The Fourth Industrial Revolution: The Role of Artificial Intelligence and Co-Bots in Industry 4.0

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Abstract: One of the targets of the United Nations' Sustainable Development Goals is 'Industries, Innovation and Infrastructure', more precisely, to build resilient infrastructure, promote sustainable industrialization, and foster innovation. This objective is marked by technological progress, which requires investment in research and development. This century is the cradle of many new advances which stand as the pillars of the Internet and Computer Science: IoT, robotics and artificial intelligence are just the tip of the iceberg that represents the 4th Industrial Revolution. Industry 4.0, which is one the results of this revolution, marries physical production and operations with smart digital technology, machine learning, and big data to improve and increase manufacturing and supply chain management in every aspect, allowing companies to be more efficient. Unfortunately, developing countries are somewhere behind on this path and need to accelerate the development of their manufacturing sector. The aim of this paper is to familiarize current and future professionals with the key concepts and pillars of Industry 4.0, highlighting their relevance strictly related to their careers, jobs, or future occupations.

***Index Terms*— artificial intelligence, big data, cloud computing, co-bots, industrial revolution, industry 4.0, IoT, machine learning, robotics.**

I. Introduction

In the middle of the 20th century, innovations in the field of Electromechanics allowed the implementation of the first industrial robots in , aiming to reduce man labor due to all the global economic issues present in that period. This scenario, together with sci fi movies and novels, served as bad propaganda for Robotics and technological innovations in general regarding automation and intelligent machines. Hence, when people think about robots or the term "artificial intelligence", there is certain rejection. Many are tempted to picture a world where machines steal their jobs or, from an extremist perspective, a world where human beings are controlled by machines that somehow realized they are a new superior species.

In the current century, humanity is going through a new revolution: the fourth one, where new advances in Computer Science and Robotics converged into a new type of Industry, allowing the return of human workers to production centers as an indispensable force. The main intention of this paper, based on the United Nations' SDG concerning industries and innovation, is to refute the repulse that people have regarding technology and to explain how humans can coexist and collaborate with intelligent machines, which main role is to assist employees rather than replace them, improving companies' productivity in a more sustainable equilibrium.

In order to achieve this, the paper is structured in two main sections. First, in a sort of historical account, the 1st, 2nd, and 3rd Industrial Revolutions are briefly covered, as well as some 20th century key events. Section two corresponds to the 4th Industrial Revolution. This section is divided as follows: firstly, all the core concepts and pillars of this revolution are explained. After this, the term "Industry 4.0" is introduced, along with some AI innovations applied to Industry. Finally, the fusion between industrial robots and artificial intelligence is discussed under the idea of "collaborative robotics". This collaboration will be analyzed as well as its advantages and main applications.

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II. THE FIRST THREE INDUSTRIAL REVOLUTIONS

Between the 18th and 19th centuries, mankind made the step from an agricultural-based way of living into an Industrial Era. By the end of 18th century, steam became the new source of energy and with it, the steam engine came up. New forms of transportation and trade appeared: steamships and trains with brand new rail systems were constructed. Textile and metallurgy industries flourished.

In the second half of the 19th Century, Science and Engineering combined to determine technological progress. This period was conventionally called the Second Industrial Revolution. The internal combustion engine quickly appeared, along with the first power plants and the arrival of electricity in homes [1]. It was a period of mechanization and Electromechanics began to gain great relevance.

New industries were developed. It was an era of scientific discoveries and inventions like the electric lamp, the telegraph, the telephone, the typewriter, the sewing machine, photography, cinema, the automobile, and the airplane, among many others. Also, scientists made numerous discoveries related to health, like the use of the first anesthesia, the discovery of the tuberculosis bacillus, the rabies vaccine, the aspirin, and x-rays [2].

