based on product memories
Software-defined platforms for active, digital product memories
Service platforms based on product memories
Thousands of CPS 4.0 Form the Nervous System of a Smart Factory

In Industrie 4.0, conventional field devices and SPS (Storage Programmable Systems) will be replaced by thousands of CPS 4.0 interconnected via industrial internet protocols.
The Smart Keyfinder with its Semantic Product Memory Chip

Semantic Product Memory Chip in the backcover plastic frame with product specification

Bluetooth circuit board with key-finder logic packaged inside a plastic shell

Personalized keychain with custom metal tag on the front produced by an engraving machine
From Bits and Bytes to Semantics

Driven by

- Electrical Engineering
- Software Engineering
- Knowledge-based Systems

Via functions

To semantic services

Common ontology

Knowledge based

Semantic Technologies

Driven by

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Key Components of Service-Oriented Cyber-Physical Production Systems

Production Service Discovery, Matching and Execution

- Machine 1
  - Active Semantic Product Memory
- CNC Milling Machine
- Machine N
  - Active Semantic Product Memory

Production Pathplanning Based on Semantic Product Memories

- Workpiece Carrier 1
  - Active Semantic Product Memory
- Workpiece Carrier N
  - Active Semantic Product Memory
- Emerging Product 1
  - Active Semantic Product Memory
- Emerging Product N
  - Active Semantic Product Memory

Semantic Product Memory
- Top Shell Selection
- Circuit-Top Shell Packaging
- RES-COM Engravature
- Top and Bottom Shell Assembly

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Dynamic Planning Based on Service Composition in a SOA Architecture for Smart Factories

Plug & Produce

Conveyor1.transport (lowSpeed)
Pick&Place.insertBottom (AssemblyPlace4)
Pick&Place.insertBoard (AssemblyPlace4)
Pick&Place.insertCap (AssemblyPlace4)
AssemblyPlace4.compress

Green Production Minimize CO2

Abstract Process Specification
The Intelligent Workpiece Carrier: A Complex Cyber-Physical System

The Taxi to Production Services
Plug&Produce based on Adaptive Service Ontologies

- Plugin of CPS production components on a physical, digital and semantic level

- Automated Expansion of the Service Ontology

New Assembly Component is installed on-the-fly
DFKI‘s Multi-Vendor Automation Line in the Industrie 4.0 Paradigm
Seamless Interoperability, Multiadaptivity, and Plug&Produce
The Smart Automation Line of Bosch-Rexroth

Cooperation with DFKI and Power4Production Center in the SmartF-IT Project

Source: Bosch-Rexroth

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The Retrofitting of Legacy Factories with an Additional Layer of Cyber-Physical Systems

Rasberry PI 1
CPS as an Active Product Memory for the Emerging Product

WLAN Router

Classical SPS

Gadgeteer with Sensors for Acceleration, Shock, Humidity and Temperature

Rasberry PI 2
CPS for Processing Sensor Data from the Additional Sensor Web

Professional Alternative
MICA by HARTING
Human-Centered CPS-based Assistance Systems for the Smart Factory

- Physical Assistance by Exoskeletons
- Mobile, Personalized, Situation-Adaptive, Tutoring Systems
- Multimodal Human-Machine Interaction
- Location-based Maintenance and Planning Assistance
- AR/VR/DR-Assistance in Complex Work Processes
- Context-adaptive Assistance for Fault Diagnosis

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App Stores for the Smart Factory
Advanced Industrial Assistant Systems Based on Augmented Reality Technologies

Industrial Environment

Industrial Worker with Google Glasses

Tools

Mobile, Interactive and Situation-Aware Tutoring
Look-Through Technology Used in the Smart Factory
Industrie 4.0: Robots are no Longer Locked in Safety Work Cells but Cooperate with Human Workers

Today

Tomorrow

A new generation of light-weight, flexible robots collaborate with humans in the smart factory
Bosch‘s APAS Cobot in DFKI‘s SmartF-IT Assembly Line
Multiadaptive Assembly System for Highly Flexible Hybrid Job Floors

- Use of OMM/OMS as an Active Product Memory
- Use of Assistance Functions in Planning and Production

**Variant 1**

5 Workers

**Variant 2**

5 Workers

**Variant 3**

3 Workers + 1 Roboter

Automatic | Manually | Transport

Bosch APAS (Automatic Production Assistants)
Human-Robot Collaboration at an AUDI Assembly Plant
Collaborative Robotics at BMW

Source: BMW
DFKI’s Fembot AILA: Using the Semantic Product Memory for Adaptive Grasping

Stereo Cameras in the Head and a 3D Camera on the Torso for Approaching an Object

Reading Size, Weight and Lifting Points from the Product Memory with an antenna in the left hand – the Robot gets instructions from the product being produced in the CPPS
Demo Task:
An object (example: cell phone) with individual interior cushioning is packed into a shipping box.

