ICT for Advanced Manufacturing

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Abstract: Information and communication technologies (ICT), automation, and robotics remain key sciences of the 21st century. Currently, manufacturing enterprises are facing challenges with regard to new concepts such as Internet of Things, Industrial Internet of Things, Cyber-physical Systems or Cloud-based Manufacturing. The Industrial Internet of Things (IIoT) is an emerging paradigm in today's control industry comprising Internet-enabled cyber-physical devices with the ability to link to new interconnection technologies. Under this perspective, new industrial cyber-physical "things" can be accessible and available from remote locations; information on them can be processed and stored in distributed locations favouring cooperation and coordination to achieve high performance in real time. The paper presents the state-of-the-art in research, development and education in new information a communications technologies for advanced manufacturing based on intelligent modelling and control methods, and their applications with the focus on new trends declared in Industry 4.0.

1 INTRODUCTION

Modern manufacturing industry has been facing several significant challenges including sustainability and performance of production. The marriage of advanced manufacturing processes and techniques with modern ICT is driving another industrial revolution. The challenges are sourced from many real needs and factors such as aging workforce, changes in the landscape of global manufacturing, and adaption of manufacturing by implementing advanced ICT, cognitive robots, virtual and mixed reality and robust and intelligent control methods in manufacturing processes. Industry 4.0 represents the fourth industrial revolution in manufacturing industry and its methodology is a current driving force at the heart of the industry development representing the realization of large-scale changes in current industries (Hermann, 2015) including digitization, automation and ICT integration at all levels of control of processes and services.

In recent years, many industrially advanced countries have established initiatives to apply modern ICT based on the Internet of Things (IoT), Industrial Internet of Things (IIoT), smart embedded computers, devices and technologies in the manufacturing industries to improve performance, intelligence, robustness and controllability of the manufacturing process. Relationship between IoT and Industry 4.0 is shown in Fig.1.

Industry 4.0 is characterized by the following paradigms (Lee, 2015):

a. *Interoperability* is the ability of integration and cooperation of intelligent machines, sensors, intelligent methods and human beings to interact through Internet of Things (IoT), Industrial Internet of Things (IIoT) and Internet of Services (IoS).
b. *Virtualization* is creation of a virtual model (or a copy) of an intelligent factory. Virtualization uses real data obtained from the real plant applied to the intelligent factory model for control and decisions.
c. *Decentralization* is the ability of each machine to carry out operations and decentralized (autonomous) control, and to make maximum qualified intelligent decisions on each sub process for optimizing process production.
d. *Real time (RT) data collection and analysis*. Intelligent production control requires data to be collected and analysed in real time. Based on the information collected, real-time intelligent control and decision-making methods can be

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used for optimization and reconfiguration taking into account failures and finding optimal solutions such as component and device failures, transfer of production, etc.

e. *Service oriented communication and information exchange* over the Internet of Things, providing information to other parties of the company's services.

f. *Modularity and reconfigurability*. The ability of an intelligent business to flexibly adapt to the production situation by changing SW and HW modules, module sharing, and reconfiguring processes (multi-criterial and multi-variant optimal intelligent decisions).

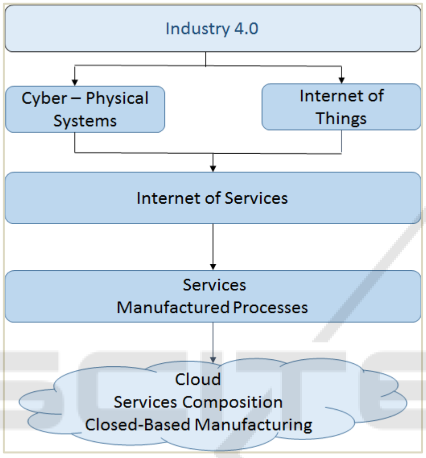

Figure 1: Relationship between IoT and Industry 4.0.