By the end of 19th century, countries that had developed the Industrial Revolution, had doubled their population. Their life expectancy increased and only a minor percentage worked in fields. By increasing productivity, the Industrial Revolution increased the per capita income and per capita consumption. Since then, the wealth of the industrialized countries has risen above their populations. Hence, the Industrial Revolution inaugurated a new economic era characterized by sustained economic growth [3].

The 20th century and the Third Industrial Revolution

The inertia from 19th century continued into the 20th. In 1905 Albert Einstein published his Theory of Relativity. In 1913, Henry Ford installed the first moving assembly line for the mass production of an entire automobile, promoting Taylor's Scientific Management Theory. His innovation reduced the time it took to build a car from more than 12 hours to one hour and 33 minutes [4]. The Scottish John Logie Baird developed the first commercial and mass-produced television in 1926 [5]. Right in the middle of the 20th century, the first microchip was introduced to the world by Jack Kilby [6]. and sooner the first personal computers began to break into the market. In 1969 Apollo 11 was the spaceflight that first landed humans on the Moon [7].

Roel [8] states that during the decades of the 50s, 60s and 70s of the 20th century, scientific and technological advances did not cease to take place at any time. In 1991, the World Wide Web was publicly announced. With the arrival of computers and television, the Third Industrial Revolution also came. It was a scientific and technological revolution.

Of course, the dark side of this century cannot be omitted. Many catastrophes also occurred in this era: two World Wars, the Great Depression in the 30s, the Cold War between the Soviet Union (USSR) and the United States (US) among many other violent events. As a result, careers and jobs mutated, society changed. Processes had to be optimized and efficiency improved to reduce costs as a must.

Roel [8] isolates other important facts of this dark period: in 1974 the price of crude oil had more than doubled with reference to the previous year, and in 1979 the price of a barrel rose to 27.4 dollars and reached a record USD 35.2 in 1980. In the 70s, the technology that was used back then was the one developed in the Second Industrial Revolution, based on the employment of cheap oil. When crude oil prices considerably increased, Industry was forced to redirect all its technology, making focus on the following statements [8, p. 26]:

1. New technology should be developed to reduce energy consumption, as well as manpower.
2. It should be a technology with a very broad impact on all aspects of individual and collective lives.
3. It should be a technology that uses the least possible amount of raw material, maintaining high productivity.

Considering these points, the groups or technologies that fully rose to meet these criteria were **Robotics, Genetic Engineering** or **Bioengineering and Telecommunications**. Regarding the first and the last one, the main protagonists were computers, which based on the new advances in electronics at that time, created a new way of operating industrial work. On the other hand, traditional petroleum-based chemistry, was replaced with genetic-based biology, which allowed the use of microorganisms in the production of a variety of chemical, pharmaceutical and textile products.

Society, Economy, and the whole Industry changed in every aspect. The mechanization of factories increased, and workers' efficiency improved. Processes where protocolized and innovation was encouraged as a strategy for market differentiation. The first PLC (Programmable Logic Controller) was employed in manufacturing, along with robots and other machines that started replacing human labor in assembly lines. The appearance of the Internet as new way of communication and sales deeply impacted society.

III. THE FOURTH REVOLUTION

A. The pillars of the Fourth Revolution

The 21st century harbors a huge growing ecosystem and a new beating revolution. Many of the new emerging technologies and innovations are reaching a point of inflexion, where they evolve and merge with each other in a fusion of technologies binding the physical, digital, and biological worlds altogether. Current computer advances are leading the levers that mark the course of digital transformation. **Cloud computing, big data analytics, Internet of things, mobility, social media, augmented reality, artificial intelligence,** and **machine learning** are becoming solid pillars and technologies that change persons' day-to-day life, to the point that some are already integrated into their lives in such a way that there is no turning back.

Facial recognition is used to unlock phones or even pay bills or buy groceries. There are self-driving cars like Tesla or recommendation systems that suggest which movie to watch on Netflix, or which book might be enjoyable to read. Social networks allow to find job opportunities, book a flight or a hotel, call a taxi and even flirt or find a date. Digital marketing has revolutionized the market and the way that customers do their shopping. On top of this, robots have evolved from those first prototypes born in the last century and digital assistants have become the elderly's best friends [9].

