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INDUSTRY AND UNIVERSITY 4.0 - AN OVERVIEW

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Abstract: The future of the manufacturing industry lies in a new paradigm coined as Industry 4.0. This term is an umbrella for a variety of intertwined concepts. The terminology revolving around Industry 4.0 can be confusing and a disambiguation is proposed in this article. In a few words, Industry 4.0 is all about connecting people, services, machines and data through nine fundamental technologies. Explanations and examples of applications for the concept of Industry 4.0 and the corresponding technologies are given. The role of the university in preparing the workforce for the future of the industry is also discussed. Universities should not only adapt their curriculum but also their teaching methods and improve collaboration with the industry.

Keywords*: Industry 4.0, IoT, Education*

INTRODUCTION

Industry 4.0, Internet of Things (IoT), Industrial Internet of Things (IIoT), Internet of Services (IoS), 4IR (4th industrial revolution), cyber-physical systems (CPS)…Everyone involved into technology has been confronted to this confusing plethora of acronyms that feeds the current discussions on the future of industry. Plenty of sometimes contradicting and opinionated definitions can be found on the Internet. The truth is that no rigorous definition yet exists for most of these terms. However, a few authors have proposed to disambiguate them through a thorough analysis of the most commonly accepted interpretations of these terms (Hermann et al. 2016) (Boyes et al. 2018). The definitions given hereafter are based on their analysis.

The term Industry 4.0, or Industrie 4.0 in German language, was first introduced by the German government in 2011. It was defined as one of the key initiatives for its high-tech strategy for the modernization of the country's industry (Kagermann 2013). Similar efforts were developed in the US and UK. They were coined as Industrial Internet and 4IR. The meaning of these three terms is similar. The main idea behind the concept of Industry 4.0 is to combine the IIoT, which is an industry-oriented subset of the IoT technology platform, with the IoS, which is a set of processes to improve the value chain organization based on the analysis of data obtained from the IIoT. These improvements include better service delivery and product customizability, boosting productivity, reducing costs, energy consumption and build to-order cycle. Human decision-making role is integrated into the Industry 4.0 framework through the so-called Internet of People (IoP). The framework resulting from the combination of IoT, IoP and IoS is referred to as Internet of Everything (IoE). The

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Industry 4.0 concept can be interpreted as the application of the IoE to the whole of the industry.

Let us describe a possible Industry 4.0 scenario for an automobile factory. The process starts from an order placed on the manufacturer website by a customer (IoP). The order data flow to the manufacturing plant to allocate machines and staff. In parallel, suppliers also receive the data listing the material needed for production of the customized car. Together, manufacturers and suppliers form a value chain creation network (IoS). The production starts with the basic chassis. All the needed material and the chassis get an electronic ID tag, which enables to track the location and status of the parts in the factory and transmit the production status through the cloud (IIoT). The possibility to accommodate a last minute request from the customer to change the configuration from the car can be evaluated from the near real-time data available to both the customer and manufacturer. From the factory worker perspective, an active assist system improve their work conditions, efficiency and safety. Hand held assembly tools have embedded smart technologies, for example to determine the exact torque to apply on a screw or limit the use of a tool to specific users. Predictive maintenance measures are also implemented. Various sensors attached to the production machines transmit regularly their data to the cloud for analysis through machine learning algorithms. Failure is predicted before it even happens. The operator responsible for fixing the machine does not need to use repair manuals. Instead, he uses video goggles and connects to the machine's manufacturer service. Using augmented reality, a specialist guides him through the repairs in real time.

