Industry 4.0: The Semantic Product Memory as a Basis for Cyber-Physical Production Systems

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Towards Intelligent Environments based on the Internet of Things and Services

1) Central Computer
   - Many Users
   - 1 Computer

2) PC, Notebook
   - 1 Computer
   - 1 User

3) Smart Phone
   - Smart Card

4) Embedded Computers

5) Intelligent Environments

90% of all computers are embedded

Many Computers, 1 User

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The German Future Project: Industry 4.0

- 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.
Future Project Industry 4.0 of German Chancellor Dr. Angela Merkel

500 M€ for 3 Years
National Program:
250 M€ Funding of Ministry for Research and Ministry for Economics

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
President Obama has introduced the “re-industrialization” strategy for the US

In the US, the great spike in unemployment over the past five years was disproportionately due to loss of manufacturing jobs. Across the entire industrial landscape there are now gaping holes and missing pieces. It’s not just that factories stand empty and crumbling; it’s that critical strengths and capabilities have disappeared that once served to bring new enterprises to life.

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

The potential of German patterns extends well beyond defending niches against lowcost competition with incremental advances.

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.

The Germans had not only their own legacy resources, but also access to a rich and diverse set of complementary capabilities in the industrial ecosystem: suppliers, trade associations, industrial collective research consortia, industrial research centers, Fraunhofer Institutes, University-industry collaboratives, technical advisory committees.
Outline of the Talk

1. From Embedded Systems to Cyber-Physical Systems in the Smart Factory

2. The Role of Active Semantic Product Memories in Cyber-Physical Production Systems

3. Semantic Web Services in a SOA Model of Cyber-Physical Production Systems

4. Industrial Assistance Systems Based on Digital Product Memories

7. Conclusion
CPSS: Based on Wireless Adhoc M2M Communication of Autonomous Sensor-Actuator Components

1. Context-sensitive Component Behaviour
2. Dynamic Adaptation Based on Individual Role of the Component

From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

1. Industrial Revolution
   - mechanical production facilities powered by water and steam
   - End of 18th Century
   - First Mechanical Loom 1784

Degree of Complexity

End of 18th Century

Industry 1.0
From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

1. **Industrial Revolution**
   - Through introduction of mechanical production facilities powered by water and steam
   - **First Mechanical Loom**
   - **1784**

2. **Industrial Revolution**
   - Mass production based on the division of labour powered by electrical energy

**Degree of Complexity**

- **Industry 1.0**
  - End of 18th Century
- **Industry 2.0**
  - Start of 20th Century
From Industry 1.0 to Industry 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
   - electronics and IT and heavy-duty industrial robots for a further automization of production
   - Start of 70ies

Degree of Complexity

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From Industry 1.0 to Industry 4.0: Towards the 4th Industrial Revolution

1. **First Industrial Revolution** through introduction of mechanical production facilities powered by water and steam (End of 18th Century)

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

3. **Third Industrial Revolution** through introduction of electronics and IT for a further automation of production (Start of 70ies)

4. **Fourth Industrial Revolution** based on Cyber-Physical Production Systems (today)

Degree of Complexity
The Internet of Things and Services as a Basis for the Smart Factories in the Industry 4.0

Internet of Services

Semantic PLM-, SCM-, CRM-, QMS- and ERP-Services

Smart Factory

App Plattform

Cyber-Physical Production System

Smart Material

App Plattform

Smart Products

App Plattform

Internet of Things

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The Semantic Product Memory Stores a Diary of an Individual Smart Object.

The Smart Product monitors itself and its environment.
Benefits of Semantic Product Memories

Benefits for Producers
- Efficient Production and Logistics
- Adaptive Manufacturing
- Improved Business Processes
- Efficient Supply Chain Management
- Enabler for Mass Customization
- Simplification of Robotic Handling
- Enabler for Process Mining

Benefits for Consumers
- Quality Assurance
- Product Transparency
- Product Security
- Anti-Counterfeiting
- Ecological Footprint
- Improved Maintenance
- Recycling Efficiency
- Extended Consumer Information
- Additional Product Functionalities
- Intelligent User Interaction
- Added-Value Services
- Self-Explainability
- Personalized Product
- Story-Telling Experience
CPS Hardware for a Digital Object Memory
embedded or attached to a physical object

- Microsensor systems
- Microprocessor
- Positioning Chips
- Own Energy Supply or Energy Harvesting Unit
- Radio Modules for Web Connectivity
- Actuators or Display

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CPS Software for a Digital Object Memory
embedded or attached to a physical object

- Sensor Interpretation Components
- Communication Interfaces
- Memory Management Functions
- User Interfaces
- Security Components
- Positioning Software
- State Transition and Processing Logic Components

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Various Platforms for Mobile Cyber-Physical Systems