Schwab [10, p. 19-27] lists a selection of topics that are considered the boosters of this revolution. He calls them "Megatrends" and he divides them into three larger groups: physical, digital, and biological.

Physical

- Autonomous vehicles
- 3D printing
- Advanced robotics
- New materials

Digital

- IoT (Internet of Things)
- Blockchain
- Digital platforms

Biological

- DNA & Genetic Engineering
- Bio-printing
- Human brain

All these fields are not isolated and cannot be analyzed without considering the rest since they are highly related. Whether the discussion is about autonomous vehicles, smartwatches, new advances in robotics or new technologies for a better DNA sequencing or monitoring the human brain, everything leads to the same pillars: The Internet and Computer Science. To get a better picture, four larger groups can be considered: all the produced and gathered data, under the concept of "big data"; the algorithms utilized to process them, grouped under the terms of "artificial intelligence and machine learning"; a third one that connects the previous two: cloud computing; and finally, "Internet of things" (IoT), which consists in the relation between machines or devices and the cloud. Even though they are closely related, they can be considered as subfields with their own complexity, making it hard to address them as a single topic. Therefore, they should be analyzed separately for better understanding of their relation afterwards:

Big data

Everything is surrounded by sensors and algorithms that create, track, process and analyze a massive amount of data that are being produced minute by minute or millisecond by millisecond. Sosa Escudero [11, p. 30] argues that 'the expression "big data" is just slang and it does not seem to have a precise meaning'. For the author, the term not only refers to massive data, but to the volume and the type of that data, which come from several sources as a result of the interaction with interconnected devices like cell phones, credit cards, ATMs, smart watches, GPS devices, personal computers, or any other object capable of producing information and sending it electronically elsewhere. In addition, he also states that the volume is just one part of the story since data are anarchic and spontaneous and most of the time full of noise, garbage, or non-relevant information. This needs to be processed, classified, or discarded in order to produce useful information; this is where algorithms come to the rescue.

Sosa [11, p. 37] explains that 'just as it takes two to tango, the other side of the big data explosion is the methods used for its analysis.' Machine learning is the name given to all the computational, mathematical, and statistical techniques associated to the big data phenomenon.

Machine Learning

Shalev-Shwartz and Ben-David [12, p. 7] address the concept from a technical perspective, observing that machine learning is the 'automated detection of significant patterns in a data set'. They also add that 'since the last decades it is a necessary tool in any task that involves the extraction of information from large amounts of data, or the performance of tasks that are beyond the capabilities of a human being.'

A machine learning algorithm receives as input certain experience in the form of data and manages to "learn", returning an answer in the form of developed and applicable knowledge. Machine learning is an interdisciplinary field that shares common threads with the mathematical fields of statistics, information theory, game theory, and optimization. It can be considered a subfield of Computer Science since the objective is to program machines so that they learn.

i. Artificial intelligence vs Machine learning

Artificial intelligence and machine learning are terms often used as synonyms, although there is a subtle difference: AI is described as a sub-discipline of the Computer Science field that seeks to create machines that can imitate intelligent behaviors, whereas the second one (ML) can be seen as a branch of the first one. However, it should be noted that, unlike traditional AI, machine learning is not trying to construct an automatic imitation of intelligent behavior, but rather 'use the special strengths and abilities of computers to complement human intelligence, often performing tasks that are far beyond man capabilities. For example, the ability to scan and process huge databases allows machine learning programs to detect patterns that are beyond the reach of human perception' [12, p. 24-25].

ii. The way machines learn

Although the number of algorithms, approaches and techniques for this endeavor is enormous, broadly speaking, the most generic types of learning in the field of Machine Learning are supervised and unsupervised learning.

