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From Industry 3.0 to Industry 4.0

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ABSTRACT
With the advent of the Internet we can say that a new industrial revolution has begun. If in the beginning only computers could connect and communicate with each other, the idea of Internet of Things (IoT) or Industrial Internet of Things (IIoT) pushes technological evolution to the next level, making possible the connection to the Internet of all the devices created for this purpose. Industrialization 4.0 is the latest industrial revolution, and is not based on the discovery of a new form of energy, but on the digital world or digitization, due to the continuous development of computers, sensors and the mass generalization of the Internet. This article provides an overview of the minimum requirements for migrating from Industry 3.0 to the first step of the Industry 4.0 concept, by highlighting the possibilities of communication between production and management lines, the advantages brought due to their interconnection and the management of the collected data using a Manufacturing Execution System (MES).

Keywords-*I4.0; IIoT; ICPS; Digitization; Real-Time data collection; MES*

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I. INTRODUCTION

Manufacturing and beyond, needed innovation in order to be able to cope with the new demands of the modern world, where access to information is easy everywhere through the use of the Internet [9]. Starting from this idea and using the same communication environment, the latest industrial revolution, known as Industry 4.0 (I4.0), wants to open a new path regarding the informational exchange of production processes. It is talked about the possibility of interconnecting the sensors, devices and production lines with people through a central system (software) that can analyse productivity in real time, based on the data collected from them. Also, the process can be considered reversi-ble, in the sense that the software can send data to the production line, so that it can be able to satisfy the imposed requirements.

Industry 4.0 represents a fusion of several ad-vanced technologies under the same concept, each of them having a well-defined role in achieving this idea, Fig. 1: Internet of Things, Cloud Computing, System Integration, Simulation, Additive Manufacturing, Autonomous Robots, Big Data, Augmented Reality [1].

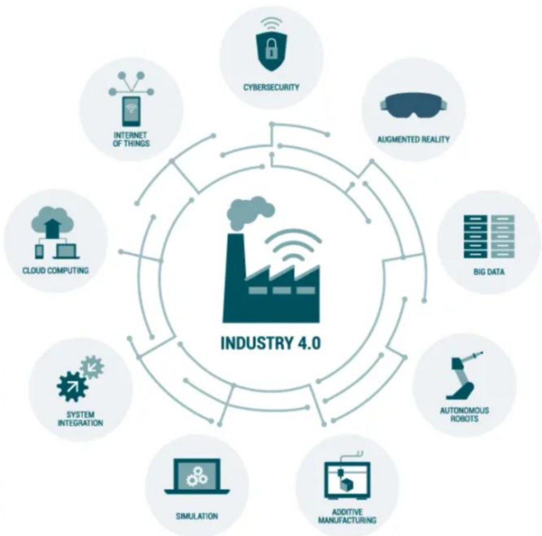

Fig. 1 Technologies of Industry 4.0

Since the 4th industrial revolution, it was ex-pected to profoundly change the vision of the manufacturing industry, transforming current factories into smart factories, by applying its fundamental design principles: interoperability, virtualization, decentralization, distributed control and communication, real -time capability, service orientation, quick and easy maintenance, low cost and modularity [10].

In a smart factory, digitization is a virtual copy of all existing equipment, through which authorized personnel can interact in real time with them [5]. By digitizing, the information is just a click away, and it can be accessed both inside a company and outside it. The minimum technology required on the way to digitization is IoT or IIoT if we refer to the industrial field, used together with a software such as Application Programming Interface (API) capable of collecting data, interpreting and processing them, and finally send back to the equipment the new requirements, so that it can fulfil them.

IIoT, is one of the main connecting bridges be-tween physical and digital applications, which leads to the concept of I4.0 [2]. It is often known as the Internet of Everything, because it defines a network of objects that incorporate electronic devices capable of communicating on the most widespread communication infrastructure, the Internet [3].

The purpose of this article is to provide an overview of the new revolutionary phenomenon, which pushes the manufacturing industry and not only, to another level of their management. In order to achieve this theme in its depth, only some of the technologies underlying the 4th Industrial Revolution will be analyzed, because its main purpose is to expose the way in which information can be digitized even from a system which was not designed to fulfilIIoT requirements.

