

SMART FACTORY IN INDUSTRY 4.0

Zuzana Képešiová, Štefan Kozák

Abstract:

Through the last few decades a humanity was encountering many challenges and succeed in fast technological development. As a trend continues, we are facing more and more new problems to overcome. A core of technology advancement lies within a field of manufacturing where several key aspects are combined in one: information and communication technologies, automation, mechatronics and robotics. All these pieces of puzzle are developing through time and offering us new methodologies such as Cyber-physical systems, Internet of Things and Industrial Internet of Things, Digital twin, Big Data, Cloud computing, Digital Factory and last but not least Artificial intelligence know as AI. These concepts are interconnecting in an emerging paradigm known as Industry 4.0. The paper presents the state-of-art in research and development of new information a communications technology, control techniques with use of AI, control structures and their applications in industrial processes with the emphasis on new trends stated in Industry 4.0.

Keywords:

Industry 4.0, smart factory, cyber-physical systems, IIoT, digital twin, artificial intelligence, big data, cloud computing.

ACM Computing Classification System:

Information systems, Information systems applications, Process control systems.

► Introduction

Technology has become an essential part of human society. Its purpose is to increase comfort and make our daily lives more efficient. We are already largely influenced by them. In modern society, it is almost impossible to find a member without a connection to technology. Over time, technology has steadily improved and is progressing. As humanity, we have gone through several industrial revolutions, and Industry 4.0, which is being formed in current time, is the next step in the development of manufacturing.

The fourth industrial revolution brings automation of production processes to a new level by introducing customized and flexible production technologies. This means that machines will work independently or collaborate with people to create a customer-oriented production environment that constantly works on its own maintenance. Rather, the machine becomes an independent entity that can collect, analyse and evaluate data. To ensure such vision to come true, a progressive manufacturing must focus on significant challenges as sustainability, flexibility and performance of production. A promise of achievement of vision of so-called Digital factory or Smart factory is a driving force and main movement towards future of manufacturing. A large-scale change in current industrial manufacturing are inevitable and include many fields as automation, cognitive robots, digitalization, intelligent control methods and information and communication technologies. These changes open opportunities to implement different way of thinking to prototype, control process, maintain and service the Digital factory and its units.

New methods as Cyber-physical systems, Internet of Things (for Smart Factories it is Industrial Internet of Things), Digital Twin, Big Data and Cloud computing all refer to the upcoming already emerging methodology Industry 4.0.

Main aspects and characteristics of Industry 4.0 as a newest movement towards modern manufacturing is described by following key points (Kozák, Ružický, Kozáková, Štefanovič, & Kozák, 2019):

- a) Interoperability – Objects, machines and people must be able to communicate through the Internet of Things, Industrial Internet of Things and Internet of Services.
- b) Virtualization – Creation and visualization of virtual model resembling the real factory and its units based on real data in virtual, mixed or augmented reality.
- c) Decentralization – The ability of Cyber-physical systems to work independently, to autonomously operate on sub processes based on smart decisions.
- d) Real time – Ability of a Smart factory to collect data in real time, store or analyse and make decisions based on new findings is essential. This is not limited to market research but also to internal processes such as machine failure in the production line. Smart objects can identify the error and reassign tasks to other operational machines.
- e) Service Oriented – People and smart devices must be able to connect efficiently via Internet of Things and Internet of Services and exchange the information.
- f) Modularity – The ability of Smart Factory to adapt to new market requirements is important. Adaptation is secured by modular implementation, where hardware or software components are interconnected and easily switched.



Fig.1. Key aspects of Industry 4.0.

Individual components should be the basis for the Industry 4.0 technology model that can be applied to any production process.

The paper consists of four areas covering Cyber-physical systems, Industrial Internet of Things and Digital Twin in first chapter. Second chapter focuses on Artificial intelligence, Big Data, Cloud computing and benefits of their integration into industrial processes. Third chapter of the paper is dedicated to research and current state of implementation of Artificial intelligence in Smart factories and manufacturing processes and describes the possible directions of technology development that Artificial intelligence will affect.

