Collaborating robots in Industry 4.0 conception

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Abstract. Nowadays the industrial model is developing and improves the capabilities of its platform through the emergence of new technologies that transform the industry to an interconnected global system in which machines and products communicate together continuously. This global evolution known as Industry 4.0 characterized by a merger between the Internet and factories, it is a concept that aims to make factories smarter and to create a digital platform that as a place of production, using modern technologies. In this article, we will discuss two parts: the first part describes this future paradigm, its advantages by identifying the challenges of this implementation and its basic elements, while the second part discusses the new technique which includes the collaborating robots via artificial intelligence which is an essential point in Industry 4.0.

1. Introduction

The industrial evolution has known three revolutions till these days: the first was the mechanization characterized by the appearance of the steam engine, the second was industrialization through production lines on the base of the electricity, and the third one was industrial revolution determined by computer integrated manufacturing [1]. These three revolutions brought the ability to change the conception of existing production. Today this industrial model is developing and improves the capabilities of its platform during the appearance of new technologies such as digitization that transforms the industry to an interconnected global system in which machines, systems and products communicate together [2]. This global evolution known as Industry 4.0 or in other words the industry of the future. In the age of Industry 4.0 the sector of manufacturing enters its fourth revolution, characterized by a merger between the Internet and factories. It is a concept that aims to make factories smarter and to create a digital platform that as a place of production brings together the main tools that are already existing as: Sensors, Big data, Internet of things, Cloud computing, Artificial intelligence, Collaboration between robots, etc. [3].

In this article, we will analyze two parts: the first part describes this future generation, its architecture and its basic elements, while the second part discusses one of the new techniques "autonomous system" which includes the technology of collaboration between robots via artificial intelligence which is an essential point in Industry 4.0 [4].

2. Industry 4.0 conception

Industry 4.0 refers to the Fourth Industrial Revolution which is the origin of a strategic project of the German government, that was highlighted for the first time at the Hanover Fair in 2011 [5], to support the digital revolution of the global industry. It is a concept that focuses on a new way of production, which is used to set up a smart factory, where everything works in interaction. The products and the machines, linked in a network itself connected to the all supply chain [2], based on the information
technologies, communicating sensors, software tools for simulation, information processing, controlling, using the highest performance devices in order to transforming industry into an interconnected global system, by applying many innovations and creating a new dynamic market [4]. Basically, Industry 4.0 includes the partial transfer of autonomy and autonomous decisions to cyber-physical systems and machines, applying information systems, it is a digital transformation that is changing up the manufacturing business by bringing radical changes not only to systems and processes, but also to business models and the workforce and management styles [7] as shown in figure 1 which represents the stages of industry development throughout history.

![Figure 1. Stages of industry development [6].](image)

2.1. Industry 4.0 concept in manufacturing

In the growing market globalization, where the customer demands are changing continuously the manufacturing companies have to improve efficiency, focus on cost reduction and profitability in order to increase their competitiveness. Manufacturing systems have to become more complex and flexible to respond to rapidly changing customer demands and economic environment.

In the production the resources (materials, machines, humans, space and other facilities) are limited. The current practice in the manufacturing is not sustainable and poses many challenges to the production. Therefore, it is very important at the manufacturing companies to produce cost effective and high quality products which can be achieved by maximized utilization of resources and minimized production cost.

The manufacturing is going through a paradigm shift, which will change the production conception. The current centrally controlled manufacturing processes will be replaced by decentralized control. The essence of Industry 4.0 concept in the manufacturing processes is the introduction of network-linked intelligent systems, which is based on the self-regulating ability of machines, equipment, components, workpieces and products that communicate with each other.

The essential goal of Industry 4.0 is to create smart factories and make the related industries such as logistics more efficient, more flexible, and more customer-oriented.

The following goals have to be achieved in the Industry 4.0 concept [7]:

- optimization of production processes which increase productivity,
- maximal utilization of resources,
- efficiency improvement by automation of processes,
- increase of flexibility to respond to rapidly changing customer demands,
- use of environmental-friendly materials and technologies,
- create new opportunities and business models.

