IoT vs Cyber-Physical Systems in the Smart Factory Paradigm

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Outline

- Industry 4.0 in brief
- Cyber-Physical Systems for Smart Factories
- IoT vs Industrial CPSs
- Best Practices
- Future Challenges
INDUSTRY 4.0 IN BRIEF
Industry 4.0

Industry 4.0 is 'the comprehensive transformation of the whole sphere of industrial production through the merging of digital technology and the internet with conventional industry' (Angela Merkel, German Chancellor, Organization for Economic Co-operation and Development, 19 February 2014).

The 4.0 designation signifies that this is the world's fourth industrial revolution, the successor to three earlier industrial revolutions.

<table>
<thead>
<tr>
<th>INDUSTRIAL REVOLUTION</th>
<th>TIME PERIOD</th>
<th>TECHNOLOGY AND CAPABILITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>End 18th - mid 19th Century</td>
<td>Water- and steam-powered mechanical manufacturing</td>
</tr>
<tr>
<td>Second</td>
<td>Late 19th Century - 1970s</td>
<td>Electric-powered mass production based on the division of labour (assembly line)</td>
</tr>
<tr>
<td>Third</td>
<td>1980s – 2000s</td>
<td>Electronics and information technology drives new levels of automation of complex tasks</td>
</tr>
<tr>
<td>Fourth</td>
<td>Today-future</td>
<td>Sensor technology, interconnectivity and data analysis allow mass customisation, integration of value chains and greater efficiency</td>
</tr>
</tbody>
</table>

Source: European Parliamentary Research Service (EPRS), Industry 4.0 – Digitalisation for productivity and growth, 2015
The Road to the Connected Intelligent Value Creation Chain

**18th cent.**
INDUSTRY 1.0
With steam power from the agrarian to the industrial society

**19th cent.**
INDUSTRY 2.0
Using electric power for assembly line and mass production

**20th cent.**
INDUSTRY 3.0
Computerization of production

**21st cent.**
INDUSTRY 4.0
Intelligent networking of humans, machines and products

Source: www.infineon.com/industry4award
Key Enabling Technologies

• Additive Manufacturing, 3D Printing
• Advanced Manufacturing, Collaborative Robotics
• Internet & Industrial Internet (of Things, of Tasks, of Everything…)
• Virtual & Augmented Reality
• Cloud
• Big Data
• Analytics
• Cyber-security
• Energy
• ……. 
Societal and Economy Paradigms

- Customer Centricity
- Open Innovation
- Open Collaboration
- Circular Economy
- Venture Capital
- ……. 
Changes

Production and technology
- Centrality of innovation and knowledge for competitiveness in a global market

Institutions
- Different distribution of power and responsibilities, supra-national and territorial policies

Economy
- Reduction of the role of raw materials, impossibility of monetary devaluation and the need to start new policies for re-industrialization

Education
- New teaching systems and disciplines; increasing role of universities and public research centers in the innovation policies
CYBER-PHYSICAL SYSTEMS FOR SMART FACTORIES
Cyber-Physical System (CPS)

Cyber-Physical Systems are engineered solutions obtained through the seamless integration of computational algorithms and physical components.

- Typically, each technological system has a dual physical and computational identity. The combination of these two identities has undergone a deep evolution in the last years, which has led to the total revolution of physical systems and to how people interact with them.

- The term cyber defines the modernity of machines, not only intelligent thanks to cybernetics but characterized by a virtual nature and the ability of interfacing with data networks, i.e. Internet.
CPS Concept

Any CPS should:

- directly record physical data from the real world with **sensors** and influences physical processes in the real world with **actuators**;
- evaluate and retain recorded data **interacting** actively and reactively both with **physical world** and **digital world**;
- be connected with other similar systems in global digital networks that leverage **cloud computing**;
- use data (**Big Data**) and globally available services that make up the cyber space;
- have **multimodal interfaces** for communicating with human operators.
CPS Concept

It records real world data and affects physical processes

It stores and assesses recorded data

It exploits Cloud Computing and Big Data

It features multimodal interfaces

It features multimodal interfaces for communication with humans

It exploits cloud computing for data management

Advanced connectivity

Physical Components

Analytical Models

Cyberspace

Twin

smart data management
Industrial CPS vs Smart Factory

✓ The use of CPSs in industrial processes can make intelligent production processes and smart factories possible.

✓ In a smart factory, machines have the ability to know their operating status and record the surrounding environment, keep the memory of the history of network operation in which they are immersed and make decisions as a result of inferential processes.