The paper is organized as follows. Section 2 deals with analysis of the current state in development of the Industry 4.0 methodology, cyber-physical systems, IoT, and integration of methods and tools at all levels of manufacturing processes. Section 3 presents research trends in advanced manufacturing. In Section 4, possibilities and new forms of multidisciplinary education for Industry 4.0 are proposed.

2 ICT AND CYBER-PHYSICAL SYSTEMS

Industry 4.0 is the current industrial transformation with complex automation, data exchange, cloud, cyber-physical systems, robots, Big Data, AI, IoT and (semi-autonomous) industrial techniques to realize smart industry and manufacturing goals within the interconnection of people, machines, embedded computers, sensors and new digital elements (Fig.2).

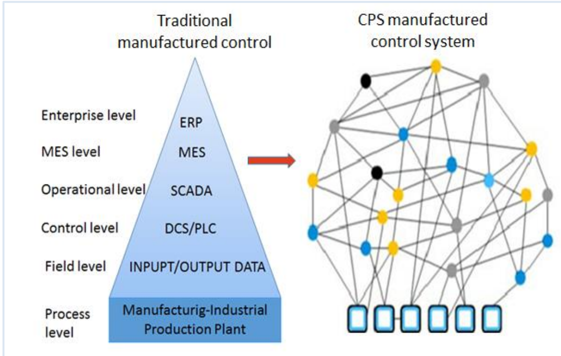

Figure 2: Conventional centralized vs decentralized IoT structure.

Cyber-physical systems (CPS) are engineering, physical and biological systems whose operations are integrated, monitored, and/or controlled by a computational core (an embedded computer system usually demanding real-time response, and most often distributed). Behaviour of a cyber-physical system is a fully-integrated hybridization of computational (logical) and physical action (Helen Gill, US National Science Foundation). CPS are the core of Industry 4.0 challenges (Fig. 3) referring to a new generation of systems with integrated computational and physical capabilities that can interact with humans through many new modalities. The ability to interact with, and expand the capabilities of the physical world through computation, communication, and control is a key enabler for future technology development.

CPS examples encompass all fields, e.g. automotive industry, energy optimal buildings, zero-fatality highways, and personalized medical devices. CPS link cyberspace with the physical world through a network of related interconnected elements, such as embedded computers, sensors and actuators, robots, and other computational engines (Fig. 3). We assume that these systems are highly automated, intelligent and collaborative.

Nowadays, for most industrial processes, multi-level control structures are used, which are gradually transforming with the development of ICT into modern cyber-physical systems (Fig. 4). CPS are engineered systems built from, and depending upon the seamless integration of computational algorithms and physical components. Advances in CPS will enable capability, adaptability, scalability, resiliency, safety, security, and usability that will far exceed the simple embedded systems of today.

CPS technology will transform the way people interact with engineered systems – just as the Internet has transformed the way people interact

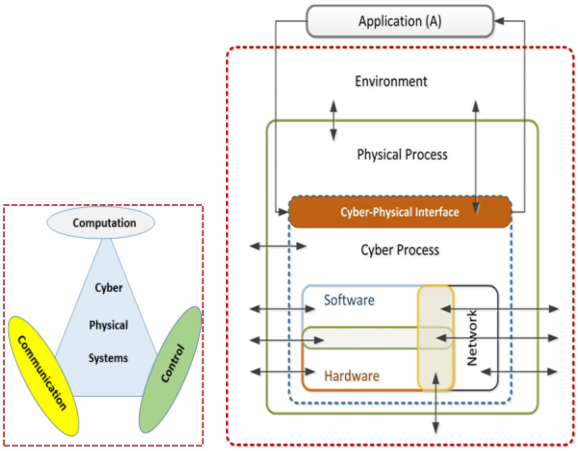

Figure 3: Principal CPS components.

with information. A CPS structure can be effectively illustrated by five-level architecture (connection, conversion, cyber, cognition, and configuration) in Fig. 4 (Lee, 2007):

