Cyber-Physical Systems

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Associate partner:

INTRODUCTION TO THE INDUSTRIAL REVOLUTION 4.0

These didactical materials, which have been developed in the framework of the European project 'Industry 4.0 - INTRO 4.0', funded by the European Commission aims to come up with an overview of what has been done in the European Industry in terms of Industry 4.0.

The content of these didactical materials provides the most relevant and useful information on Industry 4.0 to a target group that includes: adults, educators (VET & Higher Education), teachers, trainers, coaches, employers, employees, the general public, and suppliers of innovative solutions.

This information is rooted within the report 'Current Status Of The Industry 4.0' and the report 'Summary Report of the expert interviews/questionnaires and the specific research on the field of manufacturing companies", both developed by the partners of this project.

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THIS CONTENT MAY BE OF GREATER INTEREST TO THE COMPANIES

THIS CONTENT MAY BE OF GREATER INTEREST TO THE GENERAL PUBLIC

LEARNING OBJECTIVES

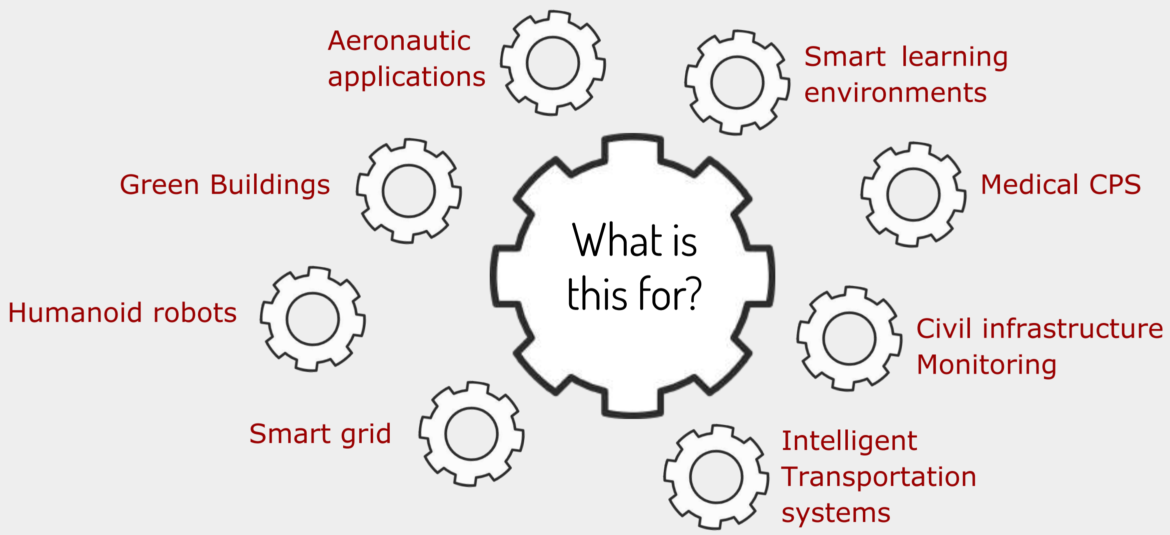
- Understand what is Cyber-Physical System and its applications.
- Identify the benefits derived from this technology.
- Know the potential of this technology and usage trends.

INTRODUCTION

Cyber-physical systems are key infrastructures for our modern society. They can improve the quality of life of citizens and the competitiveness of European industry.

Learning Objectives

- Understand what is Cyber-Physical System and its applications
- Identify the benefits derived from this technology
- Know the potential of this technology and usage trends



SOME BENEFITS

- Integration
- Integration Human - System
- Deal with uncertainty
- Better performance
- Scalability
- Flexibility
- Faster response time

FUTURE APPLICATIONS

The technical potential of cyber-physical systems facilitates the development of innovative business models which require extensive testing

WHAT IS IT?

A **cyber-physical system (CPS)** is composed of a physical system and its corresponding cyber systems that are tightly fused at all scales and levels.