1 Cyber-Physical Systems

Cyber-physical systems are the core of Industry 4.0 methodology, which interconnect other units as complex automation, cybernetic theories, mechanical engineering, design and process control, Internet of Things, Big Data, Cloud and Artificial intelligence. Thanks to Cyber-physical systems it is possible to achieve connection between human elements, machines, actuators, sensors, digital elements, embedded computers and other computational engines. Embedded computers are the main aspect of cyber-physical systems hence to their capability of highly coordinated and combined relationship between physical objects and their computational elements. (Kozák, Ružický, Kozáková, Štefanovič, & Kozák, 2019)

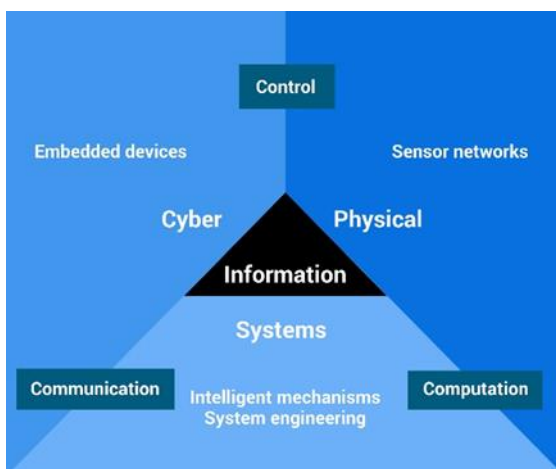


Fig.2. Principle components of cyber-physical systems.

Cyber-physical systems are considered and assumed as a system covering set of interacting physical and digital components, which may be centralised or distributed. It provides a combination of sensing, control, computation and networking functions which interwind physical objects and software to exchange information through embedded systems. A cyber-physical production system relies on the latest and further developments of computer science, information and communication technologies and manufacturing principles. A Cyber-physical system uses networked interactions which relies on physical input and output with a combination with its cyber representation consisting of control algorithms and computational functions. To achieve data about inputs and outputs a sensor plays a significant role in Cyber-physical systems.

These systems are assumed as automated to the high extent, they are smart and collaborative ending up in optimal global behaviour in the best-case scenario. A difference of CPS and ICT lies in the ability of CPS interact and control processes with the physical world in real-time. Even thou also CPS and ICT systems process data, CPS are focused on the physical processes. Cyber-physical systems are integrating cyber space and virtual systems with real world devices, which is providing a compression of development processes by using of existing methodologies, models, techniques, tools and methods to speed up the process of custom design based on previous creations using abstract layers of design. Enough analysis in case of CPS appears as one of the most important aspects to integrate various devices, designing and modelling methods that address different aspects of the development of such systems.

A CPS structure consists of five base levels: connection, conversion, cyber, cognition, and configuration. All these five levels are based on three base methodologies of Industry 4.0 – IIoT for connection of sensors and actuators into bigger images, Digital Twin for visualizing the cyber twin in the virtual space, Big Data to handle all the information, Cloud computing for increasing the computational power and Artificial intelligence for own smart choices of maintenance and maintenance predictions.

1.1 Industrial Internet of Things

During current time, many industries across globe are moving forward to Smart factory system applying latest technologies in manufacturing field, a parts of Industry 4.0 methodology. One of these sub methodologies is also Internet of Things also known under a shortcut IoT. IIoT itself is considered as an interrelated network or group of infrastructures containing interconnected objects such as sensors and actuators. These objects are parts of more complex systems as device or machine that could but also usually is not considered as a computer. These systems are considered to be “smart objects” or “smart systems” hence to their ability to generate, exchange and consume incoming data with other devices in a network for further processing such as data collection, analysis and management capabilities (Boyes, Hallaq, Cunningham, & Watson, 2018). They operate on their own without a need of human operator to intervene with such smart object. Smart objects are represented as a node in the network of smart objects, in Internet of Things, and are continuously log information about them and transmitting them to their surroundings ending up in machine-to-machine (M2M) communication.

Industrial Internet of Things is an application of IoT technology into industrial process where there are certain kinds of smart objects within cyber-physical systems used. These kinds of smart objects are set into industrial environment and are promoted for the goals of the individual industry to serve a purpose to enable real-time, autonomous and smart functioning and handling the data for optimization of whole production process including product changes and improvements, reducing the cost of production in areas such as labour costs, energy consumption, material volume and the process of manufacturing. This optimization leads into better and more accurate operation with data by machines than humans what leads into far greater speed and higher efficiency than ever before.

