A vision of industry 4.0 from an artificial intelligence point of view

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Abstract - *During the first years of the so called fourth industrial revolution, main attempts that tried to define the main ideas and tools behind this new era of manufacturing, always end up referring to the concept of smart machines that would be able to communicate with each and with the environment. In fact, the defined cyber physical systems, connected by the internet of things, take all the attention when referring to the new industry 4.0. But, nevertheless, the new industrial environment will benefit from several tools and applications that complement the real formation of a smart, embedded system that is able to perform autonomous tasks. And most of these revolutionary concepts rest in the same background theory as artificial intelligence does, where the analysis and filtration of huge amounts of incoming information from different types of sensors, assist to the interpretation and suggestion of the most recommended course of action. For that reason, artificial intelligence science suit perfectly with the challenges that arise in the consolidation of the fourth industrial revolution*.

Keywords: Industry 4.0. Artificial Intelligence, Big Data, embedded systems.

1 Introduction

Industry and industrial processes are continuously evolving. The needs for competitive advantages in manufacturing have been historically the engine for the development of advanced and cost effective new mechanisms to manufacture. In this effort, and since the beginning of industrialization, from time to time, a technological leap takes place that revolutionizes the concept of industrial production, being refer to as industrial revolutions: First industrial revolution took place in the field of mechanization and steam engines; second industrial revolution was based in the intensive use of electrical energy and mass production; and third industrial revolution was founded in the IT environment and the widespread of digitalization.

The actual scenario of industrial production is stigmatic with a low predisposition for changes and unexpected situations. Production chains are characterized by static lines (with predefined sequences), which are hard to reconfigure to make new product variants. Today, regular situations of troubleshooting decrease or even stop production and lead to demotivation of employees. In conclusion, current industrial activity is rigid and difficult to change; innovations can hardly be afforded, reduction of raw material prices generally lowers quality and can increase process costs and, in consequence, profit margins decline constantly. There is also a great dependence on the in-house knowledge base, so when it drops, improvisation increase and development times get longer. Production systems, although strongly automated, do not possess a self-conscious core to learn and act without constant human monitoring. All these inconvenient points to the need for the next great revolution in industrial manufacturing, which will lead to several enhance attributes in comparison with actual production activities, like it is shown in next table, and which is starting to be referred to as industry 4.0[1].

For this new revolutionary industrial age, there is a concept that keeps being repeated, which can be narrowed into the self-consciousness of technology. An attribute that is directly linked with what artificial intelligence (AI) aims to achieve: The creation of systems that can perceive their environment and, consequently, can take action towards increasing the chances of success.

But the trigger for the new industrial revolution is based in two great pillars; the already described fixed industrial scenario that is not ready for unexpected changes in production, which adds up with another reality, which is that the forms of consumption are changing. Nowadays, producers want to focus into almost individualized demands in their efforts to reach every potential client, hence tomorrow's industry will need to provide a dynamic production line, where not only products are made, but a combination of product + service is offered to gain advantage against their competitors and driving production to constantly changing environments [2]. To achieve this, the degree of automation should move to the next level, where sensitive computing, taking information from the environment, should be able to predict next steps in production with barely none interaction with the user, in the same way artificial intelligence can work.

For that reason, under the intention to adjust to more flexible production schemes and increase the ability to compete, it can be said that we are in the prelude of a new paradigm shift in industrial production: Every step in the industrial process generates data (energy consumption, speed, power, weight etc). Hence, once established an advanced digitalized network in factories that monitors this information, next logical step leads to the combination of internet technologies and “smart” objects to interpret this huge flow of information towards an advanced form of manufacturing, where, for example, it would be possible to foresee the need for preventive actions and adapt production before it happens. Advanced manufacturing technology is then a term that refers to a set of highly flexible, data-enabled, cost-efficient processes. In other words, the implementation of modular and efficient manufacturing systems in scenarios where products control their own manufacturing process, embedded in a futuristic environment where machines, products, humans and systems are able to communicate with each other and make decisions related with the process itself, adapting to new situations, being able to automatically detect anomalies or requirements, and acting in consequence. An example of what this fourth industrial revolution is planning to achieve in manufacturing environments, can be seen in a common object like the “airbag” from vehicles, which is one of the first developed systems that behave as a self-conscious entity; that in front of a sudden and new problem (a crash), is able to detect, by themselves, the need for actuation. And precisely the advance in fields like artificial intelligence, nanotechnology, robotics or additive manufacturing are the starting point for the development of more examples of flexible and adjustable operation of machines.