Blackboard provides all working tasks
team members can allocate tasks according to their abilities

Aila: customer interface
Compi: worker support
Artemis: intra-logistics robot

Manager/Technician: supervising/aiding the process
Worker: executing the human tasks

humans are in the center of production

Gloria: worker interface
Collaborative DFKI Robot COMPI: Resilient Plan Execution with Realtime Replanning
Hybrid Multiagent Collaboration in Cyber-physical Production Systems

Resource-oriented Architecture of Hybr-iT

Hybrid Team of Humans and Robots
Hybrid Teams: Robots Collaborate with Humans in Physically Challenging Overhead Assembly Tasks
Industrie 4.0: Smart, Green, and Urban Production

**Smart Production**
High-precision, superior quality production of high-mix, low volume smart products

**Green Production**
clean, resource-efficient, and sustainable

**Urban Production**
Smart Factories in the city close to the employees’ homes
President Obama has introduced the “re-industrialization” strategy for the US

Innovation in Germany builds on legacies: in industrial specializations, workforce skills, and proximity to suppliers with diverse capabilities.

They create new businesses, not usually through start-ups - the U.S. model - but through the transformation of old capabilities and their reapplication, repurposing, and commercialization.
Smart Data as the Jet Engine for Smart Factories, Products and Services
Siemens-SAP Cooperation on Manufacturing Cloud Platform

Optimization of plants and machines as well as energy and resources

- **Open standard (OPC)** for connectivity of Siemens und third-party products
- **Plug and play connection** of Siemens products (engineering in the TIA Portal)
- **Cloud for industry** with open application interface for individual customer applications
- Optional **cloud infrastructure** – public cloud, private cloud or on-premise solution
- Transparent **pay-per-use pricing model**
- Opportunities for completely new **business models** (e.g. selling machine hours)

powered by

SAP HANA
Core Centers selected in First Round in 2015

Secondary Centers selected in 2016
After the Seed Investment in Germany the Roll-Out of Industrie 4.0 in Europe has been started

“We are in the middle of a true revolution...the fourth industrial revolution: It will change all our industries, it will change our economy and it will change our lives”

EU Digital Economy & Society Commissioner Günther Oettinger

Funding

€40 billion p.a.

€140 billion p.a.
The German Platform for Realizing Industrie 4.0

Platform Industrie 4.0
Ministry of Economics, Ministry of Research

Decision Making, Technological Competence

Steering Board
- Industry Leaders
- Working Group Leaders
- Ministry of Economics & Ministry of Research

Political and Societal Coaching

Strategy Board
- Politics
- Trade Unions
- Industry Associations
- Academies

Market Activities

Competence Centers of Academia

Testbeds of Industry

International Standardization

Working Groups
- Reference Architecture
- Security

Scientific Advisory Board

Service Office
Standardization as a Key Success Factor for Industrie 4.0

Standardization through Semantic Meta Description Languages

Standardization through Interoperability

Communication Standards

Mechatronic Base Standards

Intefaces between Digital Enterprise and Digital Factory Layer

Semantic Service Description and Semantic Product Memory

- OWL
- OWL-S
- OMM++
- USDL
- WSDL

**DIN** EN 62264

**VDI** 2860

- Ethernet
- IP
- OPC UA
- SoA
- TCP/IP
- RJ45, WiFi…
- HAN-Modular®

**W3C**

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The Race for Industrie 4.0 Standards

- Leading Provider of Internet Hardware, Software and General ICT
- No Leading Manufacturing Industries
- Leading Manufacturing Industries
- Leading Provider of Enterprise Software
- Leading Provider of Internet Hardware
- Giant Market for Manufacturing Industries
Research Cooperation Potential

1. Collaborative Robotics: Hybrid Teamwork of Robotic Team and Human Teams
2. Semantic Technologies: Product Memories for Service Orchestration in Smart Factories
3. Intelligent Industrial Assistance Systems: Proactive and Situation-aware Worker Assistance based on wearable AI
4. Production Planning: Advanced Multiagent Planning and Dynamic Plan Revision for Industrie 4.0
5. Security Technologies: Intelligent Intrusion Detection for Smart Factories

Wolfgang Wahlster is a member of the International Advisory Board of CIIRC, the Czech Institute of Informatics, Robotics and Cybernetics, headed by Prof. Marik
Conclusions

- Industrie 4.0 is a success story of a strategic public-private partnership and secures Germany's economic power as a leader in manufacturing.

- Industrie 4.0 brings the Internet of Things to the job floor of factories and allows mass customization of smart products for a reasonable price based on semantic technologies and semantic service matchmaking.

- Cyber-Physical Production Systems and Semantic Product Memories enable Plug&Produce and Multiadaptive Smart Factories. DFKI is a key driver of these technologies.

- A new generation of Factory Workers is essential for Industrie 4.0 and will be assisted by a new generation of collaborative robots and intelligent industrial assistance systems using multimodal dual and augmented reality.

- Industrie 4.0 and Smart Service Welt are large-scale future projects between industry and academia that are the basis for a data-driven economy.
Thank you very much for your attention.