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THE CONCEPT OF AUTONOMOUS SYSTEMS IN INDUSTRY 4.0

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Abstract: Recent tendencies – such as the life-cycles of products are shorter while consumers require more complex and more unique final products – poses many challenges to the production. The industrial sector is going through a paradigm shift. The traditional centrally controlled production processes will be replaced by decentralized control, which is built on the self-regulating ability of intelligent machines, products and workpieces that communicate with each other continuously. This new paradigm known as Industry 4.0. This conception is the introduction of digital network-linked intelligent systems, in which machines and products will communicate to one another in order to establish smart factories in which self-regulating production will be established. In this article, at first the essence, main goals and basic elements of Industry 4.0 conception is described. After it the autonomous systems are introduced which are based on multi agent systems. These systems include the collaborating robots via artificial intelligence which is an essential element of Industry 4.0.
Keywords: Industry 4.0; Cooperating robots; Artificial intelligence.

1. INTRODUCTION

Industry 4.0 conception means the upcoming 4th industrial revolution. According to the theory of the conception, the 1st industrial revolution was the mechanization characterized by the appearance of the steam engine (Figure 1.). The 2nd industrial revolution was the mass production through assembly lines on the base of the electricity. The 3rd industrial revolution was the automated production by application of industrial robots [1].

The 4th industrial revolution means the age of the application of intelligent manufacturing robots. In this conception the products control their own production, since these products and components communicate with the machines and equipment by unique product codes during their production. Smart factories will be self-regulating and optimize their own operation. Consequently, it means that virtual and actual reality merges together during the production.

In the first part of the article the characteristics, main goals and pillars of Industry 4.0 conception is described. In the second part of the paper the autonomous systems are introduced which are based on multi agent systems. These systems include the collaborating intelligent robots via artificial intelligence which is an essential pillar of Industry 4.0 conception.

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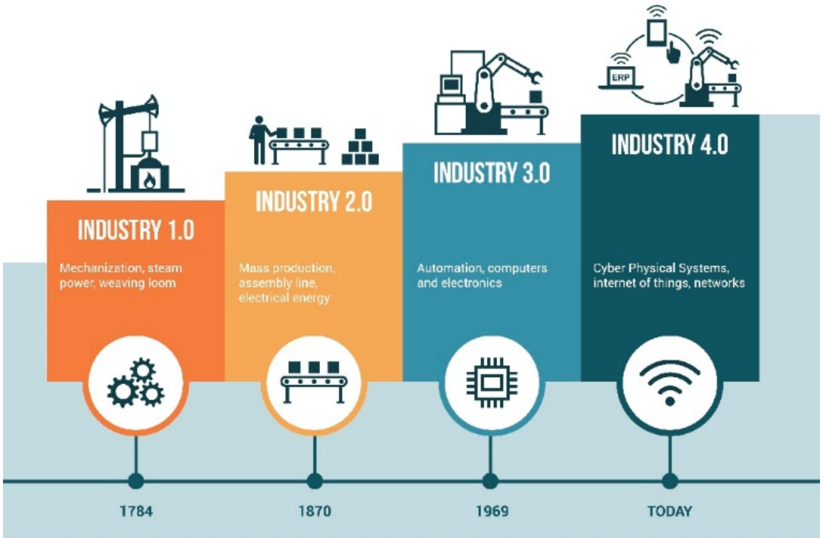

Figure 1. Stages of industrial development [2]

2. CHARACTERISTICS AND GOALS OF INDUSTRY 4.0 CONCEPTION

The essence of Industry 4.0 conception is the introduction of network-linked intelligent systems, which realize self-regulating production: people, machines, tools and products will communicate with each other continuously [3, 4]. Products control their own production; the production scheduling will be controlled by the communicating products.

In smart factories everything is working in interaction between the products and the machines, linked in a network itself connected to the digital supply chain, based on information and communication technologies, sensors, software tools, using the highest performance devices in order to transform industry into an interconnected global system [5].

New technologies appear such as digitization in order to provide continuous communication between machines, systems and products. The aim of the conception is to make factories smarter and to create a digital platform, which brings together the main tools: Sensors, Internet of things, Big data, Cloud computing, Collaborating robots, Artificial intelligence, etc. [6].

Industry 4.0 conception is the origin of strategic project of the German government, that was introduced at the Hanover Fair in 2011 [7], to support the digital revolution of the global industry. Recently this conception is widely used not only in Europe but all over the world.

The 5 main elements of the digital networked production according to the conception can be defined by the following:

1. digital workpieces,
2. intelligent machines,
3. vertical network connection,
4. horizontal network connection,
5. smart workpieces.

