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Enabling technologies, application areas and impact of industry 4.0: a bibliographic analysis

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Abstract

The demand for shorter delivery time, more efficient and automated processes, higher quality and customized products have driven companies towards the fourth industrial revolution. This study aims to contribute to the state of the art by evaluating the main application fields of Industry 4.0 and analyzing the enabling technologies used in these fields. To this end, a bibliographic analysis for Industry 4.0 was first conducted by searching relevant papers with the support of the Scopus database (www.scopus.com). Then, an overview on Industry 4.0 was performed with the purpose to deeply understand the context of this study. Finally, the attention moved on the identification of the enabling technologies and the main application areas of Industry 4.0. These latter, as they emerged from the literature, appear to be Logistics 4.0, Automotive, Smart home and Agriculture 4.0.

Keywords: *Industry 4.0; bibliographic analysis; enabling technologies; application areas*

1. Introduction

Over the years, worldwide the manufacturing context has been characterized by disrupting breakthroughs leading to radical changes in production and related processes [1]. Indeed, industries have and are still undergoing three industrial revolutions (sometimes called Industry 1.0, 2.0 and 3.0) [2]. The first industrial revolution began at the end of the 18th century and was characterized by mechanical production plants based on water and steam power [3]. Industry 2.0, from the end of the nineteenth century to the 1980s, was the period when industrial products burgeoned both in volume and variety [2]. Since the 1970s up to the present days, the third industrial revolution has been unfolding. This revolution described the use of electronics and information technology (IT) in production automation and generated a widespread digitization wave. In turn, this digitization wave created a suitable environment for Industry 4.0 [4].

The general concept of Industry 4.0 was firstly introduced by the German government program to introduce a paradigm shift toward a digital future in industrial production and to increase the competitiveness of the manufacturing industry [5,6]. Industry 4.0 involves the use of advanced Information and Communications Technology (ICT) to increase the degree of automation and digitalization of production, manufacturing and industrial processes. Its purpose is to manage the entire value chain process, improving efficiency in the production process and generating quality products and services [7]. Indeed, Industry 4.0 was and is still associated with many opportunities and benefits, like highly flexible mass production, reduction of complexity costs, emergence of entirely new services and business models or real-time coordination and optimization of value chains [8].

There are several technologies involved in this global trend: Internet of Things (IoT), Big Data, Cloud Computing, Additive Manufacturing, Autonomous Robots, System Integration, Augmented Reality (AR), Cyber-Physical Systems (CPSs), 3D printing, electric vehicles and Simulation [9]. To be more precise, IoT technologies enable the interconnection between objects and people and their information sharing, and are one

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of the most common and widely used technologies for the formation of smart environments based on sensors, Radio Frequency Identification (RFID), actuators and mobile phones [7,10]. In addition to the IoT, the fusion of the physical and the virtual world is a further important component of Industry 4.0. This fusion is enabled by CPSs, which are integrations of computation and physical processes [11]. Industry 4.0 increases the digitization of manufacturing with CPSs, in which connected networks of humans and robots interact and work together with information shared and analyzed, supported by big data and cloud computing along entire industrial value chains [3].

Industry 4.0 has become a promising production paradigm striking hard at many automotive and manufacturing industries in the recent few years [12].

On the basis of the considerations above, this study aims to contribute to the state of the art by analyzing the enabling technologies of Industry 4.0 with particular attention to the main application areas. The chosen research methodology to achieve the stated aim is the literature analysis; more precisely, a bibliographic analysis about Industry 4.0 was conducted.

The paper is divided into six sections. The next section describes the adopted methodology. Section 3 presents the overview on Industry 4.0. Section 4 details the enabling technologies of the Industry 4.0, followed by the application areas in Section 5. The paper concludes with Section 6 summarizes the paper with conclusions and future directions.

2. Methodology

The research methodology adopted in this paper is based on four sequential steps (Figure 1).