Many objects in our world are controlled by computers: cars, buildings, manufacturing machines or even musical instruments. In these cases, computers interact directly with the physical world. That is why we call them "cyber-physical systems" (CPS).

We interact with many complex objects and systems in our everyday life. Practically all of them are controlled by computers, which interact with the world not only through a touchscreen, but through direct actions performed in the physical world. The most common cyber-physical systems that we see everyday are modern cars, in which computers control not only the engine, but also the braking, the vehicle stability, and often support the driver in her tasks. Therefore we see clearly how actions controlled through computers have an impact in the real world.

Cyber-physical systems are also present in many other elements of our daily lives, such as energy networks, factories, automated warehouses as well as planes or trains. All these physically-entangled systems are of crucial importance for the quality of life of the citizens and for the European economy.

Cyber-physical systems are very complex, especially when several CPS need to be combined. That is the case for example in an airport or a large factory, where many machines have to work together to achieve a common goal. In this case, we speak about "cyber-physical systems of systems", or CPSoS.

WHAT IS IT?

Complex systems are difficult to build and to manage. If an application on your phone crashes the consequences are typically not very bad, but if the interface between two manufacturing machines breaks down, the production of a large manufacturing plant can be stopped. Even worse, in transport or medical systems, the physical safety of people can be jeopardized.

There are of course engineering techniques to manage this, but significant improvements are needed to manage the CPS of tomorrow, which will be even more sophisticated than today and very important both for our quality of life and for the competitiveness of European industry.

WHAT IS THIS FOR?

Applications of Cyber-Physical Systems:

Green Buildings:

Greenhouse effect is one of the major problems in today's world. The old buildings consume 70% of the electricity produced and generate the greenhouse gases which in turn increase greenhouse effect. By using the integrated Wireless Sensor Network, cognition manager and control systems we can achieve Zero Net Energy goal.

Smart grid:

Smart grid is an ecosystem which will rely on its basis on information acquisition assessment and decision making as well as management. In smart grid many traditional parts use Cyber Physical Systems. They are used in generation, transmission and distribution and also in customer side. In generation it will control the connection the network as well as the operational aspects in the electricity generation. CPS monitor the conditions and care for the stability of transmission and distribution networks that connect end-users to smart grid. It will provide two-way communication and control between power grid and consumers.

Medical CPS:

Wireless Sensor networks collect the diagnostic information, monitor the health and drug administration of patient's .The integration of computing and control mechanisms to the critical medical information communicated provides a fundamental prerequisite to high-confidence medical cyber-physical systems.

Intelligent Transportation systems:

Cyber Physical Systems provide a way to improve traffic system control performance. Road Traffic-control Cyber Physical System constructs an environment that exists in the natural geographical environment and manmade environment such as bridges across the sea or rivers, long and big tunnels ,high-risk sub-grade slope, urban elevated bridges and others. But also massive variety of vehicles, people and goods in the complex road environment. Intelligent Transportation System, can realize the traffic control by adding and installing a large amount of advanced electronic devices and information systems to the road traffic system, improving operational efficiency and safety level for the road traffic system Traffic control Cyber Physical Systems integrate these information into the transportation process, and operate through their coordination making the transportation more safe and efficient.

WHAT IS THIS FOR?

Humanoid robots:

Humanoid robots can be used for:

I. Taking care of the elderly people at home.
II. Scientific investigation of undersea environments, rainforest environments, space environments and critical infrastructure protection.
III. For personnel purpose.
IV. In agricultural fields.
V. Rescue operations in the event of emergencies and dangerous work environments.

Smart learning environments:

Cyber Physical Systems can be used in Smart learning environment. CPSs can used in the SLE to gather adequate information about the physical environments, convert measured data to information and knowledge, and eventually provide useful and prompt services for students, staffs and the university. Smart learning environment (SLE) will definitely transform the way people learn and work in universities.