The essential goals of Industry 4.0 conception are the following:

- to create smart factories,
- to optimize the production which increase productivity,
- to establish more efficient, more flexible, and more customer-oriented production,
- to improve efficiency by automation of processes,
- to maximize the utilization of human- and machine resources,
- to save costs and reduce wastes and lead times,
- to adapt to the changing market demands more effectively,
- to create new opportunities and business models.

The results of application of the conception:

- physical systems will be digitized,
- customers will be satisfied who demand more complex and unique products in small quantities,
- traditional centrally controlled and monitored production processes will be replaced by decentralized controlling,
- factories will be self-regulating which optimize their own operation,
- productivity will be improved,
- fast solutions can be provided in case of production problems and abnormal operations.

Industry 4.0 represents a globally interconnected world defined by digitization of economic and production processes [8].

The Boston Consulting Group has identified the fundamentals of Industry 4.0 by nine technological pillars [9] (Figure 2.):

1. **Autonomous robots**. Industrial robots are becoming more autonomous and cooperative. The intelligent robots can interact with one another in order to improve productivity and product quality. These machines can achieve more complex tasks and manage unexpected problems [10].
2. **Horizontal and Vertical system integration**. Horizontal integration of system elements aims to optimize the operation of the whole supply chain by connecting all members of the value chain (e.g. suppliers, manufacturers, service providers, customers). Vertical integration aims to optimize the reconfiguration of production processes by connecting Cyber Physical Systems (sensors, actuators, etc.).
3. **Industrial Internet of Things (IoT).** Industrial IoT allows devices to communicate and interact with one another. It is a network connection and data exchange of objects, e.g. products, machines, equipment, vehicles or other incorporated devices, so the devices can be used more efficiently and economically. System collects and shares huge amounts of data inside the digital supply chain network that ensures the exchange of information between the system elements.
4. **Simulation**. Simulation of processes is essential during product design, production planning and in case of material flow processes, or in modeling of unexpected stochastic events. In the future simulation will be used more often in plant operations as well. Simulation is a tool for providing real-time data to observe the physical world in a virtual surrounding, which can include machines, tools, products and humans. It is an effective tool to optimize the production and maximize the utilization of resources.

5. **Additive manufacturing**. Additive Manufacturing is a terminology to describe the technologies that build 3D objects by adding layer upon layer of a given material (3D printing). This technology offers the possibility of manufacturing of more complex components which is unachievable by other techniques. The technology provides higher flexibility and efficiency of manufacturing of smaller batches and more customized final products.
6. **Cloud computing**. The cloud offers an unlimited computing power to receive, store and analyze Big Data needed for the optimal operation of systems. The stored information and services can be available at any given place and device via internet [12]. It allows all system elements to synchronize their activities and work on shared data and services simultaneously in real time.
7. **Augmented reality**. Augmented reality provides the possibility of visualization by transforming the real environment to a virtual environment [13]. The information relating to the surrounding real world of the user becomes interactive and digitally manipulable by the application of augmented reality technology.
8. **Big data**. Intelligent network-like systems require huge, almost unmanageable amount of information. This data set is called big data. According to the IoT principles, the collection and evaluation of this data set coming from many different sources will become essential for real-time decision-making. The analysis of this huge amount of information will optimize the operation of manufacturing systems.
9. **Cybersecurity**. The huge amount of data shared on network should be protected. Cybersecurity includes technologies and processes which are designed to protect systems, networks and data from cyber-attacks.

Figure 2. Pillars of Industry 4.0 [11]

3. ARTIFICIAL INTELLIGENCE BASED ROBOT COLLABORATION

This age is the age of emerging intelligence, in every aspect of life. The questions of human-robot and robot-robot cooperation become actual for today [14]. While this new industrial age also has effects on social-level, industrial applications are in the forefront of our article and require deeper analysis. Our research is carried out in accordance with the Industry 4.0 concept, in which unmanned production and the development of smart factories with intensive and wide use of artificial intelligence in many aspects are aimed at automating of production forces on an unprecedented level. In the technical realization the two central AI-related disciplines are Multi-Agent Systems and Distributed AI. In addition to these essential information technologies the biologically inspired new ideas and methods are also need mentioning.

Typically, in this regard an autonomous system is based on a multi-agent system which is endowed by artificial intelligence, this concept aims to create intelligent machines collaborating together to build a flexible environment [14] as shown in Figure 3 which represents collaborating and cooperating manipulator arms in industry. These industrial innovations are in the focus of today researches, some achievements and human-related safety requirements are documented in the ISO 10218-1 Robot, ISO 10218-2 Robot system/cell and in the ISO/TS 15066 Collaborative Robots standards [15].