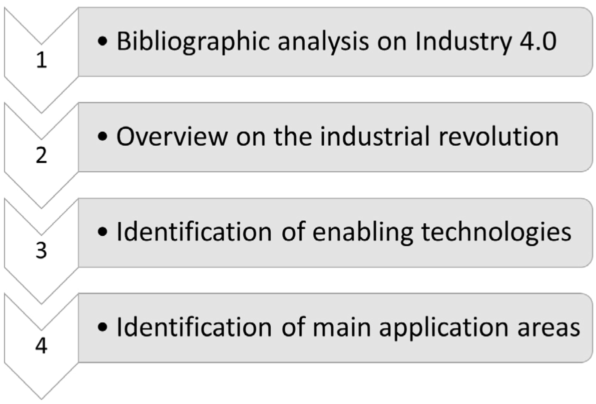

Fig. 1. Research methodology.

The first phase of the research dealt with a careful bibliographic analysis. The bibliographic search was carried out with the support of the Scopus database (www.scopus.com). The research revealed the main topics dealt with on Industry 4.0: enabling technologies and application areas. In particular, the search returned a total of 296 papers dealing with logistics 4.0, 210 with the automotive industry, 99 with smart home and 52 with agriculture 4.0, respectively. Then, an overview on Industry 4.0 is carried out in order to deeply understand the context of this study, with a particular focus on the industrial revolutions of the last centuries. As a third step, the attention moved to the identification of enabling technologies and, finally, the authors identified the main application areas of Industry 4.0.

3. Overview on industry 4.0

The twentieth and twenty-first centuries are ages of industry in which manufacturing is important. Indeed, industries have and are still undergoing three industrial revolutions (sometimes called Industry 1.0, 2.0 and 3.0) [13]. Transition from agriculture to industrial society (Industry 1.0), from Industry 1.0 to 2.0, and then to 3.0 was well recognized and accepted by the society. Similarly, the transition from Industry 3.0 to Industry 4.0 requires extensive analysis to understand irreversible changes [14]. To be more precise, the first industrial revolution took place in England in the mid-18th century and was strengthened by the invention of the steam engine. The cottage industry and manual work were replaced with mechanical production using water and steam energy [15]. In the second half of the 19th century there was the second industrial revolution in Europe and the USA. During that revolution mass production was realised with the help of electrical energy [16]. In order to meet the growing demand, a range of technologies in the industry and mechanization was developed, such as an assembly line with automated operation, allowing for an increase in performance. This period also saw a number of developments of management programs that made it possible to increase the efficiency and effectiveness of manufacturing facilities. Division of labour, where each worker does a part of the total job, increased productivity. Lastly, just in time and lean manufacturing principles further refined the way in which manufacturing companies could improve their quality and output [17]. The third industrial revolution began in the middle of twentieth century and introduced automation and microelectronic technology into manufacturing. These advances in manufacturing technologies were closely related to (ICT). In the third industrial revolution, the advancement of ICT was at the core of every major shift of the manufacturing paradigm [16]. The development of new technology has been a primary driver of the movement to Industry 4.0. Some of the programs first developed during the later stages of the 20th century, such as manufacturing execution systems, shop floor control and product life cycle management, were farsighted concepts that lacked the technology needed to make their complete implementation possible. Now, Industry 4.0 can help these programs reach their full potential [17].

4. Enabling technologies

Smart manufacturing, which is the fourth revolution in the manufacturing industry and is also considered as a new paradigm, is the collection of cutting-edge technologies that support effective and accurate engineering decision-making in real time through the introduction of various ICT technologies and the convergence with the existing manufacturing technologies [18]. As mentioned before, those digital technologies include CPS, IoT, cloud computing, big data analytics, machine learning, advanced manufacturing technologies with sensors, decentralized agent-driven control, advanced robotics, AR, advanced tracking and tracing technologies, and additive manufacturing [19,12].