Achieving the main goal can result in many benefits in manufacturing processes that are the following:
• higher productivity,
• more customized and unique finished products, higher customer satisfaction,
• higher utilization of resources,
• ensuring and enhancing the quality,
• reducing lead times,
• saving costs and reducing waste,
• realizing sustainable production, etc.

2.2. Pillars of Industry 4.0 concept
The future state of industry 4.0 represents a globally interconnected world defined by the total digitization of economic and production flows. It requires horizontal integration at each stage of the production process, interacting with the machines that communicate all together [8].

The Boston Consulting Group has identified the essential base of Industry 4.0 by nine technological pillars as shown in figure 2:

Figure 2. Pillars of Industry 4.0.

2.2.1. Autonomous systems. An automated system, including sensors, actuators and controller, capable for performing tasks continuously and designed to be applied in industrial field. Autonomous systems are providing an ever-wider range of services and becoming flexible and cooperative. Autonomous systems can be:
Multi agent system is defined as a system composed of several agents that interact together. Usually an agent is a computer system located in a dynamic environment such in robots or in intelligent machines and capable of executing independent or intelligent actions, using tools and techniques of artificial intelligence.
Intelligent industrial robot is a useful combination of a manipulator arm, sensors and intelligent controllers, which replaces a human worker and can complete tasks and resolve the problems. Eventually, it will be able to learn from humans at first. The use of these machines in industrial automation can improve productivity, product quality, creating smart industry.

2.2.2. Industrial Internet of Things (IoT). It means the ability of machines to communicate, control and collaborate with other systems, this system collects and share huge amounts of data inside the network that ensures the exchange of information between the system elements. The collected data is
sent to a central cloud service where it is accumulating with other data and then shared with end users in a useful way.

2.2.3. **3D Simulation tool.** 3D simulation of processes is a way for providing real-time data to observe the physical world in a virtual surrounding that will include machines, products and humans. It is a way to make scenarios for system operation and based on it to optimize the production and maximize the resources (human, equipment, etc.), thereby increasing productivity and reducing wastes and improving quality.

2.2.4. **Cybersecurity.** Seen that IoT has an essential effect on Industry 4.0 while it shares a huge data on network, this information should be protected, for this reason we find the concept of Cyber security comprising technologies, processes and controls that are designed to protect systems, networks and data from cyber-attacks.

2.2.5. **Horizontal and vertical systems integration.** To succeed in creating a smart factory that adapts with the concept of Industry 4.0, it is necessary to implement specific technologies mainly in the digital area which provides the integration of different vertical and horizontal system elements [7] defined as follows:

**Vertical integration of system elements** aims to optimize the reconfiguration of production processes by connecting all Cyber-Physical Systems (sensors, actuators, etc.) with the various production management tools (planning, inventory, etc.) which allows easily reconfiguring the production process according to customer demand.

**Horizontal integration of system elements** aims to optimize the product in supply chain, by connecting all the elements of the production chain (suppliers, customers, service providers, etc.), beyond the scope of the company, it also concerns the organizational problem.

2.2.6. **Cloud computing.** Cloud computing is just a metaphor for the Internet which means storing and accessing data and programs over the Internet instead of our computer's hard drive. The cloud offers industry flexibility and unlimited computing power. To receive, store and analyze Big Data, this information is secured during transfer and storage, it is using high-level encryption in terms of collaboration, the cloud remains the ideal tool to manage Big Data in Industry 4.0. It allows all machines, wherever they are, to synchronize their actions and work on shared documents and applications simultaneously in real time.

2.2.7. **Additive manufacturing.** Additive manufacturing is a terminology widely used in the industrial world, based on the manufacturing of a work piece used in industry known as 3D printing. It makes it possible to go beyond the limits of traditional manufacturing (injection molding, machining, cold forming, assembling, etc.) and offers the possibility of manufacturing of parts of more complex component, unachievable by other techniques, thus widening the potential for innovation. In the concept of Industry 4.0, 3D printing technology will be chosen for its very high quality in producing small batches of customized products.