Figure 3. Collaborating robots

3.1. Multi agent systems (MAS)

The agents can detect the signals of the environment and react to them. So people, machines, computers, etc. can be agents and can cooperate and interact each other. In the industry, these agents represent machines, controllers, robots which use a common language to provide cohabitation and collective work. To design a multi-agent system, we must know the model of each agent that will come into action and define their environment and their interactions and the essential objectives to achieve [16]. A borderline can be set up between reactive and cognitive agents: in opposition to the simple reflexive reactive agents the cognitive agents are can form plans to achieve their goals. Based on [17], two types of communication among these agents can be defined:

1. **Implicit communication**. In this method the agent that uses various sensors receives information about other agents acting in the same system through the appropriate environment. This type of communication can be divided into passive or active implicit types. The passive means that the agents communicate via their environment, while the active use sensing to get the information.
2. **Explicit communication**. In this case there is direct communication among agents for information sending and receiving, which can be done in the form of unicast or intentional broadcast messages usually through a dedicated communication module. This explicit communication helps to realize diverse coordination methods among agents.

Ought to this explicit communication the agents can realize different advantageous strategies. Meanwhile they alternate the active and passive roles and communicate with messages according to the common strategies introduced by the following definitions [18, 19]:

- **Coordination strategy** of the agent means that they make a plan for longer period that determines the arrangement and order of the tasks to be executed together. The goal of the coordination is to unite the resources and forces to achieve the common goal effectively. Agents use coordination protocols to define the requirements and actions that are needed to fulfill the common goal.
- **Cooperation strategy** of the agents aims of solving such larger or complex tasks that are too large for an individual agent. The strategy consists of the optimal decomposition of the larger task into subtasks and has to take into the capabilities and possibilities of the cooperating agents.
- **Negotiation strategy** of agents is necessary when the agents have different goals but they would like to achieve a mutually advantageous solution. The two components of this strategy are:
    - **Negotiation language** helps to perform the communication and to transfer the information analyzing the semantic of the content moreover defines the role of communication primitives in the used protocols,
    - **Process of negotiation** determines the behavior of the agents during negotiation.

3.2. Artificial Intelligence (AI)

This discipline is a prospect to the future. Includes many human intelligence inspired techniques that can substitute human beings in their mental and cognitive activity [20]. Methods of AI used by the autonomous systems to solve high level tasks and unforeseen situations. These methods implemented in machines, IoT components and in manipulator-like and humanoid robots. The AI phenomenon can't be separate from learning and from adaptation of the agents to their environment [21]. The AI agent models the necessary part of the world using different knowledge representation methods, like symbolic logic, semantic networks and frames, or artificial neural networks. For the realization of the intelligence different kinds of cognitive methods applied, like learning, concept formalization, reasoning, searching, machine vision and even communication language.

3.2.1. Distributed Artificial Intelligence (DAI)

This work deployment method can be used effectively when the tasks are distributable but every of them needs intelligent solution. The DAI structure includes agent cooperation and communication among intelligent agents [16]. DAI has an overlapping with MAS concept. The relation among software systems based on agent technologies like DAI, MAS and mobile agents (MA) is shown in Figure 4.

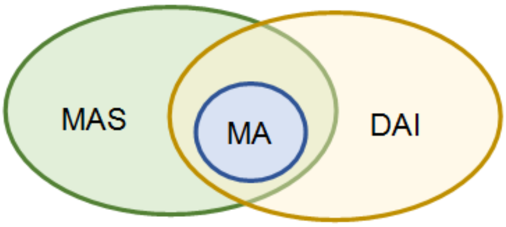

Figure 4. Relation among software systems based on agent technologies

3.2.2. Role of Multi Agent Systems in Industry 4.0.

Using a MRS in Smart factory can have several potential advantages over a single-agent system such as robot [17]:

- A MRS has a better spatial distribution.
- A MRS can achieve better overall system performance. The performance metrics could be the total time required to complete a task or the energy consumption of the robots [22].
- A MRS introduces robustness that can benefit from data fusion and information sharing among the robots, and fault-tolerance that can benefit from information redundancy. For example, multiple robots can localize themselves more efficiently if they exchange information about their position whenever they sense each other [23].
- A MRS can have a lower cost. Using a number of simple robots can be simpler (to program), cheaper (to build) than using a single powerful robot (that is complex and expensive) to accomplish a task.
- A MRS can exhibit better system reliability, flexibility, scalability and versatility. Robots with diverse abilities can be combined together to deal with complex task, and one or several robots may fail without affecting the task completion [24].