Shalev-Shwartz and Ben-David [12] describe supervised learning as a scenario in which the samples chosen for training contain significant information that is not available in the test samples. It is intended that the knowledge acquired after training can predict the missing information in these samples. Similarly, they add that ‘we can think of a teacher who supervises the student by providing extra information during the teaching process’ [12, p. 23]. This extra information that the training samples have is provided in the form of labels. A label represents the expected result or answer for a given input. For instance, a toddler can be shown a sequence of cards with pictures of animals, as well as the name of each animal written in a label below each image. After a while, his parents or teacher can display him a new card with an already known animal, this time without a label. If the toddler’s learning process has been successful, they would answer with the correct name for that animal. The same can relate to computers and supervised learning algorithms.

On the other hand, unsupervised learning consists in using samples with no previous tagging, extra information or metadata assigned. That means there is no distinction between learning data and test data; they all look the same.

What can be expected after this type of learning is to obtain an output in the form of a summary or a compressed version of the input data. Generally, this type of learning is used to cluster or order a group of data, of which very little is known, into smaller subsets with common characteristics.

Another kind of learning, which is a whole sub-field by itself, is reinforcement learning, by which algorithms interact with the environment in a way that allows certain feedback between the system under training and its experiences. As Szepesvári [13] explains, reinforcement learning refers to learn to control a system in such a way that some numerical value representing a long-term goal is maximized. A typical case is one in which the controller receives the current state of the system and a reward associated with the latest state. Then it calculates an action that is sent back to the system. In response, the system transitions to a new state and the cycle repeats. The problem lies in learning a way to control the system to maximize the total reward. For this, it must be considered how the data will be collected and how the performance of the system will be measured. This type of learning is widely applied in robotics and in automation and control.

Cloud computing

Cloud computing is a general term for the provision of hosted services over the Internet. It allows companies to consume computing resources as a utility (just like electricity) rather than having to build and maintain computing infrastructures on their offices. Therefore, it means that all the hardware and software are provided as a service from another third-party company over the Internet, usually in a completely transparent way [14].

The cloud can act as a bonding for machine learning algorithms and big data. ML algorithms can be part of cloud-based applications, where at the same time can consume all the needed produced data that are travelling through the Internet.

Internet of things

The Internet of Things (IoT) describes the network of physical objects (things) that carry integrated sensors, software, and other technologies in order to connect and exchange data with other devices and systems over the Internet or a wireless network without human intervention. These devices range from everyday household items to sophisticated industrial tools [15].

B. Industry 4.0

When the focus is set on the industrial field, the 4th Industrial Revolution and Industry 4.0 can be envisioned as synonyms. However, this revolution might not only be an Industrial Revolution, but a revolution of thought, science, and technology. In that case, the 4th Revolution might be too broad to tackle since there are multiple edges to analyze: Industry, Medicine, Education, Social Relations, Economics and Government administration, among others. They all overlap or depend on one another at some point, but for this paper and regarding United Nations’ SDGs, it is relevant to delve into the industrial aspect: Industry 4.0.

Once the big pillars of the Internet were established, along with the advances in Electronics and Computer Science, a new kind of revolution soon began to take shape. Society started to interiorize technology in every daily action and devices had to readapt to simplify such tasks. A digital camera, a phone, a calculator, a calendar, and a web browser, ended up merging into one single piece of hardware: the smart phone. Boza [1, para. 7-8] makes good use of this example to explain how technology has revolutionized people’s lives. As he notes: ‘Through the mobile we take photos, videos, listen to music, watch TV, interact by voice, ask us even about our mood, tell us how to get to an address, check the news, check the weather forecast, advise us what to buy, we buy, we check the status of our accounts, we pay, we control household items, it connects with our car, it tells us the distance we walk, we communicate on social networks. […] And if in our daily lives we adopt all the technological advances that make life easier for us and make us more productive, why don't we do it in our companies?’. Schwab [10, p. 7] states that ‘we are witnessing profound changes in all industries, marked by the appearance of new business models. Production, consumption, transport, and delivery are being remodeled’, but, in line to what Boza [1] remarks, the reality is that digital transformation processes in companies have only started gingerly. They do see a need to adapt digitally; however, they are still in an early stage of digitization, of learning about new digital tools and knowing how to apply them. In 2011, the German government promoted the computerization of manufacturing, as a part of a high-tech strategy project. Hence, the term "Industrie 4.0", shortened to I4.0 or simply I4 was born.