2.2.8. **Big data and analysis.** According to the IoT principle that we have already defined, all machines and systems connected to the production plant must be capable of collecting, exchanging and backing up massive volumes of information in a completely autonomous way. Without the need of human resources, the analysis of this amount of information will optimize the operations of systems and saving time and capacities of resources, which is needed to real-time decision-making.

2.2.9. **Augmented reality.** Augmented reality provides visualization by transforming the real environment to a virtual model. Virtual reality solutions analyze images or detect motion and correlate everything with information from various sensors, due to this technology the operator can control the entire process and detects the anomaly in case of emergency.
2.3. Challenges of Industry 4.0 concept
Since appearance of digital technology, companies real changes that have significant effects on their competitiveness [8], their investments and the development of employers skills. The challenges of this revolution are the following:

- All Cyber physical systems must be digitalized,
- Satisfying the consumer who demands more complex and unique products in small quantities,
- The traditional centrally controlled and monitored processes must be replaced by decentralized controlling,
- Factories must be self-regulating that should optimize their own operation,
- Ensure security and confidentiality in the development of Internet of Things,
- Realizing a true connection between operation fields inside the company,
- Increase productivity depending on changing customer demands,
- Being able to find solution faster in case of production problems.

3. Collaborating robots via artificial intelligence
The emergence of new technologies has an important effect on improving the concept of Industry 4.0 to create a smart factory, in the next part of this article we will focus on three of the mentioned technologies: autonomous systems, simulation and system integration.

Typically, multi agent systems integrate autonomous systems which are endowed by artificial intelligence, this concept aims to apply intelligent machines collaborating together to build a flexible environment [4] as shown in figure 3 which represents collaborating manipulator arms in industry.

![Figure 3. Collaborating robots in Industry 4.0.](image)

3.1. Multi-agent systems
It is a paradigm that contains multiple agents that interact with each other in a common environment, some of which may be machines, computer programs, etc.

In the industry, these agents represent robots, sensors, controllers which can apply a common language that structures the rules of 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 their essential objectives to achieve [9]. A classic opposition has been drawn between reactive and cognitive agents: the reactive agents are those that have just reflexes while the cognitive agents are those that can form plans for their behaviors. Communication between these agents plays a vital role in this area which can show two forms [10]:

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*Figure 3. Collaborating robots in Industry 4.0.*
3.1.1. Implicit communication. Presents a method whose agent receives information about other agents installed in the same system through the appropriate environment by integrating different types of sensors, this type of communication can be divided into passive implicit which means the agents interact via their environment, or the second one active implicit based on sensing.

3.1.2. Explicit communication. Called the direct communication presented by the exchange of information between robots, which can be done in the form of unicast or intentional broadcast messages. This often requires a dedicated communication module edge. Existing coordination methods are mainly based on the use of explicit communication.

The agents alternate the active and passive roles and exchange sets of messages according to specific protocols defined by the following points [11, 12]:

- **Coordination strategy** is the proper organizing in space and in time for all the tasks needed to solve a specific problem. Coordination protocols help agents to manage their commitments by defining the conditions and the actions to be taken, in the case where the circumstances in which they were developed.
- **Cooperation strategy** is a phenomenon that occurs when a task can not be performed by a single agent but requires a set of them. This concept consists in breaking down the tasks into subtasks and then spread them among the different agents, there are several possible decompositions, the decomposition process must therefore consider available resources and skills of the agents.
- **Negotiation strategy** occurs when agents interact to make common decisions while pursuing different goals, in this concept we can find:
  - **Negotiation language** that presents the way to analyze the primitives of communication, their semantic, and their use in protocols,
  - **Process of negotiation** proposes general models about the behavior of agents in negotiation.