- Accelerometer Module
- Barometer Module
- ColorSense Module
- Compass Module
- Distance Module
- GasSense Module
- Potentiometer Module
- Gyro Module
- Moisture Module
- LightSense Module
- Temperature Module
- Humidity Module
- GPS Module
- Camera Module
- Display Module
- Ethernet Module
- RFID Reader Module
- ZIGBEE/Bluetooth/WiFi Modules

Duinomite-Mega

- PIC32MX795L
- 80MHz
- 2MB FLASH
- 64KB EEPROM
- 100 Mbit Ethernet

.net Gadgeteer Platform

- ARM7 Prozessor
- 72 MHz
- 4.5 MB Flash
- 16 MB RAM

GNUBLIN-Board

- ARM9 Prozessor
- 180 MHz (LPC3131)
- 32 MB SDRAM
RES-COM: Resource-Efficient Cyber-Physical Productions Systems (CPPS) based on AI Methods

1. Sense
2. Evaluate
3. Control
The product memory prevents:

- tarnished chocolates → Humidity Sensor
- melted chocolates → Temperature Sensor
- crushed chocolates → Pressure Sensor
A Taxonomy of Digital Object Memories

- Internet of Things
  - Mobile Cyber-Physical Systems (CPS)
  - Digital Object Memory (DOMe)
    - Passive Digital Object Memory
    - Active Digital Object Memory
  - Digital Product Memory (DPM)
    - Digital Maintenance Memory
    - Semantic Product Memory
      - Digital Transport Memory
  - Internet of Services
Four Hardware Realizations of SemProMs

Application

Semantic Interface

Data Semantics

Block Interface

Data Container

Hardware Interface

Reference SemProM

Storage SemProM

Smart SemProM

Autonomous SemProM

- e.g. Production order
- Warranty info
- Maintenance info
- Ingredients
- Carbon footprint

- e.g. Barcode as reference to production order in SAP ERP

- Data on tag, e.g. data matrix code or RFID

- Services provided by lean embedded system, e.g. SunSPOT, Crossbow iMote2

- Autonomous complex computing based on standard embedded system, e.g. embedded PC
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

I was produced on 30 April 2010 and shipped on 3 May 2010

Grasp at the middle

2 mins open
Please close!
DFKI’s Living Lab for AI and Automation
The SmartFactory: Producing Bottled Soap in Dispensers
Future Manufacturing in DFKI’s SmartFactory
DFKI’s SmartFactory: The World’s First Living Lab for Cyber-Physical Production Systems
Realtime Monitoring of Small and Large Containers with SemProm’s Digital Product Diaries for Smart Logistics

Smart Temperature Sensor on Small DHL Packet
in the logistics chain

Track and Trace Device

- Energy Management Unit
  - Localization Component
  - Communication Unit
  - Sensor Interface
  - SemProm Access Unit

Internal Sensors
- Tracking of Light, Shock Pressure, Motion, Temperature

Access to Product Memory On Packet Level

Volume Monitoring

Packets without Smart Item
- SemProm Packet with Temperature Sensor

Database of Customers

DHL Realtime Information Hub
Closed-Loop versus Open-Loop Product Memories for Intelligent Packaging

Ad-hoc Data Formats

Semantic Data Formats
W3C Standards as a Basis for the Project of the Future Industry 4.0

EMMA: Multimodal Industrial Assistance Systems

OMM: Semantic Product Memory

USDL: Semantic Services in Cyber-Physical Production Systems

Industry 4.0 Smart Factory
The Structure of the Object Memory Model (OMM, W3C Standardization)
<omm:omm>
  <omm:header>
    <omm:version>1</omm:version>
    <omm:primaryID
      omm:type="url">http://www.w3.org/2005/Incubator/omm/samples/p1</omm:primaryID>
    <omm:additionalBlocks omm:type="omm_http">
      http://www.w3.org/2005/Incubator/omm/samples/p1/ext</omm:additionalBlocks>
  </omm:header>
  <omm:toc>...</omm:toc>

  <omm:block omm:id="11">
    <omm:format omm:schema="http://www.w3.org/2005/Incubator/omm/schema/attributeList.xsd">
      application/xml</omm:format>
    <omm:title xml:lang="en">log event</omm:title>
    <omm:subject><omm:tag omm:type="text" omm:value="event" /></omm:subject>
    <omm:payload>
      <omm:attributeList>
        <omm:attribute omm:key="action">Transport</omm:attribute>
        <omm:attribute omm:key="begin">2013-01-11T19:03:00+01:00</omm:attribute>
        <omm:attribute omm:key="end">2013-01-11T19:04:00+01:00</omm:attribute>
      </omm:attributeList>
    </omm:payload>
    ...
  </omm:block>
</omm:omm>
Factories store more data than any other industrial sector. Close to two exabytes of new production data were stored in 2010 from multiple sources in the EC:

- instrumented production machinery
- supply chain management systems
- product life-cycle systems

New ICT Coordination Action of EU:

BIG: Big Data Public Private Forum
Interoperability for M2M-Communication in Industry 4.0

**μ webservice**
- 32bit ARM processor
- 8MB SDRAM
- 100Mbit Ethernet & Wi-Fi
- LINUX on DIGI Connect

**OPC-UA**
(Open Process Control Unified Architecture)
Server for M2M

The heart of an industrial CPS: XML-based Web server or very fast binary communication based on the TCP protocols
Service-Oriented Planning of Plant Systems

Hardware-independent planning of plant systems

- ERP (Enterprise Resource Planning)
- MES (Manufacturing Execution System)
- Field Layer

Service Library:
- Sensor-Service
- Valve-Service
- Pump-Service
- Control-Service
- Communication-Service

Abstract Service
- hardware-independent
- Device Control
- hardware-dependent

Industry 4.0: All-IP Factories, no chaos of field buses, Internet-based Factory Networking based on IoS and IoT

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Semantic Web Services for Industry 4.0: The Semantic SOA Model of the Smart Factory

Physical Model

- SOA-based Smart Factory
- Ultrasound Sensor
- Inductive Sensor
- RFID-LSG
- Electronic Stopper
- Camera

Functional Model

- Function „Stop pill box“
- Function „Detect pill box“
- Function „Count pills“
- Function „Fill“
- Function „Control quality“

Service Directory

- Web-Service „stopper“
  Operation: „hold“
  IP 192.168.178.29

- Stopping Unit Services:
  - hold
  - release
  - check

- RFID-LSG Services:
  - read
  - write

- Ultrasound Sensor Service:
  - check

- Camera Service:
  - count_pills

Nach D. Zühlke, DFKI
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 keyfinder logic packaged inside a plastic shell
- Personalized keychain with custom metal tag on the front produced by an engraving machine
Key Components of a Service-Oriented Cyber-Physical Production Systems

Production Service Discovery, Matching and Execution

Production Pathplanning Based-on Semantic Product Memory

Semantic Product Memory
- Top Shell Selection
- Circuit-Top Shell Packaging
- RES-COM Engravature
- Top and Bottom Shell Assembly
The Intelligent Workpiece Carrier: A Complex Cyber-Physical System
CPS-based Industrial Assistance Systems

Infrastructure to ensure
Operating Safety, Reliability, IT Security and Privacy

Multi-Adaptivity Based on Machine Learning Methods
(Personalization, Reconfigurability, Agility)

Multimodal Input Analysis
Multimodal Assistance System
Industrial Presentation of Results

CPS Production System
Machine Control
Adaption of Equipment

History of Discourse
Factory Model
User Model
Work Plans
Learning Models
Process Models
Production Context

Paradigm shift in human-technology- and human-human-interaction with new forms of collaborative factory work based on social online networks
App Stores for the Smart Factory
First Industry 4.0 Application of Leap Motion Technology: The Worker can do Everything Without Touching Anything with his Dirty Fingers
Location-based Industrial Assistance Systems in Smart Factories for Resource Efficiency Improvements
Augmented Reality Systems Supporting Maintenance Staff
Advanced Industrial Assistant Systems Based on Augmented Reality Technologies

Mobile, Interactive and Situation-Aware Tutoring

Industrial Environment

Industrial Worker with Google Glasses

Tools

90°
close ball valve

remove the tube with 2 flanges

remove the ball valve
Augmented Reality in Intelligent Industrial Assistance Systems

In-Situ Learning of New Process or Repair Procedures
Look-Through Technology Used in the Smart Factory
Industry 4.0: Robots are no Longer Locked in Safety Work Cells but Cooperate with Human Workers

A new generation of light-weight, flexible robots collaborate with humans in the smart factory
DFKI’s Fembot AILA: Using the Semantic Product Memory for Adaptive Grasping and Intelligent Packaging

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
DFKI’s Two-armed Robot AILA Reading Digital Product Memories of Instrumented Environments
Industry 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
Most Recent and Relevant Book about Product Memories in the Springer Series „Cognitive Technologies“

SemProM
Foundations of Semantic Product Memories for the Internet of Things

Series: Cognitive Technologies
Wahlster, Wolfgang (Ed.)
412 Pages
ISBN 978-3-642-37376-3

Electronic Order:
http://www.springer.com/computer/ai/book/978-3-642-37376-3
Conclusions

1. **Cyber-Physical Production Systems** and **Semantic Product Memories** are the Foundations for **Industry 4.0** and introduce the **Internet of Things** into the **Smart Factory**.

2. The **Semantic Product Memory** controls the Production Process in a **Distributed Fashion** based on **Semantic Service Architecture** for **Manufacturing Machines**.

3. This semantic service architecture is based on a production ontology and ubiquitous microweb servers and realizes intelligent matchmaking processes between emerging products and production tools.

4. **Active semantic product memories** use semantic web technologies, agent technologies and intelligent sensor interpretation based on AI research.
Thank you very much for your attention.