Under this hypothesis, the term industry 4.0 (or fourth industrial revolution) would not only imply a technological change, but versatile organizational implications as well. As a result, a change from product- to service-orientation is sought and expected: manufacturing and service industry will become complementary, encouraging a new form of production that some authors have labeled as servitization: “Servitization is the strategic innovation of an organization´s capabilities and processes to shift from selling products, to selling an integrated product and service offering that delivers value in use. Here the market goal of manufacturers is not one-time product selling, but continuous profit from customers by total service solution, which can satisfy unmet customers´ needs” [3].

Although complete development and employment of these technologies are still years ahead of us, first steps have already been taken towards the implementation of some of these measures, in order to achieve a more intelligent and efficient way of developing different industrial objectives. The journey to a flexible, heterogeneous, decentralized, standardized, and self-aware production system has started, and, as consequence, so have all the revolutionary aspects associated with industry 4.0.

This terminology, or in its defect the term in German “Industrie 4.0”, has been embraced by the German industry (Hannover fair 2011), one of the main precursors of this new technological shift, as part of the High-Tech strategy 2020 action plan. Anyhow, a variety of different terms are used around the world to describe the phenomenon of Industrie 4.0. Some countries like Japan seem to have maintained “industry 4.0”, but others like the U.S. have defined terms like the “Internet of Everything”. Nomenclature like “Smart Production”, “Smart Manufacturing”, “Smart Industry” or “Smart Factory” are used in Europe, China and also the U.S. to refer specifically to digital networking of production to create smart manufacturing systems.

In a different field of interpretation, the terms “Advanced Manufacturing” [4] or “Predictive Manufacturing” [5] embrace a broader spectrum of modernization trends in the manufacturing environment. Advanced manufacturing is, by definition: “a family of activities that depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. It involves both new ways to manufacture existing products, and the manufacture of new products emerging from new advanced technologies” [4].

Individual companies like General Electric also invented their own name when they launched in 2012 a broad-based initiative named “Industrial internet”, with applications in several areas, but where manufacturing only plays a minor role. Others like Bosch have been using “connected manufacturing” to emphasize precisely the importance in manufacturing aspects.

Anyway, independently of the specific given name, all these proposals are driven towards the need for the construction of an automated, self-conscious, interconnected, heterogeneous, embedded system, that will push manufacturing into the next level.

2 Main challenges of industry 4.0

The main message that can be extracted from the previous paragraphs, is that the basic idea of industry 4.0 rests in the combination of hardware and software devices, constructing a “Smart factory” where humans, machines and resources communicate with each other and work collaboratively; building more complex networks that, on the other hand, will reduce efforts. Precisely, artificial intelligence structure will assist in the creation of this networks, doting machines with the capability to learn, reason and act, basing on the information gathered during the industrial process. The required changes towards those smart factories are then defined by two development directions: Changes in the operative conditions themselves towards more flexible and decentralized processes; and changes in the technological means to achieve this objective [6].

Moreover, every change is boost by the main challenges that this new revolution has to face [7, 8, 2, 9, 4]:

1. Energy and resource efficiency as decisive competition factors.

2. Reduce time-to-market by shorter innovation cycles of complex products and larger data volumes.

3. Increase flexibility towards an almost individualized mass production in the middle of high productivity and volatile markets.

4. Gradually upgrade of existing infrastructure, connecting the different embedded systems by different mechanisms (M2M, wireless etc.), towards a constant self-prognosis, self-configuration, self-decision system.