Civil infrastructure Monitoring:

Today lot of civil engineers faces the problem stewardship of ageing of infrastructure like dams, bridges, buildings etc. Fiber optic sensors and Micro electrical and mechanical sensors and wireless communication technologies offer tremendous promise for accurate and continuous infrastructural monitoring.

Aeronautic applications:

Cyber-Physical Systems are used for Aeronautic applications such as flight test instrumentation, Pilot-crew communications, Structure Health Monitoring, In-flight tests, in flight entertainment Wireless Cabin, and flight landing.

WHAT IS THIS FOR?

5C architecture for implementation of Industry 4.0.

Industry 4.0 performances are shown with the tip of an iceberg. Therefore, some researchers are considering creating the structure to give a dissection of the Industry 4.0. '5C' architecture is an example for guiding the development of the Industry 4.0, depending on the Cyber-Physical system attributes. This architecture is divided into five levels, 'Connection Level', 'Conversion Level', 'Cyber Level', 'Cognition Level', and 'Configuration Level'.

		Main Attribute	Main Function
5	Configuration Level	Self-configure	Intelligent Production
4	Cognition Level	Early-aware	Predictive Maintenance
3	Cyber Level	Controllable	Automated System
2	Conversion Level	Informational	Information Discovery
1	Connection Level	Communicable	Hardware Connection

The **'Connection Level'** focuses on hardware development, which is accomplished by the sensor network and wireless communication, and the other four levels pay attention to the controlling system and software implementation. On the **'Conversion Level'**, the raw data is transformed into useful information by using data analysis technologies. The **'Cyber Level'** controls the entire network via the CPS. The **'Cognition Level'** and **'Configuration Level'** engage the artificial intelligence in the network, which are considered as future attributes of manufacturing. Manufacturing intelligence is also the main target of many researchers who are interested in Industry 4.0, which is represented by these two levels. Comparing the attributes of these two levels and the Industry 4.0, the 'Cognition Level' is considered as a lower level of Industry 4.0, and, the 'Configuration Level' tends to reveal upper levelled features of Industry 4.0 which are regarded as the accomplishment of the Industry 4.0.

WHAT IS THIS FOR?

Therefore, when these various types of the idea (future visions, research examples, and implementation architecture) are merged and summarized, under the Industry 4.0, several concepts of future manufacturing have been abstracted. These concepts are the main design principles of Industry 4.0, which sums up two main design principles: interoperability and consciousness. These two main design principles include many sub-concepts, the interoperability consists of digitalization, communication, standardization, flexibility, real-time responsibility, and customizability. The predictive maintenance, decision making, intelligent presentation, self aware, self-optimization and self-configuration comprise the consciousness.

The core idea of interoperability is integration, which is also the key point of IoT and CPS. There are three types of integration of Industry 4.0, horizontal integration, end-to-end integration, and vertical integration. These three types of integration represent three dimensions peer to peer, horizontal integration over the business value networks, end-to-end integration across the products chain, the vertical integration through the manufacturing system.

In addition, the other main design principle of the Industry 4.0 is consciousness. Basic on this concept, Industry 4.0 requires manufacturing to be intelligent, which discovers the knowledge, make the decisions and delivers the action independently and intelligently. These results are analysed from collecting raw data from the manufacturing networks by using cutting edge intelligent technologies. Moreover, these two main design principles are cooperative to achieve Industry 4.0. The interoperability set up several connected networks as the reliable environment of Industry 4.0, the consciousness offers the Industry 4.0 the essence with the artificial intelligent functions.

WHAT IS THIS FOR?

Cyber physical systems are hybrid networked cyber and engineered physical elements co-designed to create adaptive and predictive systems for enhanced performance.

Essential CPS characteristics:

- Cyber, engineered, and human elements as treated as integral components of a total system to create synergy and enable desired, emergent properties.
- Integration of deep physics-based and digital world models provides learning and predictive capabilities for decision support (e.g., diagnostics, prognostics) and autonomous function.
- Systems engineering-based open architectures and standards provide for modularity and composability for customization, systems of products, and complex or dynamic applications.
- Reciprocal feedback loops between computational and distributed sensing/actuation and monitoring/control elements enables adaptive multi-objective performance.
- Networked cyber components provide a basis for scalability, complexity management, and resilience.

