The Cyber-Physical Systems within the industry 4.0 framework

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Abstract. The industrial world is undergoing many changes and often all these modifications are referred to as "industry 4.0", a term introduced in Germany in 2011. There are many doubts about what is going to change within and without a company, in particular as regards the Cyber-Physical Systems (CPS) concept, and its use in this new industrial framework. Starting from the main concepts of industry 4.0 in this paper the meaning of CPS inside the framework of industry 4.0 is analyzed by defining its main features and comparing it to the business model of the fourth industrial revolution, which is based on a service oriented architecture, SOA, with the aim of a flexible, modular and customized production process.

Keywords: CPS, industry 4.0, SOA

1 Introduction

With effect from 2011, when the concept of industry 4.0 was first introduced [1], this aroused a great deal of interest. This new paradigm proposes an overall vision of industrial systems by taking into account aspects related to company organization and its interaction with suppliers, partners and customers. For instance, in [2] the historical evolution of the industrial system from the second world war to present is described, focusing on the Internet of Things (IoT) and the relationship between a company and its customers. In [3] a list of political, social, economic and technological changes proposed by industry 4.0. is set out. This paradigm is based on the Cyber-Physical Systems. There is extensive literature on different ways of conceiving CPS for industry 4.0 applications. In [4] the design of an Unmanned Ground Vehicle, UGV, through an approach derived from the mechatronic field, is presented. The result of this design process is a vehicle controlled by a remote user moreover it demonstrates that CPS and mechatronics systems are different. In particular, CPS is a more holistic view of a system in which Mechatronics is a part. On the other hand, [5] proposes a 5 level model for the design of a CPS. In this case the concept of CPS is

based on the capacity of the system to provide data for remote maintenance, optimized production and quality control purposes. Great attention is paid to the communication capabilities of the system. In general, the actual meaning of a CPS depends on the technical field of the designer. Subsequent to an analysis of the industrial environment, [6] states that many concepts of industry 4.0 are not entirely new, but derive from the development of different application fields merged in an unique industrial vision. In fact, the characteristics of an industrial environment determine the direction of the development of the technologies most suitable for any context.

This article analyses the concept of the CPS, its use and importance within the new industrial framework. To fully understand the meaning of the CPS, the main reasons for and goals of industry 4.0, the new business models based on the concept of service oriented architecture (SOA) and the new industrial architecture of smart factories are presented. An overview of the CPS in the industry 4.0 applications is shown taking into consideration the original meaning of the CPS and its declination in different industrial contexts so as to highlight the common aspects from the specific ones. These concepts are of interest for those who work in the industrial field ranging from the management, technical and researchers.

2 Industry 4.0

The term industry 4.0 was launched at the Hannover trade fair in 2011. "I4.0." has been promoted by the German government which supported a working group made up of academic components such as Acatech (German academy for science and engineer) and industrial partners [1]. At the basis of the government interest, is the intention to push the German industry to become the leader in a new way of realizing and designing production systems. Following this initiative, others have tried to define what the industrial evolution will be. Among these, we find the USA initiative industrial internet consortium (IIC), focusing on industrial communication protocol standardization which is a key point in the connection of production sites. A collaboration between the platform IIC and industry 4.0. started in 2016. Despite different names and initiatives resulting in scientific papers and articles, the term and the concept expressed by "Industry 4.0" have been universally acknowledged as the best description of the fourth Industrial Revolution. Not only is I4.0. the first initiative in this context, but also describes, by means of a complete overview, the framework of the industry of the future. The changes promoted by industry 4.0 are many and related to different aspects of the industrial world. The technological milestones of this revolution, on which the entire paradigm is based, are two:

- internet
- CPS(cyber physical system

These two technologies determine a new way in the exchange of information, both internal and external to the industry, and a new way to conceiving automatic systems. As mentioned above, the definition of a CPS is not unique, for

this reason the meaning of this term must be clarified and its importance, within this context, highlighted. The progress in the sector of "information and communication technology" (ICT), as well as that related to the so called "smart objects" is increasing the amount of data available originating from electronic devices connected to internet not only in terms of quantity but also quality.

In this context the concept of IoT, internet of things, has arisen, based on the availability of data coming from, so called, smart objects. Big Data is the term used to gather the technologies and methodologies suitable for analyzing such data and obtaining the relationship between them. The innovative idea of industry 4.0 is based on exploiting such data and communication systems so as to create an industrial network where everything is connected and represented by a digital copy, called "digital twin". This allows one to create an efficient and flexible production system capable of responding to quick changes in the market, ever increasing product customization and the reduction of lead times. The changes that industry will undergo are manifold and related to different topics such as horizontal integration through value networks, vertical integration within factories and end-to-end engineering solutions [1].