1. **Connection Level:** devices can be designed to self-connect and self-sensing its behaviour.
2. **Conversion Level:** data from self-connected devices and sensors are measuring the features of critical issues with self-aware capabilities, a machine can use the self-aware information to self-predict their potential issue.
3. **Cyber Level:** each machine is creating its own "twin" by using these instrumented features and further characterize the machine health pattern based on a "Time-Machine" methodology. The established "twin" in the cyber space can perform self-compare for peer-to-peer performance for further synthesis.
4. **Cognition Level:** the outcomes of self-assessment and self-evaluation will be presented to users based on an "infographic" meaning to show the content and context of potential issues.
5. **Configuration Level:** optimization and planning of the overall production system.

The 5-level CPS structure in Fig. 4 provides a step by-step guideline for developing and deploying a cyber-physical system for a smart enterprise. Connection requires acquiring accurate and reliable data from individual machines and their components. Data source can be from IoT-based machine controllers, add-on sensors, quality inspections, maintenance logs, and enterprise management systems such as ERP and MES.

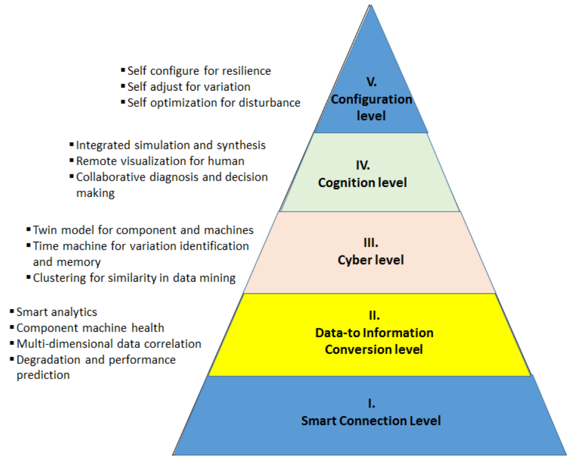

Figure 4: Multilevel architecture for implementation of Cyber-physical System.

New generation embedded ICT systems are interconnected and collaborating through the Internet of Things, providing citizens and businesses with a wide range of innovative applications and services in living and working environments. A CPS is a mechanism controlled or monitored by computer-based control and decision algorithms, tightly integrated with the Internet and its users. In the CPS, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioural modalities, and interacting with each other in a myriad of ways that change with context. Application of the IoT to the manufacturing industry is called the Industrial Internet of Things (IIoT).

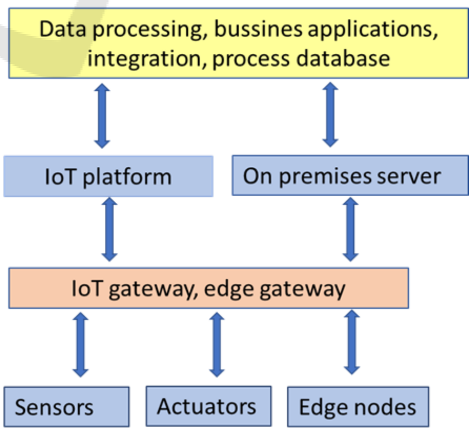

Figure 5: IIoT infrastructure.

IIoT is part of a larger concept known as the Internet of Things (IoT). The IoT is a network of intelligent computers, devices, and objects that collect and share huge amounts of data sent to a central Cloud-based service where it is aggregated with other data and then shared with end-users in a helpful way (Fig.5). IoT significantly increases the level of intelligent automation in all process industries (power plants, automotive manufacturing, food industry, intelligent homes, schools, stores, etc.).

The Industrial Internet of Things (IIoT) is the use of Internet of Things (IoT) technologies in manufacturing processes. IIoT incorporates machine learning, cloud computing and big data technology, harnessing the sensor data, machine-to-machine (M2M) communication and automation methods and technologies.