CPS are automated systems that enable connection of the operations of the physical reality with computing and communication infrastructures [20]. IoT is described as the concept of gathering information from physical objects using computer networks or accelerated wireless connections [21]. Moreover, cloud manufacturing is the cloud computing technology that is applied to the manufacturing area, and it is considered as an innovation of the existing manufacturing paradigm similar to smart manufacturing [18]. Other sources of data are design records, customers' order, suppliers' delivery, stock and logistic related information. As a whole, this large quantity of data is defined as big data, which is another major notion in Industry 4.0 [21]. Machine learning is a group of computer techniques that focus on extracting useful knowledge and make appropriate decisions from big data, the large volume of data, both structured and unstructured, that can be obtained from a business or factory at any given time [22]. Robotics will play a key role; innovative technologies and solutions, traditionally associated with the service robotics sector, are going to migrate to industrial smarter robots that will draw on a much broader range of technology, allowing higher levels of dexterity and flexibility, the ability to learn tasks without formal programming, and to autonomously collaborate with other autonomous devices and human operators, thanks to the enhanced capabilities offered by advanced communication networks [23]. AR is a technology enriching the real-world factory environment of the smart operator with digital information and media (sound, video, graphics, etc.) that is overlaid in real-time in his/her field of view. Hence, AR can be considered a key enabling technology for improving the transfer of information from the digital to the physical world of the smart operator in a non-intrusive way [24]. Additive manufacturing processes, also known as 3D printing, have a digital dataflow that transforms the raw materials into final parts [22]. Additive manufacturing has advantages, as compared to the existing manufacturing methods in material efficiency, resource efficiency, part flexibility, and production flexibility, and has weakness in size limitation, imperfection, and cost [18].

Industry 4.0 has two key factor: integration and interoperability [25]. In particular, vertical integration allows CPS to be used to create flexible and reconfigurable manufacturing system in factories. It refers to the integration of various IT systems at different hierarchical levels during a manufacturing process. While instead, horizontal integration refers to the use of these technologies to exchange and manage information across different agents around a manufacturing process such as resources management system, logistics, marketing and intercompany value chain [26].

5. Application areas

According to [6], mechanical and plant engineering with particular attention to logistics field, the automotive industry, the smart home, and the agriculture area would be primarily affected by Industry 4.0.

5.1. Agriculture

The Industry 4.0 in the field of agriculture is being referred to as Agriculture 4.0, wherein technologies are being promoted and precision agriculture is emerging rapidly, perfecting many conceivable future technologies to create new value [27]. The interoperability and digital networking of agriculture will enable new process control systems and new sales models such as online slurry sales points, exchange platforms where data is traded for advice, or online direct marketing [28]. There are several components of Agriculture 4.0 involved in this global trend. From soil fertility to connectivity, IoT sensors are critical parts of modern agriculture; the rise in indoor farming is being driven by advances in LED technology; some robots are doing what farmers used to do in farms; most devices in farms are powered by solar, and solar panels are important; drones and satellites are used for data collection of farm vegetation. These solutions are captured as farm financial technology and they include payment, lending and insurance, which are done digitally for farming [29].

5.2. Logistics

Increasing customers' requirements together with the current trend of digitization in the spirit of Industry 4.0 puts pressure on manufacturing companies to increase both the flexibility and the performance of their manufacturing and logistics processes with the origin of Logistics 4.0 [30]. An efficient and strong Logistics 4.0 must rely and use the following technological applications: Resource Planning, Warehouse Management Systems, Transportation Management Systems (TMS), Intelligent Transportation Systems (ITS) and Information Security [31]. Some examples can be used to describe the Logistics 4.0 environment: autonomous robots and vehicle along with tracking and decision-making systems keep control over inventory; smart products and cloud-supported network keep the information flow intact; real-time big data analytics of vehicle, product and facilities locations can find optimal routing for material and product transportation [32].

5.3. Smart home

Smart home environments have emerged as a serious field of research and commercial development over the last decades [33]. Constructing a smart home is not a task without intricate challenges due to involvement of various tools and technologies [34]. A range of applications have been developed to provide improved convenience, energy savings, security and entertainment for residents, and special environments have been developed to improve the living standards and autonomy of the elderly and disabled [33]. To be more precise, the services provided by those modern technologies can be divided into three categories: Emergency Assistance, Autonomy Enhancement and Comfort [35]. In fact, smart home system has proved to contribute to increase independence and safety and made our everyday house-hold tasks easier [36].