2.1 Business models

The digital dimension of industry 4.0 leads to new possibilities of horizontal integration, meaning the interaction among industry, suppliers and customers, and thus leading to a new way of doing business. Such new business models are based on the possibility of accessing a great amount of data in an ever faster way and to a complete digitalization of the surrounding world. Industries, in the form of CPSs connected to an industrial network, provide third parties with a set of services according to a service oriented architecture, SOA[1, 7]. In the industrial world the concept of SOA arose from the field of business IT in an attempt to create an IT support for companies. This support should be capable of giving assistance for flexible production and able to follow rapid business changes in the companies themselves. Bieberstein et al.[8] defines the SOA as a framework for integrating business processes and supporting IT infrastructure as secure, standardized components—services—that can be reused and combined to address changing business priorities. This concept is directly transferable to the CPS whose functions can be reused and recombined to create new and different value streams. The concept of SOA was conceived to conciliate the business requirements of a company with the IT functions or services that it needs via the use of a platform which integrates the abovementioned services and make them available to all the interested parties requiring them.

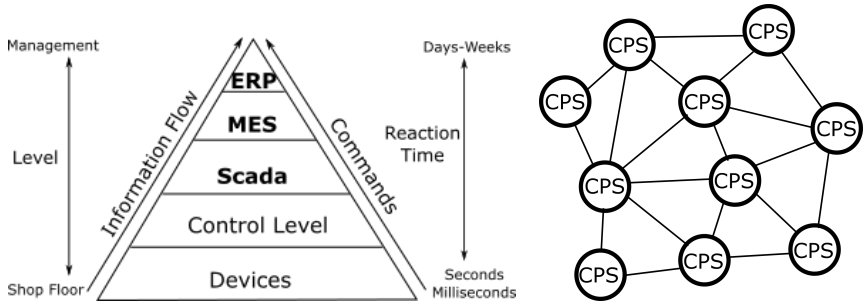
One of the main problems related to the actual implementation of this concept is the different perspective of a service from a technical point of view and a managerial one. Perrey et al.[9] point out very well the difference between them. On the business end, a service is something for which a client is prepared to pay. For a technician, a service is something to be implemented regardless of how it is actually realized. The utopia of SOA relies on ensuring an IT platform which can provide services from a business point of view which can be recombined to

form new ones virtually on demand [9]. Industry 4.0 exports this concept expanding it to every 4.0 component in the form of CPSs providing services. Such services can be called upon and recombined due to the IT architecture of CPSs and their business layer which defines their utilization. An industrial network, which connects thousands of industries, allows one to have an infinite number of value streams considering all the possible combinations given by the CPSs connected within such network.

One of the main consequences, in terms of new business models, is the so-called "Cloud Manufacturing, CM. Such concept derives from the cloud computing idea as explained by Xu[10], and can be described as manufacturing resources provided as a service over the internet. In the same way as computing resources are made accessible on cloud platforms, such as very heavy engineering analyses like FEM, Finite Element Method, or CFD, Computational Fluid Dynamics, the same could happen for production resources in production sites conceived as CPSs. The sharing of production resources for a product manufacturing is the virtual enterprise described by Camarinha-Matos et al.[11] as a temporary alliance of enterprises that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks. At the time this definition was coined, 1999, the implementation of such an idea was remote from the possibilities provided by modern technologies. The evolution of the ICT and the automation world has led to the progress of advanced manufacturing resulting in the CM [12]. The CM platforms have many analogies with the CPS platforms defined in [1]. Liu et al.[13] by executing a comparison between industry 4.0 and CM and their related platforms concluding that they are interchangeable. CM focuses on the IT issues of connecting customers and their personal requests, with the services they require. Industry 4.0 focuses on connecting the industries in a single production network. These two things are complementary.

3 The industrial architecture of a smart factory

In order to achieve a flexible and customized production, industry 4.0 needs to change the internal organization of production systems. During the industrial evolution, the well-known standard ISA-95was developed [14], as shown in fig.1a. This standard represents a business according to a pyramidal architecture in which the information flows from the bottom to the top, from the shop floor to the management level, and vice versa. This vision abstracts two different concepts: one being the conceptualization the relationship of the responsibility within the company, the other being the definition of mutual interfaces between the IT components developed through the years. At the top of the pyramid we find the ERP systems which today are very versatile packages performing numerous management tasks for different departments ranging from the management of material to the management of the employees [15]. Directly below, we find the MES systems which manage the production according to the decisions and the programs developed at the upper levels, after we have the supervisory con-



(a) ISA-95 model (b) Distributed control

Fig. 1: Transformation of the industrial architecture

trols and data acquisition (SCADA) which actually collects the data from actual production components, such as PLCs, CNC machines or other devices used in production lines.

With the introduction of CPSs, this architecture is going to change drastically. We are witnessing the transition from a pyramidal concept, where the tasks are well defined and separate, to a distributed system, where every CPS has a certain degree of intelligence and autonomy and participates in the value stream of the production process [16]. This new paradigm is usually represented by a set of CPSs connected to each other, as shown in fig.1b. Their collaboration focuses on the production process. Every CPS participates in the tasks previously performed by ERP and MES systems. Even the latter are capable of becoming CPSs. This happens when their software skills are shared with the internal network of a company. For instance, this is the case when a machine independently asks for the replacement of a working tool without the command of a MES, or when it asks to a human operator to load a new component into the machine. These are simple but effective demonstrations of duty redistributions. A smart factory is strongly flexible due to the fact that every CPS provides functions which are usable by the management levels in order to create services which can be combined as required.