These changes involve obvious benefits under the influence of “smart environments”, like for example: processes will be more quickly (autonomous collision avoidance), more precise (nanotolerance manufacturing), more automated (analysis and determination of best suitable specifications by artificial intelligence), safer for workers (smart robots working in dangerous or inaccessible environments), more coordinated (automated traffic control), more efficient (energy sustainability), and maintaining a more collaborative relation between machines and humans (assistive technologies).

To achieve this goal, there are different factors that need deep consideration during this transition:

- Individualization: As it was said before, future production chains will drive to what years ago sounded as an utopist idea: Efficient production in batch sizes of 1 [7, 8, 10, 11, 2, 12].

- Flexibility not only during the process itself, but with simulation tools that can assure the feasibility and security of every change [7, 8, 10, 2, 12].

- More dynamic designs of business and engineering processes towards a holistic optimization that eliminate possible bottlenecks [7, 8, 10, 2, 12].

- Older employees must adapt to newer process dynamics (smart assistance systems). This challenge is bidirectional. On the one hand, older employees must adapt to a new production technology (intuitive tools), and on the other hand this smart system needs to adjust to every worker’s speed in order to constitute a real collaborative and safe partnership [7, 8, 11, 13, 4].

- Proactive maintenance of machines in order for it to fall under periods of already scheduled process stops. For that, intelligent diagnostic protocols must be embedded in all devices. Final goal is to eliminate unplanned stops, thus increasing productivity [8, 11, 3].

- Secure communication networks and high availability independently to unpredictable threats [8, 11, 14, 15, 9].

- Unification and integration into a common platform of hardware and software from different applications or generations. Main objective for the instauration of a global network of communication is that the entire lifecycle information of all the assets in the plant can be managed homogeneously [16, 7, 8, 14, 15, 9].

3 Main challenges of industry 4.0

As it was said before, the shift in manufacturing processes will be settled in the employment of smart objects interacting with each other and with the user. It has already been stated that the basic pillar in this trend will be defined by the combination of hardware and software into embedded systems denominated cyber physical systems (CPS) that will make use of the internet of things (IoT) and big data to connect every device, that will have its correspondent identifier and basic computer capabilities in order to sense and/or act.

Hence, several tools are needed not only to conform and function in the embedded system, but to develop as well some kind of interface or network in order to extend it, which constitutes the base for the development of this industry 4.0, from the sensors, actuators and control units that gathered information provided by different elements in the process, to a cyber physical system that can manage this information and make decentralized decisions, to the smart machines that will follow the self-deduced actions to take, to the platform that must sustain great flows of information, to even the simulation of processes and design and testing of prototypes based on intelligent and self-aware systems. Indeed, the science of artificial intelligence is settled in the same principles (statistical methods, machine learning, mathematical optimization, neural networks, probability, computational intelligence etc) that the ones that will help constructing the combination of physical and conscience worlds.

However, although the combination of hardware and software into an interconnected system is the base of industry 4.0, there are other variables that are important during this transition and can help to ease the different steps and conditions that a production chain from the fourth industrial revolution must reached in this new paradigm. These include autonomous robots that can work collaboratively with humans in safe conditions, simulation and virtualization tools to help during decision-making stages, or additive manufacturing with utilities not only in the fabrication of prototypes, but also as final product candidate. Next sections describe some of these tools in charge of receiving, gathering, managing, analyzing, interpreting and intercommunicating huge amounts of information proceeding from every part of the manufacturing system; executing decentralized decisions based on the analysis of information; developing 3D models from objects previously designed with computer programs; and allowing the simulation of the entire supply chain and every process included in it in order to make efficient decisions.

3.1 The internet of things (IoT) and cyber physical systems (CPS)

Citing the Federal Ministry of Education and Research in Germany (BMBF): "Industry is on the threshold of the fourth industrial revolution. Driven by the internet, the real and virtual worlds are growing closer together to form the Internet of Things" [18]. Hence, IoT can be defined as the network system that supports the tools for communication between smart devices and their interconnectivity. In the configuration of IoT, two separate and equally important variables are required: On the one hand, a complete gear of sensors and tags in charge of capturing the information that the different stages and machines in the process generate; and on the other hand, communication software protocols to transfer this information to a central server.