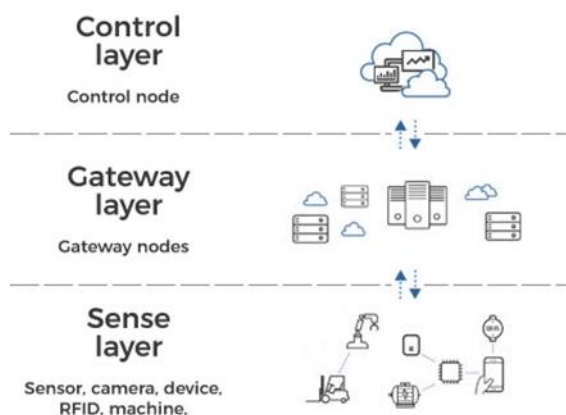


Fig.3. Three-layer architecture of IIoT.

Industrial Internet of Things is divided by (Wang K. , Wang, Sun, Guo, & Wu, 2016) into three main layers: sense layer, gateway layer and control layer.

- a) Sense layer – Sensing nodes at sense layer are considered as sensors, actuators, devices or machines and are responsible for data collection about their own state and their surroundings and for data exchange with gateway layer.
- b) Gateway layer – Gateway nodes are in charge for managing the data flow between Sense layer and Control layer hence their relatively high processing capabilities to run complicated routing protocol.
- c) Control layer – Control nodes have job to process data from lower layers, analyse them and decide the further machine operations, which are transmitted through gateway nodes back to sense nodes, that are a part of bigger complex structure such as a machine or device capable of not only collecting the data, but also to change its behaviour.

1.2 Digital Twin

To move a Smart Factory to the higher level, a digitalization of a factory and its internal and external processes with use of virtual space is making a Smart Factory also a Digital Factory capable of visualizing processes remotely and its supporting a better understanding of production procedures and more effectively conceptualize and change the factory and its units behaviour. To ensure such technology, a Digital Twin is utilized.

A digital twin in its original form is described as a digital construction of information about a physical system created as an entity as such and associated with a given physical system. Digital representation should optimally include all system related information that could potentially be obtained by control of a physical device.

The main feature of digital twin is the ability to provide various information in a consistent format. Digital twins are more than just pure data, they contain algorithms that describe their true counterpart and decide on steps in the production system based on these processed data.

Based on the definitions of Digital Twins in any context, it would be possible to identify a common understanding of Digital Twins as digital equivalents of physical objects. Within these definitions, the Digital Model, Digital Shadow and Digital Twin are often synonymous. However, these definitions differ with the level of data integration between physical and digital associates and they could be divided into three categories based on the integration level (Kritzinger, Karner, Traar, Henjes, & Sihm, 2018):

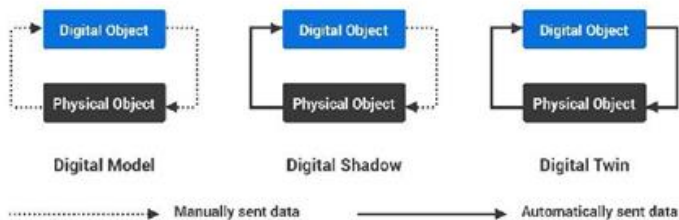


Fig.4. Digital Twin by the level of integration.

Digital Model is a digital representation of an existing or proposed physical object that does not use any form of automatic data exchange between a physical object and a digital object. A virtual interpretation may contain a complex description of a physical object. Digital data of existing physical systems can still be used to develop such models, but all data exchange is done manually and there is no automatic data exchange supported.

Digital Shadow is defined as the Digital Model capable of one-way automatic data flow between a physical object and a digital object. The automatic flow of information goes from a physical object to a digital object. This means that each physical object change is automatically projected into its digital model.

Digital Twin is a digital object that automatically displays not only physical model changes, but also changes the digital model automatically to physical level, making the digital object not only a mirror of the physical object but also its control unit.