The Internet of Things (IoT) for industrial application can be characterized as follows:

- it is the network of physical items equipped with embedded computers, electronics, transducers such as sensors and actuators, connectivity and software to capture, filter and exchange data about themselves and their environment. IoT enables effective inter-operability between individual devices, and machines that can be use different protocols and different architectures,
- it can also be effectively used for technological and business purposes,
- it is a significant driver for customer-facing innovation, data-driven visualization and optimization, artificial intelligence techniques, automation, digital transformation and entirely new applications, business models and revenue streams across all sectors,
- modern industrial enterprises are the integration of all recent IoT technological advances in computer networks, control engineering methods, data integration, and analytics to bring transparency to all manufacturing factories.

The driving philosophy behind the IIoT is that smart machines are better than humans at accurately, consistently capturing and communicating data. The IIoT will revolutionize manufacturing by enabling the acquisition and accessibility of far greater amounts of data at far greater speeds and far more efficiently than before.

The Industrial Internet seeks to improve manufacturing and supply chain efficiency via data, information, mathematical modelling, optimal control and effective coordination. General practical structure and components of IoT architecture for Industry 4.0 are shown in Fig. 5.

Individual IIoT levels are the following:

- IoT device. Sensors and actuators with communication interface are considered as an IoT device. The IoT devices can have its certain computational power for basic automation processes control.
- IoT Gateway. The aim is to aggregate measurements and data from IoT devices, and to actuate commands to them.
- IoT Backend. It resides in data centre with scalable CPU power and memory capacity. Its responsibility is to do high level analysis, statistics, actuation, data provision and data interface for end users.

One possible application of IIoT in manufacturing process control is presented in Fig. 6.

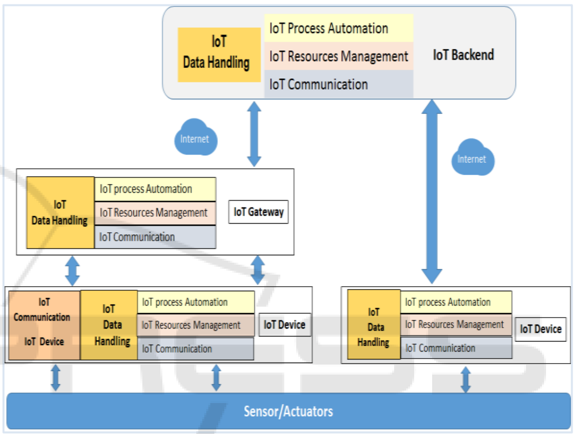

Figure 6: Application of IIoT in manufacturing process control.

3 RESEARCH TRENDS IN ADVANCED MANUFACTURING

The last ten years have witnessed an explosion of research activity around the CPS, conceived as architectures, protocols, standards, platforms, services and applications with a high level of integration and interaction of software, hardware and physical modules and components (Lee, 2007). Research of CPS is still open and in its infancy. Professional and institutional barriers have resulted in narrowly defined, discipline-specific research and education venues in academia for the science and engineering disciplines. Research in this field is partitioned into individual sub-disciplines such as embedded computers, sensors, communications and networking, virtual and mixed reality, control engineering theory, artificial intelligence (AI), mathematics, software engineering, Big Data, Cloud, RFID and computer science.

Achieving high production quality is not possible without research, development and application of new intelligent modelling and control engineering methods (Kozák, 2012; Didekova, 2017) implemented on embedded control systems based on recent technologies of electronic, electrical equipment and components production. Several sectors have lately exploited the enormous benefits foreseen for CPS, from Energy (smart city, smart grids, energy efficiency and optimization for intelligent buildings, agriculture) up to Industry 4.0 (automotive, smart robotics, mechatronics) through Health processes (Body nets, robot surgery), Operations Research (firefighting, disaster missions) or Transport (collision avoidance, driving efficiency) among many others. CPS are composed of intelligent cyber-physical entities (Holon's, physical agents that can cooperate, self-organize, act on their environment and make autonomous decisions) (Yang Liu, 2017).