3.2. Artificial Intelligence

In the past several years, AI techniques have become more and more robust and complex. AI is a branch of science and engineering which deals with building intelligent machines and helping them to find solutions to complex problems in a more human like fashion, this generally involves borrowing characteristics from human intelligence [11, 13], and applying them as algorithms to computing the behaviors of each machine. This concept has two classic limitations:

- **The anchoring of A.I.L.:** Artificial Intelligence Located, the relation of each agent to his environment, to realize by adaptation, learning.
- **Distribution of problems D.A.I.:** Distributed Artificial Intelligence realized by cooperation between agents [9].

Artificial Intelligence has conveyed to the multi-agent systems the concept of the use of logical formalisms in the manner of Knowledge-Based Systems. Following this approach, an agent has a knowledge base representation of his current state and an inference mechanism modeling his reasoning. Among these possibilities we intend to deal with three tasks.

3.2.1. Application example of AI in the tasks of cooperation between several manipulator robots. The essential goal of our research is creating a virtual simulation model of an assembly line that includes a few robot manipulators equipped with sensors, cameras and intelligent controllers. These robots as members of a multi-agent system can help each other and cooperate to finalize the tasks defined in this line, if some malfunction or another problem occurs in the production line, the robots can reconfigure themselves and reorganize the steps of the same task. One sketch of a similar system is shown in figure 4, our process is presented in two scenarios:

**I. First scenario:** Presents the normal process or the static mode including tasks, processes that take place as were planned. In this scenario the planning methods of AI are used for creating the optimal scheduling for the tasks taking into the parallel work of the robots. These AI methods mainly mean search algorithms and first order logic.
II. Second scenario: Presents the disturbed process including some problems, random happenings, errors, etc. when intelligent reordering, rescheduling of the steps needed. In this scenario the AI is intended for finding quasi-optimal strategies for continuing the work after the random happening. In this case the mentioned AI methods are completed with probability algorithms.

![Cooperating manipulator arms in an assembly line](image1)

Figure 4. Cooperating manipulator arms in an assembly line

As we can create larger systems virtually only, using simulation, smaller tasks were created to demonstrate the robot cooperation in reality. These will be introduced in the followings. In the real tasks we intend to use our two Mitsubishi robots shown in figure 5.

![Cooperating of two manipulator arms in our laboratory](image2)

Figure 5. Cooperating of two manipulator arms in our laboratory

3.2.2. First application example for demonstrating robot cooperation. The task is the following: providing some building elements ("cards"), the two robots have to build up a house of cards. This task needs the cooperation trivially if there is no some sort of supporting element, because to build an A shape from the two cards needs two hands, in our task it needs two robots. The drawing of one "card" building element is given in figure 6(a). The structure of the house of cards to be built is shown in figure 6(c). If one of the robots fails then the other has to use the supporting element that is depicted in figure 6(b). Using this for supporting a card and removing this supporting element later needs extra time opposite to cooperating robots, so the demonstration can prove the advance of robot cooperation.

3.2.3. Second application example for demonstrating robot cooperation. In this task we would like to apply robot cooperation and AI methods. The task is to solve a 3D packaging job in the case of two co-operating robots, that is to put the bricks in a 3D work space (on one another) into a larger rectangular space. Concrete example could be to fill a large, over-open container box with different sized boxes having top-holders, for example, suction pads. To make easier the task for the first the boxes have the same height, so layers of boxes can be formed in the container.
Target function: the spatial location of the common center of gravity of the put in boxes should be at a minimum height. Unfortunately, this value can be determined after creating a ready filling. Due to it the problem is NP-hard, combinatorially exploding task.

Starting conditions:
Any box is less then the container. The boxes can only be rotated 90 degrees around the vertical axis (due to the holders on the top of the boxes).

Limits:
1. Only the top down function works, no horizontal pushing.
2. The boxes in the second, third, etc. layers have to be well-underpinned, so without side forces they have to sit stable on one or on more boxes.