The proposed article is structured in five sections, each of them having a well-defined role in achieving the purpose of this study. Section I presents a brief introduction to what means the latest industrial revolution, offering from the beginning a perspective on the essence of the I4.0 concept. Section II presents the current state of research, by exposing the technologies underlying I4.0, as well as the impact it has on modern industry. The analysis of an optimal hardware configuration, depending on the existing com-munication networks, is fulfilled in Section III. Section IV presents the necessary functions and features, which the API should accomplish, as a control tool for I4.0. The final discussions and conclusions can be found in Section V of this article.

II. SURVEY OF RELATED WORKS

The term "Industry 4.0" has its origins in Germany, being mentioned for the first time at the exhibition in Hanover in 2011, but has been recognized by other leading industrial nations under other names: "Connected Enterprise" in the US or" Fourth Industrial Revolution" in the United Kingdom [5]. This allows the extrapolation of the third industrial revolution, creating a new world, in which physical and virtual systems can communicate with each other in the most flexible way [2]. In support of the informational exchange between the two systems, IIoT intervenes, a technology that facilitates machine-to-machine (M2M) communication. The core of IIoT is the Internet, a communication mechanism that has revolutionized the manufacturing industry by bringing significant economic growth through the mediation of seller-buyer relations [5]. Compared to IoT for consumers, IIoT differs in storage and computing capabilities for larger amounts of data, both shared and locally processed, depending on application requirements [7].

Industrial Cyber-Physical Systems (ICPS) is an-other term belonging to I4.0, similar to IIoT by using the same type of architecture, being composed of physical entities, such as automated production lines and computerized algorithms for their monitoring [9]. IIoT and ICPS are expected to become "ubiquitous" in modern industrial settings, leading manufacturing production to the age of digitalization. By using IIoT and ICPS, it is expected to be revolutionized the way companies work, by optimizing the communication relations between production and management or between supplier and customer [13].

Following Fig. 2 you can see the connection be-tween the two technologies that facilitate the transition to I4.0. Thus, IIoT has the role of mediating the communication between the equipments, as well as the connection between the equipments and the environment in which they are virtualized, while ICPS represents the system in which the physical world is digitized and transformed into the cyber world. In other words, IIoT is concerned with the physical connection of the two worlds, while ICPS is the virtual path in which they intersect.

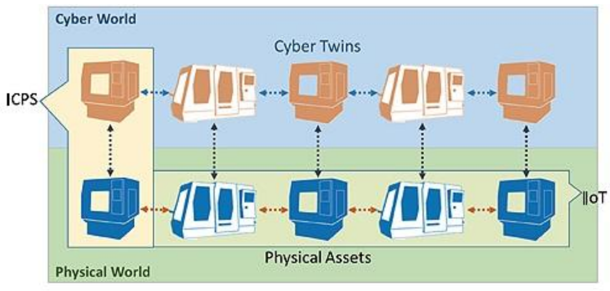

Fig. 2 IIoT and ICPS

The concept of "digital / cyber twin", as part of ICPS, is a collection of tools and methodologies through which physical objects are transposed into the virtual environment digitally, thus opening a path to cyber-physical convergence. The role of virtual models is to be able to understand the state of physical systems, through the data collected from them, to predict, estimate and analyze their dynamic changes [14]. The use of a closed loop model of cyber-physical systems could simulate and optimize the entire production line.

Data is the connection bridge between the two worlds (physical and cyber), which allow digital twins to represent their physical counterparts, through the computer content obtained from them. We can consider that data is the fundamental element for the promotion of I4.0, from the automation of the production line to the automation of information and then to the automation of knowledge [7]. On the other hand, in more and more industries, decision-making has begun to be based increasingly on analysis and data and not on experience, so collecting and analyzing as much data as possible is the key to intelligent production [14].

The main challenge remains the improvement of cyber security, the risk being very high due to the fact that IIoT represents the backbone of I4.0 [5]. Thus, by using a low level of security, it increases the risk of a cyber-attack, which could jeopardize both the control over production equipments and especially the collection and handling of data in a way that could affect the entire company.

Smart factories will be characterized by the optimal integration of different levels of automation, as to obtain a satisfactory compromise between flexibility, performance and resources, through a strong network between physical and cyber world to ensure the security of real-time data exchange [10]. Also, another important feature is that it allows simulations of the finite product, before moving to the production phase, allowing the planning of the production process in a flexible way, optimizing process times and offering a collaborative production [8]. Thus, I4.0 fully promotes the traceability of the production cycle of a product, being able to provide information about each process it has gone through.

III. HARDWARE SYSTEM ARCHITECTURE

The hardware architecture of the system refers to the types of network topology that this research topic will address and because we are talking about IIoT and IPCS it goes without saying that data transfer is done through an Industrial Ethernet (IE) network. There is also the possibility of using another communication network, but not on the whole system, only up to a certain level, which we will present later.