When the physical part of a CPS is a physical person, different aspects should be taken into consideration, be they technical or not. Industry 4.0 does not exclude manpower, but tries to integrate it by means of, for instance, the development of the augmented reality (AR), collaborative robots and the use of various human machine interfaces (HMI). In the near future, operators with new skills, capable of working within a complex system such as smart factory, will be required [17]. In particular, the emphasis will be on communication skills, ability to organize work and new IT skills. Furthermore the social issues arising from a job strictly related to a virtual world must be taken into consideration, with the training of so called “click and cloud” workers[17]. This is why, Industry 4.0 should take into great consideration the work quality within the industrial environment.

4 The CPS inside industry 4.0

The term CPS was coined by Helen Gill in 2006 at the National Science Foundation in the USA [18] as the integration between computation and physical processes within the context of embedded systems. In [19] we find how Cyber-Physical Systems (CPS) are integrations of computation with physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. The physical part of a CPS can be a mechanical part, a chemical or biological process and even a physical person [18]. The computational part is made up of two or more computational systems connected within a network. They interact with the physical part through sensors and actuators. This network concept is strongly linked to a CPS. More particularly, it is about the interconnection of all the parts of which it is made up. The design of a CPS originates partially from the design of a mechatronic system [4]. For the latter, the environment is considered to be a source of disturbance, to be isolated and eliminated [20]. Thus, the design purpose is to obtain a closed system with the object of accomplishing a function regardless of the external environment.

Industry 4.0 defines the CPS as a convergence between physical and virtual world [1]. The acatech, academic party of the industry 4.0 working group, describes the CPSs as systems based on embedded software capable of having access to physical data and able to influence physical processes through sensors and actuators. They must be able to interact with both the physical and the digital world. Furthermore, they must be connected to a global network with the capacity to obtain information and services and with the possibility to interact with a physical person[21]. In this context, the CPSs must be able to accomplish specific tasks independently and to communicate with the external environment in order to accomplish different tasks. According to the RAMI model [7], Reference Architecture Model Industrie 4.0, every component can become a CPS, even a software which, obviously, contains no physical parts. Nevertheless, it can provide useful and vital services within an industrial company. In order to give a practical example, a CPS could be a simple sensor capable of providing a measuring function shareable in a network with an internet connection. Otherwise, a CPS could be an entire industry which realizes specific goods with real time monitoring and controlling of every production task at all management levels.

The concept of CPS within industry 4.0 is not the same as that presented by Lee. Industry 4.0 pays attention to the capacity of the CPS to communicate with the external environment. Any industry 4.0 component can be regarded as a CPS if it has a digital representation and the capacity to communicate with the external world, independently from the internal design. Table 1 summarizes the final comparison of this study highlighting the differences. Notice that Industry 4.0, borrows the name CPS from the embedded system field, but changes the meaning. The necessity for a flexible and customized production leads to the development of machines capable of working in an interactive environment in which data and information run at an ever increasing speed. In order to achieve this result it is necessary to realize the production lines through the use of

Table 1: Features of classical CPSs and CPSs 4.0

CPS Classical	4.0
Internal Network	External Network
Physical part necessary	Physical Part optional
Saving on energy and space	Focus on services provided
	Modularity

CPSs that make any component able to exchange data and information with anything which is involved in the production process, such as physical persons, software, devices and the like. The concept of communication and modularity is well presented by Mosterman et al.[22] where a pick and place system built to move some simple colored blocks along a line on specific positions is described. Every block is a smart device capable of performing a specific pick and place task. For instance, a block can require to be moved in two positions along the right direction with respect to its current one. The pick and place machine manages this request coming from the blocks according to a precise logic. The working capacity of the system is nothing other than the working capacity of each component. In this case, the capacity of the blocks to effect a request, and the capacity of the "pick and place" machine to manage and deliver it.

Conclusion

The vision proposed by industry 4.0 for the production systems of the future is lead by the desire to obtain an increasingly customized production process. This requires flexible and modular systems whose basic components are the CPSs. The idea of these systems, which was conceived in the embedded systems field, has been adapted to the framework of industry 4.0 and differing definitions are found in scientific literature. In this article we clarify the main differences between a classical CPS definition and one developed for industry 4.0 framework, outlining the main features that these components should have in order to support the evolution of new production systems. Smart-factories development, based on an architecture which is no longer pyramidal as in ISA-95, but rather on a distributed control model, has been reached through the use of modular components, such as machines, physical persons or software. These are taken into account, from a managerial point of view, as a set of services available according to a SOA architecture, and from a technical point of view, as a set of tasks to be implemented independently.

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