To divide the hard task, filled layers are created in the first subtask, then the search for the best solution among the overplacement variations of the layers is executed. In the first subtask when creating layers, boxes are put into the extreme "corner" position, to leave the largest rectangular shape free for the next boxes.

This NP-hard task can easily result in practically infinity long computer run. To avoid this first the algorithm has to calculate the estimated calculation time. If it is too large then looking for quasi-optimal solution is allowed, and the selection of AI search methods resulting in local optimum is accepted.

AI methods that can be used:
- Heuristics based on symbolic logic (to make easier the task and create heuristic target functions)
- Dijkstra’s search algorithm (to find optimal solution)
- Iterative Deepening search algorithm (to find optimal solution)
- Depth first search algorithm (to find quasi-optimal solution)
- Best first search algorithm (to find quasi-optimal solution)
- Tabu-search. (to find optimal solution).

Second phase:
If the optimal or quasi-optimal computer solution is ready, the generation of the robot programs follows where the cooperation of the two robots is preferred. Opportunities for cooperation:
A., The two robots are looking for boxes and placing them alternately, so long as one of them is in the container the other is looking for new box. If one robot breaks down, the other will continue the task substituting the failed robot.
B., If there is not interference between the robot hands, the two robots can place in boxes parallel.
4. Conclusion
The main purpose of this paper is presented in two parts, firstly it explored the concept of Industry 4.0 by discussing its essential goal and its advantages, then highlighted the base that brings together the nine pillars of this industrial revolution, which can be defined as a cyberspace that controls everything from demand to product design. It is characterized by intelligent automation and integration of digital technologies: 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. The third part of the paper introduced three demonstrative example tasks that can be used for collaborating robots. The first is intended for 3D simulation only, while the two others will be realized using our two Mitsubishi robots.

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References
[1] Ahuett-Garza H and Kurfess T 2018 A brief discussion on the trends of habilitating technologies for Industry 4.0 and Smart manufacturing Manuf. Lett. 15 60–3.
[2] Tjahjono B, Esplugues C, Ares E and Pelaez G 2017 What does Industry 4.0 mean to supply chain? Procedia Manuf. 13 1175–82
[3] Zhong R Y, Klotz X, Xu E and Newman S T 2017 Intelligent Manufacturing in the Context of Industry 4.0: A Review Engineering-London 3 616–30
[4] Robla-Gomez S, Becerra V M, Llata J R, Gonzalez-Sarabia E, Torre-Ferrero C and Perez-Oria J 2017 Working Together: A Review on Safe Human-Robot Collaboration in Industrial Environments,” IEEE Access 5 26754–773
[5] Sung T K 2017 Industry 4.0: A Korea perspective Technol. Forecast. Soc. Change 132 40–5, 2017.
[6] Sambamourthy M 2002 Industry 4.0 [Online] Available at: http://www.cans2u.com/industry4.php [Accessed 15 May 2018]
[7] Gubán M and Kovács G 2017 Industry 4.0 Conception Acta Technica Corviniensis Bulletin of Engineering 1(2017) 19.
[8] Vaidya S, Ambad P and Bhosle S 2018 Industry 4.0 - A Glimpse Procedia Manuf. 20 233–8
[9] Stone P, Ave P, and Park F 1995 Multiagent Systems: A Survey from a Machine Learning Perspective Robotics 8 345–83
[10] Yan Z, Jouandeau N and Cherif A A 2013 A survey and analysis of multi robot coordination Int. J. Adv. Robot. Syst.10 399
[11] Zoghby N E, Loscri V, Natalizio E and Cherfaoui V 2014 Robot Cooperation and Swarm Intelligence World Scientific Publishing Company (2014)168–201
[12] Nicolle A 2000 L’organisation dans les systèmes multi-agents Journées Colline (Ch. 1)
[13] Lima P U and Custodio M. M 2004 Artificial Intelligence and Systems Theory: Applied to Cooperative Robots Int. J. Adv. Robot. Syst. 1 141–8