To analyse the topologies proposed in this study, we will use two of the most commonly used industrial communication networks, Profibus (marked in purple) and Profinet (marked in green). Essentially, both types of network are similar in terms of data exchange, which is done digitally. Significant differences are noticeable in the Profinet network, which is an industry technical standard for data communication over IE, through high data transfer rate, flexible network topologies as well as wireless com-munication. All these advantages mentioned above make this standard of industrial communication more and more widespread in almost all applications. The problem arises with automated lines using a Programmable Logic Controller (PLC), which was not designed with such a data transfer interface.

The two types of architectures proposed by this study, offer a perspective on how to connect between the production lines of a factory, in order to integrate it in I4.0. The creation of an optimal communication network is based on the analysis of the communication capabilities of all equipments and represents the first stage on the way to digitalization.In principle, a network is composed of two primary elements: a computer on which to run the API and acts as a server and all the automated equipments and devices from which the data collection is desired, which can be associated with the term network customers.

3.1. Direct access to the machine PLC data

The first architectural model studied and presented in Fig. 1, is composed of a server and its clients, represented by the controllers of the targeted equipment. Using this network topology, it is assumed that each PLC has an IE communication interface.

Following Figs. 1 from left to right, it can be observed that the first three PLCs are connected to the network by using a Communication Processor (CP), because they were not designed with the IE communication interface. CPs represent an extension module, through which a communication interface can be extended to a PLC.

The use of this type of architecture offers an advantage through the direct interaction between the API and the targeted production line, but it can also offer a disadvantage by increasing the cycle time in changing the data, if a large number of equipments are connected in the network. This can be optimized by managing the interaction of API-PLCs. Direct access to equipment data is a major advantage of this network topology in terms of the fact that the failure of any PLC in the network will not affect the functionality of others, therefore the entire system can still run.

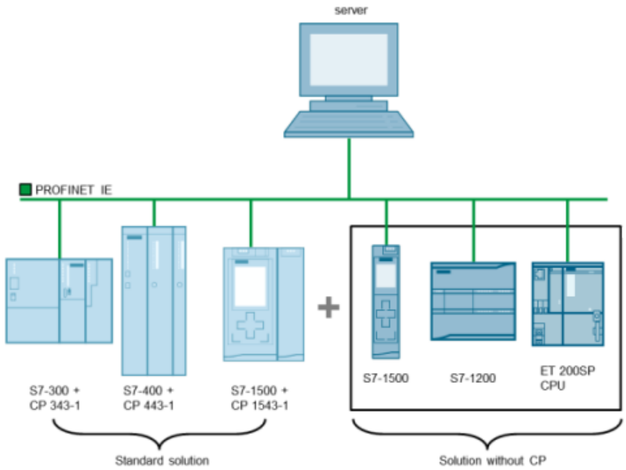

Fig. 3 Direct access to the machine PLC data

3.2. Indirect access to the machine PLC data

Due to the fact that IIoT does not support another type of communication than IE, in the second hardware configuration model, presented in Fig. 4, the production lines communicate indirectly with the API, through a master PLC. It will deal with the exchange of data between the API and other equipment, theoretically, an Ethernet connection being required only between the master PLC and the server.

By using this type of configuration, you can keep / protect the investment of a production line that has been designed to communicate on a different type of interface than IE, for example Profibus. In this case, the master PLC needs to be equipped with all the communication interfaces that can be found on the equipments from which the data collection is desired, referring to the example in Fig. 4, Profibus and Profinet.

Since API interacts with a single PLC, the ad-vantage that stands out in this topology is a very low cycle time compared to the first version. The use of an intermediate PLC between the API and the production lines has a disadvantage, due to the fact that a fault could occur into it, which would lead to the shutdown of the entire system. This risk could be removed by creating a redundant system.