3.2.3. Applied AI Methods in Intelligent Robot Behavior

The intelligence coming from different AI methods can be used in standalone robots to help its working, like Swarm intelligence based joint position optimization, or use of feedforward Artificial Neural Network for solving the inverse kinematical problem when the determination of joint functions depending from the necessary path of the robot hand is needed. In the future robots the use of AI will not be limited for solving such motion-oriented tasks but can be imagined in cognitive processes like sensing, learning, problem solving, machine vision and using language for communication [25]. These high level cognitive functions that may evolve to machine problem solving, play important role in robot coordination, cooperation, evaluation and collaboration [18, 26]. The next table systematize the well-known AI methods that can be used in different scenarios of collective behavior of robots (see Table 1.)

Table I.

AI methods and their possible use in robots collaboration

AI method	**Role in collective robots behavior**
Rule and symbolic logic based systems [28]	Knowledge representation, cooperative decision making
Fuzzy Logic [29]	Flexible common answering on environment changes, decision making
Machine vision and sensing [30]	Getting visual information of the objects and location and actions of other robots, help self- and cooperative localization Possibility for detection of malfunctions Serves as information source for – collective – learning
Search methods	Cooperative decision making and optimization
Evolutionary and genetic algorithm [31]	Robot group efficiency and quality improvement
Swarm intelligence [32, 33]: - Ant colony optimization - Particle swarm optimization - Shortest route finding	Creation of complex structures System self-reorganization Collective behavior planning and directing: - Collective optimization - Resources integration - Common goal realization
Artificial Neural Networks [30]	Process control and abnormality detection Learning new features of the environment and new scenarios through clustering Cooperative decision making

3.2.4. The potential advantages of AI to many solutions in practice

Thanks to recent advances in artificial intelligence (AI), we are now at the cusp of a major transformation in business, many leading companies have begun to embrace a new view of business processes as more fluid and adaptive. In essence, they are moving beyond rigid assembly lines toward the idea of organic teams that partner of humans with advanced AI systems. This collaboration between workers and smart machines is leading to the reinvention of many traditional processes. As BMW and Mercedes-Benz have experienced, rigid assembly lines are giving way to flexible teams of employees working closely alongside robots. Moreover, these novel types of teams can continuously adapt on the fly to new data and market conditions [34]. They are enabling companies to actually reimagine various work processes.

Contrast the traditional assembly line with a factory where robots are much smaller and more flexible, able to work alongside humans. This is a factory, where those robots and other types of machinery are using embedded sensors and sophisticated AI algorithms. Unlike earlier generations of industrial robotics which were typically bulky, unintelligent, and somewhat dangerous pieces of machinery these new types of collaborative robots are equipped with the ability to sense their environment, comprehend, act, and learn, thanks to machine-learning software and other related AI technologies. All this then enables the work processes to be self-adapting, with fixed assembly lines giving way to flexible human-machine teams that can be put together on the fly.

Now, in order to fulfil customized orders and handle fluctuations in demand, employees can partner with robots to perform new tasks without having to manually overhaul any processes or manufacturing steps. Those changes are baked into the system and are performed automatically. The advances are not just in manufacturing. AI systems are being integrated across all departments, everything from sales and marketing to customer service and production.

3.2.5. Implementation of AI at Companies

For a century, factory floors have been at the leading edge in robotic automation. From conveyor belts to robotic arms with AI-infused operations systems, the factory is getting smarter every day [27].

- Hitachi is using AI to analyze big data and workers' routines to inform its robots, which deliver instructions to employees to meet real-time fluctuating demand and on-site kaizen objectives. In a pilot, the company observed an 8 percent productivity improvement in logistics tasks.
- At Siemens, armies of spider-styled 3-D printed robots use AI to communicate and collaborate to build things in the company's Princeton lab. Each bot is equipped with vision sensors and laser scanners. In aggregate, they join forces to manufacture on the go.
- At Inertia Switch, robotic intelligence and sensor fusion enable robot-human collaboration. The manufacturing firm uses Universal Robotics' robots, which can learn tasks on the go and can flexibly move between tasks, making them handy helpers to humans on the factory floor.

4. SUMMARY

The content of the paper was divided into two parts. In the first the concept of Industry 4.0 automatization trend was introduced by introducing its main goals and its expectable benefits, then the components that bring together the nine pillars of this industrial revolution were analyzed, which can be defined as a cyberspace that controls everything from demand to product design. This evolution includes intelligent automation and integration of digital technologies like 3D printer, cloud computing, augmented reality, Internet of Things, etc.

Secondly it discussed the autonomous systems that represent a useful factor for successful digital transformation of the manufacturing and create a smart factory, known as multi-agent systems, in the industrial field these agents can be manipulators arms, sensors, controllers endowed by artificial intelligence, this approach is one of the technologies supported by Industry 4.0, it regroups different fields of research such as collaboration between these agents based on the communication among them and their environment and the principle of collective work led by swarm intelligence. The role of AI in the environment of collaborating robots was described in a table covering all the important main AI fields.

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