5.4. Automotive

The automotive industry lends itself particularly well to the analysis of application cases of the Industry 4.0 technologies. Indeed, it includes many characteristics which could be the basis of the factory of the future: client orientation by the personalization/customization, modularity and interoperability [37,38]. Production lines in automotive feature a predefined versatility for multi-model and multi-variant production at high volume by combining advanced automation with the flexibility of manual work [39]. Indeed, the automotive industry recognizes the value of technology and disseminates the technology throughout the industry [40]. For example, during Toyota's annual general meeting in June 2017, President Akio Toyoda introduced some new challenges and opportunities, such as electric and automated vehicles, connected cars and car-sharing business models [2]. The original equipment manufacturers and their major suppliers already started the transformation process in this field having a number of major programs initiated, inter alia, new stage of interconnectivity by introduction of the comprehensive IP protocol in the vehicle. It embraces full communication functionality and facilitates enhanced infotainment, better safety, highly automated and autonomous driving and enhanced parking capability [41].

6. Conclusions and future research

This paper has tried to contribute to the state of the art by analysing the enabling technologies of Industry 4.0 with particular attention to their main application areas. The objective of this study is twofold: on the one hand the identification of Industry 4.0 enabling technologies, on the other hand the analysis of the main Industry 4.0 implementation areas.

To this end, a bibliographic analysis for Industry 4.0 was conducted with the support of the Scopus database (www.scopus.com). Then, an overview on Industry 4.0 was performed with the purpose of deeply understanding the context of this study. Finally, the attention moved to the identification of the main enabling technologies and application areas of Industry 4.0.

All Industry 4.0 enabling technologies that emerged from the bibliographic analysis were mapped. The results show that the enabling technologies most frequently considered in the literature are Robots, Smart products and Big data.

From the analysis carried out, the main application areas of the Industry 4.0 appear to be: Logistics 4.0 (with 296 papers), Automotive (with 210 papers), Smart home (with 99 papers) and Agriculture 4.0 (with 52 papers).

Table 1 lists, for each application area considered, the main results in term of enabling technologies and impact on industry.

The results in Table 1 are useful to provide a preliminary analysis of the main application areas of Industry 4.0 and of the relating enabling technologies, and can be used as a basis for future research in this field.

To be more precise, starting from this paper, future research activities could be directed toward carrying out a systematic review of Industry 4.0 in the application areas identified in this study. Similarly, it could be useful to develop a framework to drive managers in the practical implementation of Industry 4.0 in the contexts emerged in this study.

The results of this study also highlight that the interest towards Industry 4.0 has increased in recent years and that Industry 4.0 applications have reached a number of different industrial sectors, as can be easily argued from the number of papers found during the bibliographic analysis. Hence, a further possible future research activity is to evaluate whether Industry 4.0 represents a well-established and mature research area, which could be justified on the basis of the fact that Industry 4.0 is a complex set of technologies whose characteristics distinguishes it from previous industrial revolutions. Such an evaluation could be supported by a more detailed, systematic review of the literature, coupled with bibliometric analyses.

Table 1. Main I4.0 technologies and effect per field.

Area	Enabling technologies	Effect
Agriculture	Interoperability and digital networking	New process control systems and new sales models
	LED technology	Indoor farming
	Robots	Do the farmer's work
	Drones and satellites	Data collection of farm vegetation
Logistics	Autonomous robots and vehicle along with tracking and decision-making system	Keep control over inventory
	Smart products and cloud-supported network	Information flow intact
	Real-time big data analytics of vehicle, product and facilities locations	Optimal routing for material and product transportation
Smart Home	Emergency Assistance, Autonomy Enhancement and Comfort	Increase independence and safety and made our everyday house-hold tasks easier
Automotive	Comprehensive IP protocol	Better safety, highly automated and autonomous driving and enhanced parking capability

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