With the growing deployment of the Internet, the concept of the digital version of every physical thing has gained its importance in industrial area as well.

2 Artificial Intelligence in Industry 4.0

A system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation is called artificial intelligence. Artificial intelligence is a set of algorithms and learning techniques to try to mimic human behaviour. Such as image recognition, data interpretation or prediction of development of certain events like assumed time of needed maintenance of a machine, control and regulation of a machine run and behaviour.

Machine learning is one of proposed soft computing methods used for learning the machine to perform efficiently and up to date. Artificial intelligence could be applied on basically every aspect of life, whenever it comes to healthcare, finances, entertainment industry or manufacturing, technology development, automotive or industry. To achieve such accomplishments, a machine must be thought how to process the data. There are three main types of machine learning distinguished: supervised, unsupervised and reinforcement. In case of supervised learning a machine is thought to categorize provided data based on the labels, to predict a development of the tracked event, optimize the process or detect objects or anomalies. For unsupervised learning a machine is thought to group and cluster provided data by their character and content and the last type, reinforcement learning, is used for real-time decisions, navigation or skill acquisition (Sun, Liu, & Yue, 2019).

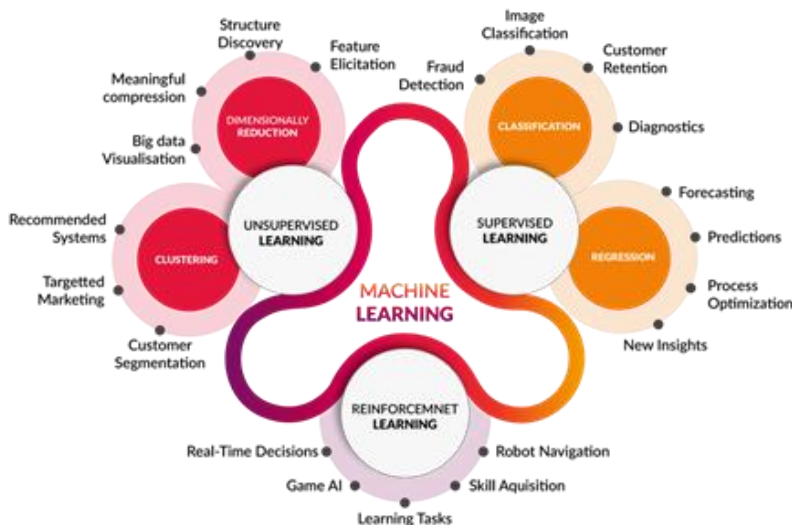


Fig.5. Machine learning approaches.

A basic approach how to achieve a machine to learn is to use neural network (NN). An artificial NN (ANN) is an interconnected group of nodes, inspired by a simplification of neurons in a brain. There are several architectures and techniques to apply ANN such as Convolutional neural networks for subtracting features from smallest to greatest, Recurrent neural networks for repeated events and especially Deep learning referring to multilayer neural network. All these techniques and many other assure to create a complex NNs to solve difficult problems to overcome many complex challenges.

Despite of Artificial intelligence being proposed several decades ago, its popularity raised up drastically only in past few years. Due to a significant improvement in computational power and networking field a computational task that took several months before, now takes only several hours. To develop a functional and fast algorithm addressing hardly achievable solutions for certain problematics having enough data and computational power is inevitable. Ensuring enormous amount of data and secure their processing capabilities new players come into game of Industry 4.0 – Big Data and Cloud.

2.1 Big Data

A term Big data does not refer to the volume of data, but to the analytics of data. Since the IoT became a popular trend in the not only everyday life of a person, but also a part of industrial part, a great amount of data started to be generated by all kinds of sensors and devices. A great number of datasets and their volume became no longer processable by conventional analytic software and new approaches had to be established. Analytics of data are more focused on revealing hidden patterns, relationships between data and other valuable business information. A deeper analysis of various data from devices, machines and processes can discover a critical parameters with the greatest impact on quality of the manufactured product as well as the speed the production process and amount of required components or materials (Zhong, Xu, Klotz, & Newman, 2017).