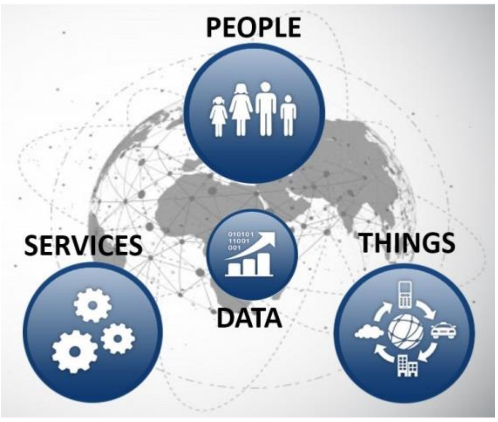

Figure 1. The internet of Everything (IoE)

Many core technologies involved in Industry 4.0, such as deep learning, autonomous robots or digital twins, have not yet reach a level of maturity that guarantees their applicability in real life scenarios. Following Gartner's hype cycle terminology, these technologies have just reached their peak of inflated expectations (Panetta 2018). Therefore, the odds are great that the current vision of Industry 4.0 is over idealized. Many challenges have yet to be overcome, amongst which standardization and data security are critical (Schroder 2015).

Despite these reservations, the industry will undoubtedly experience tremendous transformations in the coming years. Universities will play an important role to prepare the future workforce, which will necessarily be highly educated, particularly on the technical level. The first obvious role of the university is to adapt their curriculum to the upcoming demand. To help to determine the way curriculum should be refined, a description of the different technologies involved in Industry 4.0 is given in a first section. In a second part, the role of the university is discussed.

KEY TECHNOLOGIES IN INDUSTRY 4.0

The generic architecture of an Industry 4.0 system is given in Figure 2. It is based on the nine key technologies described by Russman et al. (2015) and organized in three layers. The first layer connects the physical and digital world. It is made of sensors, actuators and various machines able to sense, modify or interact in some way with the physical world. The second layer controls and secures the flow of data between the services, people and machines. The third layer stores and adds value to the digital data by processing them in various manners. A system based on this combination of technologies is sometimes referred to as cyber-physical system (CPS). A short description of the different technologies involved in the three layers is given below.

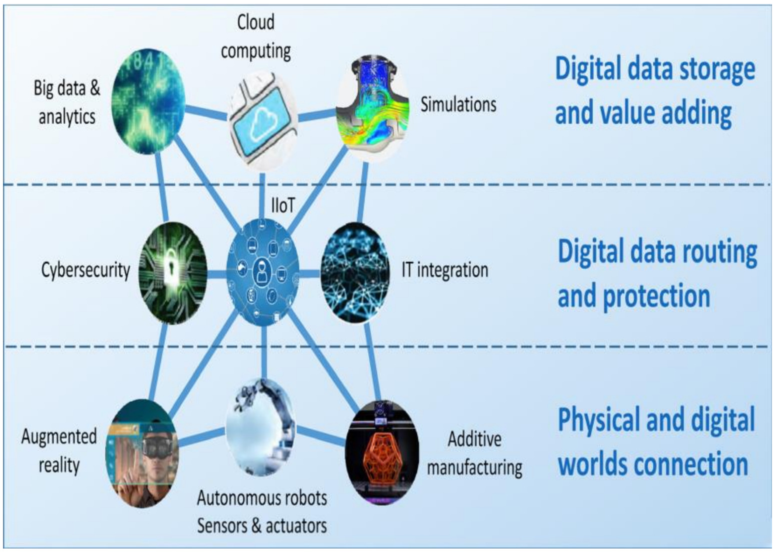

Figure 2. Overview of the core technologies in Industry 4.0

Augmented reality (AR): with AR, virtual information is superimposed to the physical world with the aim of enriching human's perception of reality with augmented objects and elements (Syberfeldt et al. 2016). Application cases include machining, production, factory planning, assembly and security to name a few. In the smart automotive factory scenario described earlier, an AR helmet could be used to help a factory worker to visualize repair instructions given by a remote expert, identify overheating parts in his environment, pinpoint the location of tools or parts…AR is mostly associated with smart vision systems but it includes more senses

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than the visual. It can potentially apply to hearing, touch and smell (Azuma et al.2001).