For cyber-physical systems, consistent customer focus and, thus, user-friendliness and intuitive usability are the key to success.

GOOD PRACTICES

SANTANDER Smart City

SmartSantander is a large-scale research project that spreads thousands of sensors around the city of Santander in Spain. Its purpose is to build a smart solution and improve various aspects of the city life, such as reducing traffic, reducing energy consumption, improving the quality of the environment, and encouraging citizens' participation. Also, the project hopes to share this environmental information and develop other useful applications. The research is also testing to see whether it is possible to reduce distances between theoretical designs of smart infrastructures and the adoption of practical applications in a real-world environment. The results of this test will help increase the spread of Internet of Things (IoT) and CPSs in real scenarios in the future.

Smart Nation SINGAPORE

Singapore, which was named as the world's smartest city for many years, is becoming a leading nation in implementing smart infrastructures and providing quality services. Singapore is one of the world's most important business centers, has one of the busiest ports, and is home to Asia's fifth largest airport. Singapore expects to create the first smart nation in the world to boost economic growth, to meet population needs, and to be an example for other nations. The insights of this smart nation are grouped as:

- Better policies to manage different contexts
- Development of novel business models and revenue streams that can strengthen the economic growth
- An increase in active citizens' participation towards the creation of quality services that can improve everyday life of the community

GOOD PRACTICES

WAYMO

It is the brand under which Google operates and has just launched its first hundred units by Chrysler with the Pacifica model, a car that can circulate without a driver, has the relevant licenses and has planned its first tests in real scenarios this month.

It has to be said that Google has already been in the autonomous car business for seven years and that it has been the first brand to complete a journey with a car without a driver. Since he turned in the development of the autonomous car has rolled more than one million kilometers.

Some leading companies:

FORTINET · FIREEYE · leidos

sparkcognition · DARKTRACE

haystax · THETARAY · INTRINSIC ID

Echosec · AVIRTEK Smarter Cyber Resilience

BENEFITS FOR THE COMPANY

Integration

The integration of cloud and Wireless Sensor Networks is also an important part of Cyber Physical Systems. CPS provides network integration characteristics such as media access control techniques and their effects on system dynamics, middleware, and software that provide coordination over networks control over timing of network transactions, and fault tolerances.

Interaction between Human and System

Modeling and measuring situational awareness-human perception of the system and its environmental changes in parameters are critical for decision making.

BENEFITS FOR THE COMPANY

Dealing with uncertainty

Certainty is the process of providing proof that a design is valid and trustworthy. Cyber physical systems can be able to evolve and operate with new and unreliable environment.

Better System Performance

CPS is able to provide better performance in terms of feedback and automatic redesign with close interaction of sensors and cyber infrastructure.

Scalability

As a part of cloud computing CPS is able to provide the resources to users according to their requirements.

Flexibility

CPS can provide more facilities than WSN and Cloud Computing alone.

Faster response time

CPS will increase the fast response time and facilitate the early detection of failure, proper utilization of resources such as bandwidth.

"Intelligent" and networked objects (for example, using RFID technology) are mainly used in trade and logistics.

Cyber Physical Systems are Smart Systems that comprises of the merging and integration of Industry Control Systems, Critical Infrastructures, Internet of Things (IoT) and Embedded Systems.

FUTURE APPLICATIONS

For cyber-physical systems and smart cities to be successful, people need to think and act differently and get more involved in city life. Active communities that can aggregate the distributed knowledge of each individual and can complete synergistic actions to improve the city services are essential.

Technology today allows for distributed computing and crowdsourcing, sharing information among users, and building a collective intelligence. Collective intelligence is one of the keys for the success of CPSs and smart cities. Collective intelligence uses the crowdsensing for the cooperative monitoring of the urban environment. It also targets cooperative actuation of operations to perform tasks of general interest in an efficient way.