The CPS is then the final responsible for the management and analysis of the information sent by these interconnected systems between its physical assets and computational capabilities; while the advanced connectivity network integrated in the IoT must ensure real time data acquisition from the physical world, as well as posterior information feedback from the cyber space [16]. These capacities allow self-comparison between present and past states, and assist in the decentralized decisions of recommended course of action, making machines self-configure and self-maintainable. The structure of a CPS can be divided in different levels to make machines self-aware and self-adaptive: Smart connection level (gathering of all information); data-to-information conversion level (extract the relevant information); cyber level (includes the virtualization hub to exchange information through other cyber interfaces); cognition level (where optimization decisions take place); and configuration level (for feedback deployment) [1].

Last fundamental concepts for this pillar of industry 4.0 are Big Data and cloud computing, which creates a medium that can handle all the managed information by CPS and IoT. Huge amounts of information is expected to be stored and processed, so later on can be accessible from anywhere at any time, thus, cloud computing constitutes an optimum solution for storage performance, as well as Big Data analysis aids in the management of the information. The capacity to support and control big flows of information is one of the most important applications of industry 4.0, which relies on the maintenance of artificial intelligence networks supported by digital product memories, translated into the collection of all data records for all data stages during the product life cycle, for posterior analysis, that could lead to newer and innovative methodical approaches for planning and development of products [6, 16].

3.2 Autonomous robots

Once the information has been received and analyzed; and decisions have been taken, another logical step consists in the actual execution of those measures. In the context of industry 4.0, self-learning and self-configurative robots are in charge of these actions, in complete collaboration with human workforce. Traditional concepts like proper design, operation performance, energy efficiency or maintenance are still important, with the difference that autonomous robots will have the capacity of managing some of this data to adjust and suggest changes by themselves to improve and predict their functionality and flexibility [3]. The proper combination of sensors, artificial intelligence and even robotic design are fundamental in this field. Technological enhancements have already improved robotics substantially over the past years, making robots suitable for almost every sector [8]. The increasing autonomy of robots will lead, however, to another consequence, which is the need for the establishment of safety protocols for operators working in the same area by, for example, changing to soft structural materials to minimize damage by impact, or the design of annulling mechanisms when a human enters in a sensitive area.

Nevertheless, machines from this new revolution and AI networks must ensure the means to support an infrastructure where robots are intended to work collaboratively with humans, facilitating their work instead of replacing them (adapting precisely to the human work cycle [19, 11]). Machine vision sensors, AI and learning software are the three most important variables that will allow the synergy between independent productive entities and shop-floor operators in a safe environment.

3.3 Additive manufacturing

Additive manufacturing or 3D printing, that is the capability to produce three-dimensional objects directly from virtual models, is another pillar of industry 4.0, with multiple possibilities, especially for designing and testing prototypes, where newer methods of modeling and reference models are continuously appearing without the need of moulds, so one machine can be used for the manufacture of different products, thus reducing production costs [6]. Even though so far, this application has not been broadly applied mainly because of slow production rates, few available materials and high prices, great developments are being made to solve these issues and improving the efficiency of producing individually customized products, allowing for rapid prototyping and highly decentralized production processes. One positive impact of this can be found in; for example, by counting with different printing locations; transportation, storage and other manufacturing costs would decrease, since the product model could just be sent off to the nearest printing site to the customer [8]. This can be applied the other way around, enabling customers to print their own 3D designs, allowing them to discuss the possibilities of the desired final product with the manufacturer prior its construction [2].

3.4 Augmented reality, simulation and visualization systems

Every decision, whereas it is related with logistics, manufacturing or future changes must be sustained in well-founded arguments. Industry 4.0 technologies will ease the deployment of simulation scenarios where different configurations can be tried and tested before their actual implementation, thus allowing the implantation of more complex systems. Simulation of how changes can affect process behavior are a huge benefit towards the prediction of how these resources or services will impact final value added for end users [17]. Again, artificial intelligence can provide the means for simulation in every stage of the life cycle of a product (from model and design, to functionality prediction). One example of this application may consist in the development of newer methods of modeling and reference models, like integrated computational materials engineering (ICME), where the performance of design materials and dimensions can be tested before construction of the element [6]. However, this pillar of industry 4.0 does not only refer to product properties, being possible as well the implementation of virtualization technology that creates complete digital factories which can simulate the entire production process, in order to optimize layout disposition. This is especially useful for launching new products in already existing plants; by first simulating and verifying virtually the consequent impact in production and human-machine interactions; and only when the final solution is ready, the physical map is done, meaning that all software, parameters, and numerical matrixes are uploaded into the physical machines controlling the production.