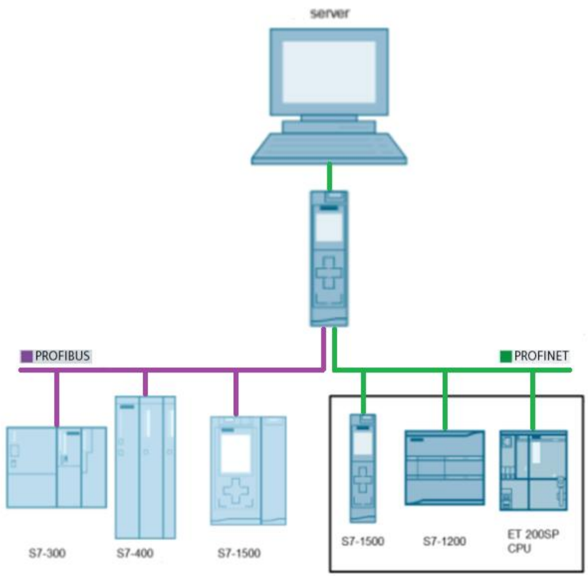

Fig. 4 Indirect access to the machine PLC data

IV. API with MES

All the technologies that revolve around the fourth industrial revolution need an environment that unites them so that they can fulfill its purpose. Its realization becomes possible by creating a computerized platform that can manage them. It is generally built in the form of a website. The advantage of developing a web application, gains ground over a classic application, as it can be accessed from any device, whether mobile or not, both inside and outside the company, without having to install it beforehand. Due to the fact that this platform helps to unite the training technologies, we can say that it represents the engine, without whom I4.0 could not express its utility in the development of intelligent production.

Thus, at the base of decentralized control of automated production lines, there must be an API, which is nothing more than an application or a suite of software applications that run independently of equipments, but which is in continuous communication with them. Created on the basis of very powerful algorithms, this application must be able to collect and interpret data in the shortest time possible, so as not to slow down or affect the proper functioning of production. It also represents the control center of an intelligent factory, which ensures the interoperability between management and production. From here, the management has the possibility to make decisions, based on the analyzed data from the equipments, without the need for an interaction with the production staff.

MES systems have been essential in terms of performance, quality and agility needed for business challenges and the desire for globalized production [16]. The integration of such a system is essential for the efficiency of production processes. Its role is to observe the life cycle of the product, to schedule resources or to analyze the performance and availability of the equipment.

For ICPS, API is the platform in which the physical world and the cyber world intertwine. Through it, the information extracted from the production lines is digitized, transforming into their digital twins. Virtualization offers the possibility to simulate the entire equipment chain, while they should respond to changes, according to the optimized simulation scheme.

The API should respond to the main design principles of I4.0 [15]:

4.1. Interconnection

The first principle refers to the facilitation of communication relations between production lines, as well as between them and people. This interconnection is managed mainly through the API. It also supports remote connection, thus offering the possibility of intercepting data from any location on earth. In this way, employees of the same company, who are in different cities, have the opportunity to analyze the same data, as these are updated in real time.

4.2. Transparency information

Through a collection of data collected from all areas of a process, the entire team, regardless of location, has access to pattern recognition and total supervision. Risk assessment and management are just two of the operations that become less assumed and quantifiable with this level of information. This level of data is the most complete diagnostic tool that any company should want, in order to identify and solve problem areas in real time.

4.3. Decentralized decisions

The third principle is formed by combining the first two principles. Once this level of data is available through sharing, it can be used from anywhere in the company. In the new era of industrialization, the dedicated staff who must check the performance of the equipment and make recommendations of good practices, no longer have to go to the field. Data is now available instantly and can be analyzed from a single location. Also, the shippers of materials can coordinate the production programs with their buyers, through logistical information, so as to eliminate the waiting time.

4.4. Technical assistance

The last principle is the logical extension of the first three. If technology connects people with cars, helps predict the trend of a process and can be used from anywhere, then it can certainly be used to provide suggestions and corrective measures autonomously. This is achievable through advanced technical systems, based on complex algorithms that should be behind an API.

V. CONCLUSIONS

I4.0 is at the intersection of a suite of technolo-gies, without whom it could not fulfill its purpose. Each technology applied in I4.0 has a well-defined role, which simplifies the management of a company. All these features of I4.0 will profoundly contribute to changing the vision of the production process, the product and the business model, by creating a close link between management and production or supplier and customer.

The rate of technological development of I4.0 is exponential, which anticipates new challenges as well as huge benefits, compared to what the world experienced in the previous industrial revolution [5]. This will imply the need for competent staff that can understand and make the most of all these benefits offered by I4.0.

In modern industrial applications, centralized control and centralized point-to-point communication cannot serve the increasingly challenging new requirements of Industry 4.0 [11]. For this reason, most members of the I4.0 community think in terms of decades until this new concept becomes state-of-the-art [12].

The research approached in this study, delivers a perspective of the main training technologies of I4.0, as well as their application for the transition from I3.0 to I4.0.

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