AI role in Industry 4.0

AI has become the most disruptive technology called to revolutionize the management and business models of organizations. Its implementation promises to double annual growth rates by 2035 [16, 17]. The automation of industrial processes, workforce capabilities improvement and the development of new products are the main areas in which the use of artificial intelligence applied in Industry 4.0 will benefit the industry in its digital transformation process. Its main applications are:

- **Overall Equipment Effectiveness** optimization through predictive repair and maintenance. OEE indicates how good the equipment is being used and is considered as one of the key performance indicators, which, in turn, is based on three other indicators: availability, or the percentage of time that an equipment can operate; quality, the percentage of good, produced parts; and performance, that is, the percentage of maximum operation speed used [18].
- **Quality 4.0**, which enables industries to continually improve the quality of their production while collecting usage and performance data [19]
- **Generative Design**, where AI facilitates the simulation of manufacturing process or to forecast the behavior of manufacturing systems, during the design phases. [19].
- **Collaborative Robotics:** co-bots are replacing industrial robots while becoming an ally for workers in the production line. They are thought to work synergically along with humans instead of replacing manual labor [20].

This paper makes focus on the last item of the previous list: collaborative robots (**co-bots**, for short), which are one of the greatest innovations regarding Industry 4.0 and allow to explain how man labor and machines can collaborate with greater synergy. The shift from traditional automation based on independent industrial robots to networked cyber-physical system has revolutionized the way production plants work and imposed new standards of competitiveness on the market, bringing several benefits to producers and consumers. The specific application of AI to robotics aims to enable robots to perform tasks autonomously, as well as enabling them to make decisions about what to do in a determined work environment, under pre-established parameters. In this sense, robots are a good example of how artificial intelligence can accelerate processes to achieve perfection in production. Some of their practical applications are [21]:

- **Monitoring**: a robot can detect changing workplace conditions, collecting, analyzing, and using that information to optimize its operation.
- **Artificial Vision**: a robot can detect and recognize the presence and orientation of an object or part, carry out inspection and selection tasks, as well as analyzing the results of an operation and make the corresponding decisions.
- **Adaptation**: the force required for operations like pick and place, can be dynamically adjusted. Collisions with other objects can be detected and avoided.
- **Learning**: production errors can be predicted and diagnosed by the automated identification of patterns based on previous experience.
- **Implementation**: thanks to smart communication through the cloud the exchange of any data stream is efficient. Additionally, a robot can start its first task in just over an hour, without any external help.
- **Machinery Supervision**: the efficiency of nearby equipment and tasks can be controlled and improved by machinery monitoring applications.

Fig. 1. Collaborative robotic arm. Source: https://blog.universal-robots.com/es/inteligencia-artificial-y-robotica

In summary, the application of AI to robotics translates into significant improvements in production processes such as the early detection of issues on the production line, stopping the activity accordingly; the identification of improvements than can be made on a certain task, optimizing a procedure; or the recollection and further analysis of data, which can help decision-making processes.

Collaborative robotics

As noted, co-bots are one of the greatest innovations of this industrialized era, summarizing the expression of AI applied to robotics for the sake of a new kind of human-machine collaboration. However, their implementation is still scarce, especially in developing countries, yet their benefits must be emphasized.

i. Conventional vs Collaborative robots

Present for decades in mass production lines, conventional industrial robots have long proven themselves. Nevertheless, they take up a lot of space and often remain in a fixed position, they are expensive to build, acquire, program, and maintain. In addition, they can be dangerous, since the absence of force sensors (which gives the robot the ability to know its surroundings and allows it to stop automatically in the event of an intrusion into its space), added to its high weight, makes industrial robots potentially dangerous tools.