Autonomous robots: they result from the progress in robotics, AI and IoT. They become smarter in terms of not only computing, communication and control but also in terms of autonomy. Based on the data that they acquire from their environment, share with fleet mates or receive from the cloud, they can complete tasks intelligently with minimal human input. For example, they can transport materials through the factory, avoid obstacles, coordinate with fleet mates and determine in real-time where pickups and drop-offs are needed. Only in case of exceptions, interferences, or conflicting goals, they can choose to request the attention of a human operator (Hermann et al. 2016). Wireless sensors networks (WSN), actuators and RFID tags are other important elements of Industry 4.0. They may be integrated with robots, parts, materials or the factory infrastructure and help for logistics and condition monitoring (Wang2018) (Schütze et al. 2018). Low cost sensors are essential for wide adoption of WSN technologies. Micro-Electro-Mechanical-Systems (MEMS) technology is an excellent candidate to provide such sensors. Additionally, energy harvesting techniques converting energy from the environment (vibrations, thermal difference) into useful electrical power can further reduce the costs and inconvenience of battery replacement for the sensor nodes (Alioto 2017).

Additive manufacturing: it is a synonym for 3D printing. 3D printers produce object by depositing layer over layer of the desired cross-section based on computer-assisted designs. The term “additive manufacturing” differentiates this method from traditional CNC machining and its subtractive nature, i.e. material is removed from a block that must be at least as big as the part that is to be made. Compared to CNC machining, additive manufacturing offers flexibility in terms of shape and materials, the possibility to customize small batches, lower production costs, lower energy consumption and the possibility to print in a single session parts that would require the assembly of multiple separate parts using traditional manufacturing technologies. On the other hand, 3D printing of a part is definitely slower than CNC machining. However, a CNC produced part requires considerable planning and may involve a multistage process with several machines. This may make the whole manufacturing process slower than with additive manufacturing (Gibson 2010). Compared to injection molding or casting, 3D printing does not require molds, which are costly elements of such processes.

IIoT: it is the backbone of the routing layer in Figure 2. The IIoT is the network infrastructure that enables the flow of digital data between machines, services and humans. It involves many connectivity technologies that must be combined to fulfill the needs of a particular application. For example, in the case of wireless sensor network monitoring the temperature distribution over a factory, low power, low bandwidth and low latency are essential. These requirements can be met by Zigbee or Bluetooth Low Energy (BLE) protocols. Forcommunication between robots over the floor of the same factory, high bandwidth and low latency are necessary but low transmission power is not as essential as previously. In that case, Wi-Fi may be

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the best candidate. Sending data from the robots or sensor network to remote servers or on the smartphone of the plant manager requires a technology that can accommodate long distance transmissions. In that case, a classical wired TCP/IP or wireless 4G connection will fit the bill. Prior to being transmitted, the data from the sensor network or robots will have to be converted to the chosen long distance protocols through a gateway. Different groups try to solve the IIoT connectivity puzzle by standardization of the communication protocols (Sethi and Sarangi 2017). However, many companies will prefer competition to partnership. Therefore, business itself may be the biggest roadblock to standardization.

Cybersecurity: in 2016, access to some popular websites such as Netflix and New York Times was blocked through a Distributed Denial of Services (DDoS) attack. Hackers had hijacked possibly millions of webcam or IP cameras to flood the above-mentioned websites with data and prevent them to function properly. In 2015, hackers were able to remotely take control of a Fiat Chrysler and disable its brake and engine (Hilgendorf 2018). These examples demonstrate the vulnerabilities of the IoT, which exist because electronics consumers prioritize cost over security. Further complications occur because many IoT devices depend on a global

supply chain, are made with parts from various national origin and with heterogeneous standards of security. Additionally, it is difficult in many cases to detect that an IoT has been compromised. As in the case of botnets, the device may work as intended while performing nefarious tasks in the background. Potential security threats are present on the three layers of Figure 2 and various countermeasures should be considered (Zhao and Ge 2013).

IT integration: integrating the IT infrastructures of the participants in the value chain will lead to new business, innovation and logistics models. The mass customization paradigm, defined as "producing goods and services to meet individual customer's needs with near mass production efficiency" (Tseng and Jiao 2001) is an example of a new business model made possible by the transparency and real-time access of product and production data by the different departments of the manufacturer, suppliers and customers. Another example is collaborative manufacturing where several organizations join forces to multiply the available capacities without the need of further investments (Lin et al. 2012). The fragmentation of the production process over several locations requires strong coordination that can be achieved through proper integration of the IT systems of the business partners. In terms of innovation, Industry 4.0 will see the emergence of a new paradigm emphasizing a strong degree of collaboration and coined as co-innovation (Lee et al. 2012).