4 Inclusion of ICT in embedded systems

The previous section has shown the most important tools for the development of industry 4.0. As it was said before, the combination of hardware and software into smart embedded systems will be greatly resting in AI applications. However, sometimes those smart devices are generally referred to as a whole scale with blurred barriers, where it is difficult to establish when one element ends and the other starts. For example, during the first years of development of this concept, IoT was proposed to refer just to uniquely identifiable interoperable connected objects with radio-frequency identification (RFID) technology. Later on, however, as the connectivity of these networks were getting bigger and including new technologies and concepts, the term was growing with it to include all these innovations, applied to measure, identify, position, track and monitor objects [10], referring now to IoT more as a dynamic global network where self-conscious objects connect with each other. In this new context where CPS can be considered the proper “brains” inside industry 4.0, one way to establish some frontiers can be to consider IoT as the global framework where identification and sensor technologies become integrated with interpretation technologies like CPS. In other words, CPS forms part of IoT´s new step towards its development [19] [2] [14], with the help of ICT elements to guide the autonomous communication between all of them. Next paragraphs will depict the most relevant parameters in this established network by IoT and CPS that constitute the embedded system; including sensoric equipment, their communication protocols through software architecture, standardization languages for the gathered information, big data management, cloud computing and middleware connectivity, or architecture guidelines for construction of CPS.

4.1 Sensors for IoT

It has been said that the integration of sensors/actuators, radio frequency identification (RFID) tags, and communication technologies served as the foundation of IoT, and consequently industry 4.0. According with that line of thinking; from a conceptual standpoint, sensors settle the principles for which smart objects are able to [17]: Be identifiable, communicate and interact with each other, with users and/or other entities within the network.

In the context of identification, sensing and communication devices, radio frequency identification systems (RFID) are the key components for industry 4.0 [22]. RFID systems are composed of one or more readers and several RFID tags. Tags are characterized by a unique identifier and can be applied to objects or people. The readers are used to trig the tag transmission by generating an appropriate signal, which represents a query for the possible presence of tags in the surrounding area and for the reception of their IDs. From a physical point of view, a RFID tag is a small microchip attached to an antenna (that is used for both receiving the reader signal and transmitting the tag ID) in a package which usually is similar to an adhesive sticker. Dimensions can be very low (0.4x0.4x0.15 mm) [22]. Depending on how the energy is supplied, we have to differ between passive RFID tags (energy for operation is supplied by the RFID interrogation signal itself), active tags (on-board power source feeds the on-board receiver and transmitter, allowing for an increased radio range), and semi-active or semi-passive, where on-board power source is used to feed the microchip, whereas transmission is either active (semi-active) or performed using back-scattering (semi-passive) [17].

4.2 Communication protocols for sensors

Along with RFID technology, other complementary devices for identification are sensor networks or wireless sensor networks (WSN) [16]. Sensor networks consist of a certain number (which can be very high) of sensing nodes communicating in a wireless multi-hop fashion [14, 15].

Usually nodes report the results of their sensing to a small number (in most cases, only one) of special nodes called sinks. Typically, a node, which is the WSN core hardware, contains sensor interfaces, processing units, transceiver units and power supply [15]. In fact, they can cooperate with RFID systems to better track the status of things, thus augmenting the awareness of a certain environment and act as bridge between physical and digital world, helping the exchange of information inside the network.

Some of the most common hardware and software available for WSN that serve as communication protocols with unique addressing schemes and standards are IPv6 (to connect unlimited number of devices) [22, 10, 15], WiFi and Wimax (to provide high-speed and low cost communication) or Zigbee and bluetooth (for local communication) [10]; or others like WLAN, M2M or RFID [14].