From the technical perspective, many hard challenges must still be solved, at least in an efficient and industrially applicable way. Some of the challenges are:

- **Data heterogeneity.** Data heterogeneity is a significant issue that can affect communication performance and the design of communication protocols. Systems need to be able to support a great number of different applications and devices.

- **Reliability.** CPSs are suitable to use in critical contexts like healthcare, infrastructure, transportation, and many others. Reliability and safety are basic requirements because of how actuators affect the environment. In fact, the impact of actuators can also be irreversible, and therefore the presence of unexpected behavior must be minimized. Moreover, the environment is not predictable so CPSs must continue to work under unexpected circumstances and adapt themselves in case of failures.

FUTURE APPLICATIONS

- **Data management.** It is necessary to store and analyze big data from different connected devices, process them, and show real-time results. Data can be managed by using offline or online stream processing in relation to the goals of the system. In particular with an online stream, information can change frequently with real-time conditions and are based on adaptive and continuous queries.

- **Privacy.** The challenge is to balance privacy concerns and personal data control, with the possibility to access data to provide better services. Because CPSs manage large amounts of data, including sensitive information like health, gender, religion, and many others, significant issues about data privacy are raised. CPSs require privacy policies in order to address privacy issues, thus a data anonymization management tool is required to have anonymized information before the system processes it.

- **Security.** CPSs must ensure security during communications because all actions among devices are coordinated in real time. As CPSs expand and increase interactions between physical and cyber systems, security problems affect more CPSs. Traditional security infrastructures are not enough to address the issue and new solutions must be found. Security issues are critical on new data and stored data that was collected for future use. Lastly, CPSs are based on heterogeneous applications and wireless communications, which often raise critical security issues.

- **Real-time.** CPSs manage large amounts of data that is derived from sensors. The computations need to work efficiently and be timely, because physical processes keep going independently from the results of the computations. To satisfy this requirement, CPSs must ensure that they have the bandwidth or system capacity needed to meet time-critical functions because failures on time of actions can cause permanent damages.

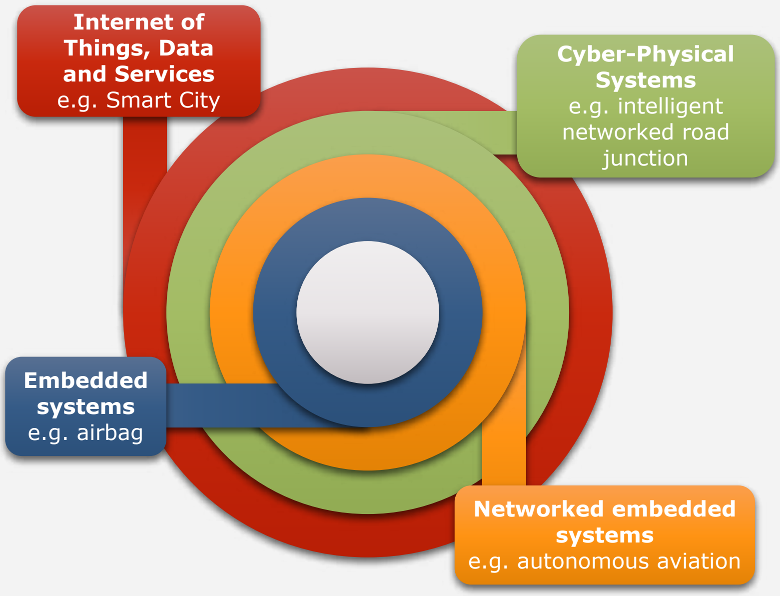
ADVANCED CONTENT

What is the difference between Cyber-Physical System and the Internet of Things?