Cloud computing: it corresponds to the distribution over the Internet of services such as networks, servers, databases or software. Cloud computing allows small sized companies, which cannot afford to invest in their own IT infrastructure or software development team, to join the digital revolution. Cloud computing comes in three flavors (Rani and Ranjan 2014). Infrastructure as a Service (IaaS) provides a remotely accessible IT infrastructure including virtual machines, network and operating system, which enable the customer to build its own cloud based IT platform. In Platform as a

Service (PaaS), the IT platform is already available forthe customer to develop and test his software without having to manage the server, database and storage network. With Software as a Service (SaaS), the provider manages both the platform and software. The customer accesses the remote software by login in a web browser. Cloud computing is advantageous in terms of cost, flexibility, performances and reliability. On the other hand, energy consumption and security management are some of the most pressing issues with this technology (Zhang et al. 2010). While the centralized nature of cloud computing brings many gains, some critical application cannot afford the latency inherent to the transfer of data between an IoT device and a remote server. For example, a sensor node monitoring the state of the engine of a plane should process data immediately to detect a potential fault. Transferring the data over the IoT and the resulting time delay would jeopardize the safety of the plane. The combination of local and remote processing of data gives rise to the notion of fog and edge computing (Hassan et al. 2018).

Big data & analytics: it refers to the large volume, fast refreshed, multiple format data coming from a variety of source such as the web, sensor networks on the factory floor, mobile phones or social networks. Traditionally, Standard Query Language (SQL) has been the method of choice to store and access structured data, i.e. data organized in the form of a relational database. However, the unstructured nature of many of today's data, for example images and emails, requires different approaches based on Not Only Standard Query Language (NoSQL). The large volume of data also requires new storing approaches based on distributed file systems, where the data are clustered over several nodes of a network (Elomari et al. 2017). New data processing methods such as massively parallel processing are also developed to overcome the limitations of traditional approaches (Zhang et al. 2016). The field of data science, synonymous to analytics, brings the real value to big data. It enables enhanced insight, decision-making and process automation. Data science combines statistics, computer science and domain specific expertise (Blei 2017). Machine learning techniques that draw patterns from large set of data are an integral part of data science. Popular frameworks integrating technologies for big data storage, analysis and visualization include Apache Hadoop and Microsoft Azure (Ramadan 2017).

Simulation: the use of Computer Assisted Engineering (CAE) for product, material and process simulations is well established in the industry. It reduces costs, shortens development cycles, improves the quality of products and greatly facilitates knowledge management. Finite Elements Analysis (FEA) is one of the leading engineering simulation approach. On top of engineering aspects, advanced simulation tools integrate various aspects of the product lifecycle management such as production planning and logistics (Law and McComas 1998). Simulations are also extensively used for training purposes when using the real equipment would be too expensive or dangerous. Examples include surgeon and plane pilot training (Lateef 2010)(de Winter 2012). Essential to the integration of simulations with the other elements of Industry 4.0 is the concept of Digital Twin. The concept of Digital Twin extends the use of simulation to all the phases of the product life cycle and to all the elements in the factory including products, machines and environmental characteristics (Rodič 2017)(Yang 2017). The near real-time status of these elements is duplicated in the

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digital world thanks to the data transmitted by the sensor networks and robots present in the factory. A few potential applications of Digital Twin include training on virtual machine, predictive maintenance by combining real-time data with failure models, digitally testing the effect of a process modification over the whole factory ecosystem before implementing in the physical world, early detection of process fault through identification of discrepancies between the digital model and the physical data.