For this reason, they cannot be installed without safety barriers that protect people.

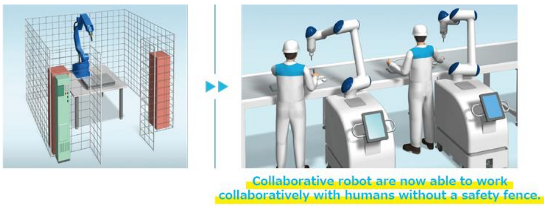

Fig. 2. Conventional vs. collaborative robots. Source: https://www.yaskawa-global.com/product/robotics/collaborative

Co-bots, instead, are compact and take up little space. Also, they can be relocated anywhere without any hassle. They are light-weighted and are equipped with sensors that allow them to stop in case of obstruction or need, ensuring the worker safety and preventing possible injuries. Their programming and handling are simpler and can be done without the need of going through a previous training period. Besides, unlike conventional industrial robots, co-bots can be fully operational in less than 12 hours.

The major difference between conventional and collaborative robots is their purpose and their applications. A traditional robot is designed and developed from the beginning considering a single purpose, which can be solved with optimal efficiency. On the other hand, a collaborative robotic arm, can be built for multiple applications according to production needs. Their easy programming allows the machine to be quickly reprogrammed for a new series of tasks.

Lastly, unlike traditional robots which are meant to do their jobs alone, co-bots' role is to assist human workers. They can work uninterruptedly for a whole day and can face the heaviest tasks and perform repetitive work efficiently, improving product quality and allowing companies to achieve higher levels of productivity [22].

Fig. 3. A collaborative robot assisting an operator in an assembly task. Source: https://blog.universal-robots.com/es/industria-40

ii. Advantages of co-bots in SMEs

From an industrial point of view, production is focused on automation, although, nowadays, consumers are in pursuit of personalized products. Customers trends are focused on the acquisition of handmade or artisan products. As Pelegrí [19, para. 9] notes, 'products like individually configured cars, hand-made clothes or even craft beer, require the presence of people to elaborate the product.'. In this scenario, collaborative robots perform a crucial role: assist man workforce instead of replacing it.

Furthermore, Pelegrí [23, para. 7] affirms that 'co-bots are also suitable for manufacturers in developing countries or places where labor is scarce'. This also extends to small and mid-size enterprises (SMEs) and startups, which are focused on increasing competitiveness thanks to research and innovation, yet in terms of industrial robotics, traditional robots are completely inaccessible due to high costs. In contrast, collaborative robotic arms are accessible to any company, since they are affordable, versatile, and easy to integrate without the need of major renovations. Moreover, they are safe to operate without special cages or fences, and their programming can be done by non-qualified professionals.

IV. Conclusion

Industry 4.0 and the Fourth Industrial Revolution cannot be explained one without the other. Artificial intelligence has revolutionized the operation of Industry, facilitating a new way of communication between man and machine.

When talking about these topics, many would be tempted to bet that the human of the future will be an unemployed human, discarded in pursuit of machines. In every revolution, change will occur and humanity, once again, will have to readapt. But mankind needs to understand that this readaptation implies an effort.

AI and machines are blamed for replacing man labor, but who operates these machines? Who builds or maintains them? Who designs and programs the required algorithms? This type of functionality will only express its value if companies invest not only in technological, but in human capital, while being aware and open to processes refactoring. For instance, replacing conventional robots in production lines with innovative collaborative robotics will allow human workers to improve their labor not only speaking from an efficiency perspective, but from safety and comfort as well. Man-workforce can be assisted by machines instead of being replaced by them.

A new kind of Industry is brewing. Near future is about the return of people to production centers as an indispensable force. Intelligent factories with humans working synergistically with interconnected, cyber-physical systems that interact with the cloud are just a taste of things to come.

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