2.2 Cloud computing

A Cloud computing is considered to be a network of resources available on demand in a required size what evokes a higher interest of business owners due to the scalability of provided resources and their price. Cloud computing services are offering manipulation, configuration and access to hardware and software resources online. Access to the scalable resources based on cloud computing is served and released with ease and with minimum interaction required with the service provider. A cloud model consists of five essential characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity and measured service (Zhong, Xu, Klotz, & Newman, 2017).

- a) On-demand self-service – A consumer can adjust a computational resource by himself automatically without interaction with the provider.
- b) Broad network access – An Access to the service is provided from standard devices such as smartphones, laptops, PCs etc.
- c) Resource pooling – Computational resources of provider are clustering to serve more consumers with dynamic allocation of physical and virtual resources.
- d) Rapid elasticity –The available possibilities are secured and released automatically, and they are changing on-demand. These possibilities may seem without limitations.
- e) Measured service – Cloud services are automatically controlling and optimizing the resource providing based on traffic.

With the application of appropriate middleware, a Cloud computing service can handle the same tasks as any other computer in shorter time.

3 Smart Manufacturing in Industry 4.0

A technological evolution allowed industrialism to move forward by taking huge steps one at the time and resulted in current era of Industry 4.0. A core idea of Industry 4.0 is to apply autonomous methods to every possible aspect of manufacturing process and create a heterogenic environment capable of interconnection on homogenic plane, creating a Smart Factory. Independent behaviour and M2M interaction can assure more efficient, faster, cheaper and more scalable manufacturing processes. For converting a factory to Smart factory, a spirit of autonomous decision making must be blown into it, an Artificial intelligence. To fulfil the vision of a Smart factory there are several areas one can dive into. From smart design, smart machining, smart monitoring, smart control, smart scheduling to application in industrial applications. From the bottom to the top. When we address smart designing we talk about shifting design to the virtual plane with a use of virtual reality and augmented reality to serve a purpose of better understandings of physical objects and processes by not only modelling them, but also testing them, accessing them, evaluating them and controlling them virtually or remotely in later stages. Smart machining refers to real-time sensing and interacting capability of robots and objects to ensure synchronization of real devices with their digital twins to provide insight of the current situation and pass it to smart controllers to make decisions. Smart monitoring talks about not only about connecting all smart robots, devices and sensors but also about the widely spread implementation to capture the current state efficiently and from many different aspects to conclude in complex understanding of the situation. Smart control is achievable by applying cyber-physical systems into production to secure adaptive production control in real-time. Smart control is mainly executed to manage physical devices via cloud-enabled services accessible from multiple platforms such as PCs, laptops, smartphones or tablets. Having an autonomously running factory is a feature managed by smart scheduling. Smart scheduling enhances data-driven techniques to evaluate and plan the future actions of physical machines based on the provided data with the minimum cost required (Zheng, et al., 2017).

Many different aspects of Smart Factories and Industry 4.0 components were already successfully applied whenever in theoretical plane or in real life application as shown in Table 1. Movement towards Industry 4.0 trend is visible in countries from Europe, Asia and America, from small industrial countries to the biggest ones. Industry 4.0 is inevitable, and a society is adapting the new paradigm and approach to improve manufacturing processes. Industry 4.0 methodologies are available to apply not only to the manufacturing processes but also on other aspects of life in society such as healthcare, business, entertainment or government. This flexibility in field of use also provides insight into elasticity of algorithms to wide range use inside of these processes and securing even wider range of use and possible interconnection.

Table 1. Application of Smart Factory and its subcomponents by methodology Industry 4.0 .

Application	Objective	Improvement
Cross-Domain Internet of Things Application Development: M3 Framework and Evaluation, Ireland and France (Gyrard, Datta, Bonnet, & Boudaoud, 2015)	- Machine-to-machine measurement framework	- Cross-domain connection - Improved performance
Energy management based on Internet of Things: practices and framework for adoption in production management, Italy and Spain (Shrouf & Miragliotta, 2015)	- Proposes IoT-based energy management in production - Provides a framework to support the integration of energy data gathered in real-time into production management	- Integrated energy data management - Improved energy efficiency - Enhanced energy data analysis