The Internet of Things uses special sensors (e.g. cameras or RFID readers) to identify products and materials. Those products and materials contain special information about, for example, what should happen with them. This means that they can communicate with production or material flow systems and tell them what the next step in the manufacturing process should be. The technology thus removes any need for human involvement.

Cyber-physical systems are when the mechanical and electrical systems (e.g. sensors and communication tools) embedded in products and materials are networked using software components. The result is a complete merging of the virtual and physical worlds. Cyber-physical systems use shared knowledge and information from processes to independently control logistics and production systems. They are therefore the bridge that connects the Internet of Things with higher-level services – known as the Internet of Services.

In this virtual world, software providers, service providers, brokers and users collaborate to develop flexible applications that can be dynamically integrated with one another. If we are to achieve the goals of the fourth industrial revolution, scientists need to embrace both cyber-physical systems and the basic idea and technologies behind the Internet of Things.



ADVANCED CONTENT

Impact of Cyber-Physical Systems in cities:

Smart cities can be seen as wide-scale cyber-physical systems, with sensors monitoring cyber and physical indicators and with actuators dynamically changing the complex urban environment in some way. Governments, organizations, and technology industries are rising to the challenges of increased urbanization, working to improve urban life by offering improved efficiencies with energy utilizations or services, for example.

According to the *United Nations Population Prospects, 2014 Revision* report, the urban population of the world is growing rapidly, and it is continuing to increase. In 2014, 54% of the world's population resides in urban areas, and the coming decades will bring further profound changes to the size and spatial distribution of the global population. In 1950, 30% of the world's population was urban; by 2050, 66% of the world's population is projected to be urban.

ADVANCED CONTENT

Security of Cyber-Physical Systems:

To ensure cyber-physical systems are safe, we need to address two fundamental scientific challenges. First, we need to reason about the discrete and continuous at the same time. Fortunately, much progress in formal verification has been made in the past 20 years on this front. One approach is to model a cyber-physical system as a hybrid automaton, which is a finite state machine where each state's behavior is defined by a set of differential equations over continuous variables. Model checking technology can be applied to hybrid automata, making it feasible to prove properties about and find bugs in models of cyber-physical systems.

Another approach is to write logical formulas describing the behavior of a hybrid system and then use theorem proving technology to prove properties from the formulas. An example of an appropriate logic in which to write such formulas is differential dynamic logic, developed within the last decade along with rich tool support. Active research addresses the scalability of these techniques, since currently they support only tens of state variables, whereas an operational cyber-physical system typically has orders of magnitude more.

Second, cyber-physical systems operate under the presence of uncertainty. This uncertainty is due external conditions not under system control: Mother Nature, e.g., earthquakes, hurricanes and snowstorms; and The Human, acting mistakenly, surprisingly or maliciously.

This is an example of a self-organizing factory that is configured and fully organized and responds to changing requirements, and in which humans and machines collaborate perfectly.

https://youtu.be/wro3uoHR-ZY

EDUCATION

Because of the nature of CPSs, the study of CPS spans several different disciplines, such as software-hardware engineering, computations, control, communication, sensing and actuation. Results show that CPSs have been successfully deployed in smart grid and other "smart" applications.

MOOCS:

- Cyber-Physical Systems: Modeling and Simulation - Coursera
- Homeland Security & Cybersecurity Connection - Coursera
- Embedded Hardware and Operating Systems - Coursera
- Web Connectivity and Security in Embedded Systems - Coursera

EXTERNAL MANUALS FOR MORE INFORMATION:

- Guide to Cyber-Physical Systems Engineering
- Cyber–Physical System Security for the Electric Power Grid

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SELF APPRAISAL

- ★ After reading this text, do I have a clear idea of what Cyber-Physical System is?
- ★ How could I incorporate Cyber-Physical Systems technology in my company?

- ★ Could I say four applications of Cyber-Physical Systems?
- ★ Could I differentiate the Internet of Things and Cyber-Physical Systems?

INTRO 4.0

INTRODUCTION TO THE INDUSTRIAL REVOLUTION 4.0