4.3 Standardization languages

Information can be provided from different sources in the network, whether it is measured by sensors, controllers or manufacturing systems such as ERP. One of the first steps in the development of the network is to acquire this data in a reliable way and interpret it. However, considering that the different sources may give different types of data, there is a need for a seamless method that can manage the acquisition of information, the connection between various types of networks through various communication technologies, and the transformation into a final uniform type of data to be sent to the central server. For this matters, specific protocols such as MTConnect, OPC or ROS are effectively useful [1] [3]. In the same way, machines and robots in industry 4.0 must ensure as well certain level of standardization and trustworthy in the management of information, so it can be integrated with other branches within the same industry, and with other industries and industry types; in order to extract conclusions from hypothesis of how is the best way to support different types of plant with information technology [6]. In conclusion, standardization methods must be sought and implemented to support heterogeneity at architectural and protocol levels [17], where artificial intelligence is necessary not only for the interpretation of different languages, but for the transmission of the main conclusions to user, in an accessible way.

This idea is linked with innovative concepts for manufacturing execution systems (MES) or enterprise resource planning systems (ERP) [6], that can complement the shift towards new business models, where products become modular and configurable in order to be able to adapt to specific requirements [12]. Nevertheless, this task would include a very complicated heterogeneous network, and that is why there is still lack of a widely accepted common platform that can embrace the large heterogeneity of communication technologies. In addition, the large traffic of data at the same time would also cause delay and communication issues.

4.4 Big Data, cloud computing

The great flow of information in these embedded systems needs for technologies that ease the automation, and Big Data can be a solution for that, by enhancing as well important variables like mobility, flexibility and energetic efficiency, providing a temporally and spatially independent access to them [12] [17]. In conclusion, the application of data mining serves to sustain the analysis, modeling, simulation, fusion and computation, and scientific prognosis for decision making [10].

Cloud computing is, on the other hand, basically a large-scale, low cost flexible processing unit, based on IP connection for calculation and storage. The need for cloud computing is founded in the fact that some relation must be established between identification devices towards a storage for huge amounts of information [16] and the need for a centralized infrastructure to support this storage and posterior analysis [15]. Some of the most relevant characteristics are the possibilities for ubiquitous network access; rapid elasticity by increasing or decreasing capacity at will (pay per use concept); and independent location of the resources pooling [10].

5 Conclusions

Industrial environments are currently setting the foundations for a new shift in the production and manufacturing processes, drawing away from static production chains, to a more flexible, individualized and efficient idea of production. The base of this revolution is settled in the combination of hardware and software components, towards a more intelligent, self-conscious, self-configurative and self-optimize structure that can foresee problems and launch preventive actions to minimize stopping times during production; and to understand the whole lifecycle of the production process in order to be ready to respond to new and continuously changing environments. Four main challenges rise in this revolution:

1. Energy and resource efficiency

2. Reduce time-to-market

3. Increase flexibility towards an almost individualized mass production

4. Gradually upgrade of existing infrastructure

There are different variables that configure the embedded systems that influence in this new, flexible, standardized, decentralized, heterogeneous, innovative form of production, where processes are more clients focused and more resource efficient. Those main tools are cyber physical systems, the internet of things, big data and cloud computing (with the entire required infrastructure to support them); and other complementary elements like autonomous robots, simulation and virtualization models, and additive manufacturing. In this embedded systems, information gathered by different sensors and devices is interconnected and communicate with each other to, based on the compilation, process, and analysis of this great amount of data by smart objects, take decentralized decisions towards optimization of the production. Although this idea as a whole is still in its first steps of development, some possible applications are already being identified and tested in domains such as transportation, food supply chain, logistics, environmental monitoring, prototypes domain or industrial activities.

This situation gives form to a broth of several ideas and technologies where artificial intelligence may have a perfect niche for its thrive and implementation in the industrial environment, since its applications can give answers to different questions and possibilities within each one of the main pillars in which industry 4.0 will be structured.

6 References

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