Computational Intelligence (Soft Computing based on Machine- and Deep Learning techniques) are promising technologies enablers of the intelligence and self-learning capability required in complex CPS. The research fields in the development of advance CPS can be declared as follows:

- Advanced control engineering methods (Kozák, 2012) and algorithm development (process level control, process optimization, multi-criterial decisions, pattern recognitions, discrete-time, and discrete-event modelling and control, recognition, modelling and control).
- Advanced control methods research and design as a service (IoT, IIoT, Cloud computing, Proportional–Integral–Derivative (PID) controller, Model Predictive Controller (MPC), Linear Quadratic Gaussian Controller (LQG), Artificial Intelligence (AI) controllers).
- Advanced soft computing techniques (Kozák, 2012), i.e. fuzzy logic, neural network, hybrid fuzzy-neural and their application to problems related to CPS (multi-criterial decisions, distributed predictive modelling, hybrid optimization algorithms, online learning, collaborative reasoning and weakly/semi-supervised learning).
- Data analytics and scalable/parallel/distributed computing algorithms for CPS.
- Energy efficient methods and paradigms for CPS tackled via Soft Computing (Deep and Machine Learning).
- Distributed computing, data fusion and aggregation over large-scale CPS in industries.
- Predictive and clustering models for CPS self-configuration, self-resilience and self-autonomy.
- Optimization algorithms for optimal management and multilevel control, intelligent sensor actuation.
- Autonomous computing, inference of human patterns, analysis, monitoring, and situation alertness in CPS.
- Collaborative robots and machine learning and distributed AI.
- Process Controller as a service (Cloud computing, Big Data).

4 EDUCATION FOR ADVANCED MANUFACTURING

Modern industries need specialists with skills across a variety of theoretical and practical disciplines. Today, advanced manufacturing incorporates knowledge of many different aspects of engineering to create complex intelligent systems. Modern industries need specialists with skills across a variety of theoretical and practical disciplines. Education institutions and universities have been urged to implement the methodology and elements of Industry 4.0 into the current syllabus to make sure that future graduates will not be taken by surprise with the evolving demands of the industry. CPS are only one of important several current drivers of change in engineering education.

Industry needs new engineers with a knowledge balanced between theory and practice, an attitude of professionalism, experience in multidisciplinary teamwork, and outstanding communication skills (Huba, 2017).

Multidisciplinary form of education requires changing the traditional way of teaching, launching new and modifying conventional courses to adapt them to the requirements of industry. In the forthcoming years, it is inevitable to change teaching technology at universities. Already at the very beginning of the study it is necessary to change the forms and methods of teaching, and the contents especially of basic courses such as Physics, Mathematics, Materials, Electronic, and Electrical Engineering, but also Informatics and Communication Technologies, Virtual and Mixed Reality.

These core subjects must be taught in such a way that theoretical knowledge can be demonstrated using directly connected teaching modules (stands) with built-in real components, sensors and embedded computing systems with direct visualization and evaluation of studied phenomena and relations (Kozák, 2015). An important factor of education is teaching students to design and develop new complex systems in environments that are user-friendly, interactive and allow to develop software and hardware modules in parallel. According to the development of new information and communication systems and practical requirements we must not forget the new design trends in manufacturing connected with virtualization and platformization of whole systems, components and modules (the V-form design).

Teaching multidisciplinary knowledge in the bachelor and master studies requires modernization of the research and computing laboratories. These have to be equipped with complex modules, with real components included in the process. This trend is evident in teaching processes in automotive industry using HW and SW modules for modelling, testing and creation of optimal production lines, cognitive robots, communication systems and virtual reality models to demonstrate functionality of individual processes but also to evaluate reconfiguration of processes and impact of smart features and embedded control systems on the design of production processes.