Real-time information capturing and integration framework of the internet of manufacturing things, China (Zhang, et al., 2014)	<ul style="list-style-type: none"> - Provides a new paradigm of IoT to manufacturing - Designs a real-time manufacturing information integration service 	<ul style="list-style-type: none"> - Real-time information capture - Improved logistics
Implementing a real-time cyber-physical system test bed in RTDS and OPNET, USA and Canada (Chen, Butler-Purry, Goulart, & Kundur, 2014)	<ul style="list-style-type: none"> - CPS test bed implemented in RTDS and OPNET 	<ul style="list-style-type: none"> - Providing a realistic cyber-physical testing environment in real time
Enabling cyber–physical systems with machine–to–machine technologies, China (Wan, et al., 2013)	<ul style="list-style-type: none"> - CPS safety and efficiency 	<ul style="list-style-type: none"> - Improvement M2M to CPS
A collaborative and integrated platform to support distributed manufacturing system using a service-oriented approach based on cloud computing paradigm, Iran (Valilai & Houshmand, 2013)	<ul style="list-style-type: none"> - Distributed manufacturing collaboration and data integrity - XMLAYMOD platform for distributed manufacturing agents based on cloud computing 	<ul style="list-style-type: none"> - Upgrading the XMLAYMOD procedures and structures
Cloud Computing for Power System Simulations at ISO New England—Experiences and Challenges, USA (Ma , Luo , & Litvinov, 2016)	<ul style="list-style-type: none"> - Cloud computing-based power system simulation 	<ul style="list-style-type: none"> - Higher computational power without cost of cyber security nor data privacy
Intelligent predictive maintenance control using augmented reality, Slovakia (Kostoláni, Murín , & Kozák, 2019)	<ul style="list-style-type: none"> - Development and deployment of maintenance system with HoloLens 	<ul style="list-style-type: none"> - Increased quality of maintenance processes and failure prediction - Reduction of unexpected production stops
A manufacturing big data solution for active preventive maintenance, China, Saudi Arabia and Sweden (Wan, et al., 2017)	<ul style="list-style-type: none"> - Propose of collection of manufacturing Big Data for prevention maintenance 	<ul style="list-style-type: none"> - Real-time and offline prediction and analysis
Wireless Big Data Computing in Smart Grid, China, Russia and Norway (Wang K. , et al., 2017)	<ul style="list-style-type: none"> - Propose of wireless Big Data computing architecture 	<ul style="list-style-type: none"> - Optimization for daily energy scheduling
Towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies, Mexico, Sweden, USA and Germany (Romero, et al., 2016)	<ul style="list-style-type: none"> - Presentation of concept so-called Operator 4.0 for work oriented on collaboration with robots and work aid by machines 	<ul style="list-style-type: none"> - advanced human-machine interaction technologies - automation towards achieving human-automation symbiosis work systems
Development of a Smart Cyber-Physical Manufacturing System in the Industry 4.0 Context, Vietnam and Korea (Tran, Park, Nguyen, & Hoang, 2019)	<ul style="list-style-type: none"> - Propose of Model of Smart manufacturing - Implementation of a Model in testbed and on real machine 	<ul style="list-style-type: none"> - Improvement of intelligent and autonomous behaviour of components in flexible manufacturing system

Conclusion

There is visible and catchable movement towards use of modern methods such as Cyber-physical systems, IoT, Digital twins, Artificial intelligence, Big Data and Cloud computing in manufacturing and the growth of newest industrial era Industry 4.0.

Through the past few decades, computational power and networking of all sorts of devices across the smallest units as sensors and actuators to the large multiprocessor computers and group of such computers that interconnect each other a significant upturn of evolution rate was encountered. As a high demand of computational power and well networking is needed by such technology as artificial intelligence, nowadays it is no problem to successfully deploy this technological method in industrial area with satisfactory results. Artificial intelligence, as it is shown in previous chapter, could not only equal a human being in performance but overpass it in short time to the great extent. Nevertheless, there are still many opportunities and a lot of space for growth in field of artificial intelligence in industrial and manufacturing area and certainly has a great potential to improve the manufacturing process.

▲ Acknowledgement

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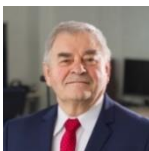
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