✓ This interconnected system can transform machines into self-learning and self-awareness systems that can be optimized and dynamically reconfigured.
Industrial CPS: 5C Model

I. Smart Connection Level
- Plug & Play
- Tether-free communication
- Sensor network

II. Data-to-Information Conversion Level
- Smart analytics for
  - Component machine health
- Multi-dimensional data correlation
- Degradation and performance prediction

III. Cyber Level
- Twin model for components and machines
- Time machine for variation identification and memory
- Clustering for similarity in data mining

IV. Cognition Level
- Integrated simulation and synthesis
- Remote visualization for human
- Collaborative diagnostics and decision making

V. Configuration Level
- Self-configure for resilience
- Self-adjust for variation
- Self-optimize for disturbance

FUNCTIONS

ATTRIBUTES
Expected Benefits

- **Flexibility**
  - Higher flexibility - production of small lots at the cost of the great scale

- **Speed**
  - Greater speed – from the prototype to series production through innovative technology

- **Productivity**
  - Larger productivity - shorter set-up times, reduction of errors and machine stops

- **Quality**
  - Better quality and less scrap – distributed sensors for real-time production monitoring

- **Product Competitiveness**
  - Wider competitiveness – added value from IoT and IIoT technology
IoT vs INDUSTRIAL CPSs
Internet-of-Things: Key Foundation of CPS

- Allowing objects to be remotely sensed or controlled across existing network infrastructure, Internet-of-Things (IoT) can aid Cyber-Physical Systems revolution.

- Within the smart factory paradigm, IoT can act as a major enabling technology for industrial CPSs.
IoT: Lightweight Protocols for Low Performance Devices

Main features of an IoT Communication/Transportation Layer:

- **Wireless link**: to the aim of reducing wiring.
- **Low bandwidth**: IoT devices usually need low data rate.
- **Low Power**: IoT devices are usually supplied by batteries.
- **Wide Coverage**: depending on specific application (Smart City, Industry).
IoT: Focus on LoRa Protocol

✓ The advantage of LoRa® is in the technology’s long range capability.

✓ Range highly depends on the environment or obstructions in a given location, but LoRa® and LoRaWAN™ have a link budget greater than any other standardized communication technology.

✓ LoRa® offers multi-year battery lifetime and is designed for sensors and applications that need to send small amounts of data over long distances.
LoRa Protocol Performance Assessment

A suitable test-bed has been implemented, in order to perform laboratory **cross-layer analysis** for assessing the relationship between the signal-to-noise ratio at the physical layer and the transmission quality at the highest layers.
## Indoor Scenario

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<td>680</td>
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</table>
Outdoor Scenario

A LoRa gateway has been installed close to Federico II Engineering headquarters, and an experimental campaign for a comprehensive performance assessment under actual operating conditions is going to be launched.

<table>
<thead>
<tr>
<th>Distances</th>
<th>SF7</th>
<th>SF 12</th>
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<tbody>
<tr>
<td>(~1km)</td>
<td>-105 dBm</td>
<td>-100 dBm</td>
</tr>
<tr>
<td>(~1,6km)</td>
<td>-114 dBm</td>
<td>-110 dBm</td>
</tr>
<tr>
<td>(~2,7km)</td>
<td>-117 dBm</td>
<td>-115 dBm</td>
</tr>
</tbody>
</table>
Man looks at a real-life size immersive environment of **Augmented Reality** reproducing the plant under test.

All the information related to design and monitoring are integrated in the immersive environment of **Augmented Reality**.
IoT : Augmented Reality and Monitoring

- User interacts with the Augmented Monitoring System by **haptic sensors** integrated in a suitable interface.
BEST PRACTICES
IoT Best Practice: Hi-Tech FabLab DIETI Unina

The first FabLab of the University Federico II aims at driving and accelerating the development of innovative IoT projects within Industry 4.0 paradigm.
CPS Best Practice: Ph.D. Student Game
CPS Best Practice: Structural Monitoring of Concrete Structures

3D-Printed Concrete Sensor:
- Limited relative error
- Cost-effectiveness and ease of installation
FUTURE CHALLENGES
CPS Future Challenge: Self-Awareness

The multiplicity of CPS strategic applications requires that the learning methods and the resulting decisions are totally reliable. This requirement can only be achieved by developing time correctness by design systems, that is, by entering time references within CPS management software and freeing time from hardware characteristics.

<table>
<thead>
<tr>
<th>Component</th>
<th>Data source</th>
<th>Key attributes</th>
<th>Key technologies</th>
<th>Key attributes</th>
<th>Key technologies</th>
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</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>Data source</td>
<td>Precision</td>
<td>Smart Sensors and Fault Detection</td>
<td>Self-Aware</td>
<td>Degradation Monitoring &amp; Remaining Useful Life Prediction</td>
</tr>
<tr>
<td>Controller</td>
<td>Data source</td>
<td>Productivity &amp; Performance (Quality and throughput)</td>
<td>Condition-based Monitoring &amp; Diagnostics</td>
<td>Self-Predict</td>
<td>Up Time with Predictive Health Monitoring</td>
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<tr>
<td>Production System</td>
<td>Data source</td>
<td>Productivity &amp; OEE</td>
<td>Lean Operations: Work and Waste Reduction</td>
<td>Self-Configure</td>
<td>Worry-free Productivity</td>
</tr>
</tbody>
</table>
CPS Future Challenge: Problem Avoiding

✓ Multidimensional and multivariate information allows a single machine to appreciate its own role within the CPS system, thanks above all to time correctness, make the right decisions to optimally manage the industrial process.

✓ A radical change in the philosophy of industrial manufacturing is expected, moving from the current problem solving philosophy to the more exciting and fructuous problem avoiding philosophy.
THANK YOU