When establishing multidisciplinary education, new forms of teaching are to be launched also at technical universities and directly implemented in cooperation with big, mainly industrial enterprises but also in chemical and biotechnological processes etc. Experience in effective implementation of these new education forms has shown a clear economic benefit in Europe and world-wide. Important factors that support multidisciplinary learning are the new information and communication technologies based on Internet of Things and Big Data, Machine and Deep learning and Cloud computations. Along with applications in collaborative robotics and smart systems for sensing and intelligent automatic control it is necessary to introduce a new system of intelligent communication, solution to complex control tasks, and virtual modelling and platformization in all areas of production.

Thus, implementation of the IoT, Big Data, Virtual and mixed reality, and Cloud computation methodologies in education is an essential part of multidisciplinary learning forms, especially in higher grades of engineering studies. Other important courses in the multidisciplinary education form are soft computing methods that allow to model and control complex non-linear processes. Their implementation into real processes is evident mainly in automotive, aerospace and power industries.

Universities emphasize their role in shaping future technology by being the testbeds for innovation and educating future generations (Sackey. 2017). Traditional education has contributed greatly to the current levels of industrial evolution and technological advancement. However, in order for higher education to deliver future generations with the right set of skills and knowledge, an imperative question has to be asked regarding how higher education institutes would be affected by the Fourth Industrial revolution.

In future, the following main areas for CPS systems teaching are necessary to be incorporated in existing curricula (Sackey, 2017):

- data science and advanced (Big Data) analytics,
- virtual, augmented and mixed reality,
- advanced simulation and virtual plant modelling,
- data communication and networks and system automation,
- novel human-machine interfaces,
- digital-to-physical transfer technologies, such as 3-D printing,
- closed-loop integrated product and process quality control/management systems,
- real-time inventory and logistics optimization systems,
- advanced soft computing methods for modelling, prediction and control in real-time with effective parallel and Cloud computing.

CPS are only one of several important current drivers of change in engineering education.

Modern interdisciplinary education forms for Industry 4.0 (bachelor and master study) is today introduced in many education institutions. Professional (dual) education bachelor and master is a new form of study for effective integration of HW a SW devices and methods (control, optimization, computers, ICT, AI) for practical experience providing ideal start to improve professional career of students at many universities. The most important benefits it brings to both students and industrial partners are practical training in industry companies, opportunity to acquire practical to skills on modern industrial plants and production equipment, as well as to feel how it is to be employed or learn what are requirements and culture of companies.

The proposed study courses (the core) tightly corresponding with future education in ICT for

Industry 4.0 are as the following:
Architecture of CPS systems, Embedded computers, Sensors and actuators, Control engineering methods, Additive and alternative technologies, Automation of manufacturing and assembly processes, Computer networks and communications, Communications and networking, Modelling and simulation of complex production systems, Multi-criterial decisions, Pattern recognitions, Decentralized control, Simulation of production processes, Production systems design, Production lines design, Digital twins, Security in industry, Distributed control systems and architectures, Artificial intelligence, Software engineering for Industry 4.0 (Product Life Management, PLM), Designing IoT and IIoT, Project management techniques, Knowledge and Data, Big Data, Cloud computing, Optimization of manufacturing systems, Industrial cognitive robots and manipulators, Computer vision, virtual and mixed reality, Autonomous devices and systems.

5 CONCLUSIONS

Today, developed countries are flexibly responding to the worldwide challenge for development of industrial productions. In many European countries, large companies develop their own methods, means and strategies to respond to these challenges. The current state in the modern digitized production and business processes forces mainly small and medium-sized companies to adapt to these challenges and build modern digitized factories co-operating with large companies, especially in engineering and automotive industries. In many countries, the Smart Industry concept is a national initiative based on latest research realized at universities and in firms to transform and strengthen the industries using the Industry 4.0 methodology. In the next years based on analysis of the present development in CPS it is necessary to eliminate the gap between theory and practice and prepare new professionals and university graduates with multi-disciplinary skills and knowledge.

ACKNOWLEDGEMENTS

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