UNIVERSITY 4.0

To prepare the workforce for Industry 4.0, the first role of the university is to adapt their curriculum. From a popular estimate, 65% of today's children will occupy a job that does not yet exist (WEF 2016). It is not straightforward to develop a curriculum fulfilling needs that are not yet understood. Nevertheless, it can be envisioned without doubts that basic ICT skills will become a necessity for employees at all levels. Generic literacy about the nine technology pillars described in the previous section and programming skills with high-level languages such as C++ or Python will become essential. Therefore, these skills should be taught to everyone and possibly introduced before university education.

Most of the Industry 4.0 workforce will have a strong engineering background. The requirements for an Industry 4.0-ready engineering curriculum can be classified into four categories (Onar et al. 2018). The first category corresponds to Big Data and related analytics, i.e. data science. It requires a strong background in mathematics, computer science, machine learning and Big Data specific IT. Big Data and analytics is on the top list of the technologies adopted in various industries (WEF 2018). Therefore, the demand for data scientist, which is already high, will continue to rise. The second category focuses on automation, robotics, IoT and additive manufacturing. Traditional mechatronics, sensors and system engineering can serve as a basis to teach the skills in that category. However, most of the current educational programs in these disciplines do not include IT as part of their training. In the framework of Industry 4.0, it is essential to integrate them with IT expertise and elements of software development. The third category in the Industry 4.0 engineering curriculum is composed of domain knowledge specific to a particular industry such as automotive or aeronautics.

The final category described in (Onar et al. 2018) is innovation and entrepreneurship. Companies need to implement innovation methods and business models that ensure their long- term success. All members of the workforce should be aware and possibly involved in these efforts. While teaching innovation tools such as TRIZ (Feniser et al. 2017) or trend spotting (Andreassen and Calabretta 2015) are helpful, soft skills are more important for the development of an innovative and entrepreneurial mindset. To name a few, communication, negotiation, people management, emotional intelligence, risk and decision making under uncertainty are essential for Industry 4.0. In addition, economic prosperity should not be the only life goal promoted by universities. They need to instigate ethical, societal or even spiritual values that

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promote social wellbeing, environmental protection and sustainability. Despite their importance, soft skills have only been introduced recently in engineering curriculums. One of the upcoming role of the university is to implement effective teaching methods for these skills such as project-based learning or global service learning (Shuman et al. 2015).

In addition to refining their engineering curriculums, universities should adapt to new teaching models. Online courses offer advantages in terms of cost effectiveness and flexibility for both teaching and studying participants. They provide universities with new revenue sources, an effective method of branding and opportunities for pedagogical innovation. For example, analytics can be used to tailor courses towards the needs of students (Johnson et al., 2013). Students can access anytime and from anywhere a large selection of trainings and can contribute actively within forums or blogs, thus taking an active stance in the learning process. Online learning can be combined with face-to-face interactions to obtain the best of two worlds. Universities should also take advantage of tablets and smartphones, which are nowadays ubiquitous. This led to the education concept of Bring Your Own Device (BYOD) (Song and Siu 2017). It is convenient for students to carry their device from one classroom to another, to access their digital textbooks and share files with fellow students or teachers. They offer the flexibility to extend learning spaces and study time outside of the classroom. Smartphones are also an excellent platform to implement educational games and gamification, which refers to the use of game-based elements in non-game contexts to motivate people and enhance learning(Deterding et al. 2011). Incorporating gaming into classroom scenarios provide students with opportunities to train their competencies act autonomously and interact with a group while having fun. In addition, gaming is a good support to familiarize students with technologies at the core of Industry 4.0, such as augmented and virtual reality. These technologies can also be integrated in other aspects of teaching such as virtual learning environments (Schuster et al. 2015).

Universities need to collaborate actively with the industry in all phases of the education process (curriculum design, project sponsors, visiting lectures, financial support). Particularly, universities should provide current industry workers with opportunities to scale up their competencies and engage in a continuous learning process. They should also provide the future workforce with competencies that cannot all be acquired in the classroom but require practical experience. To that aim, internships in industrial companies have been since a long time an integral part of engineering curriculum. In addition, the concept of learning factory recently gained attention. The Industry 4.0 learning factory involves a realistic manufacturing environment including the nine technology pillars. Teams of students are assigned manufacturing projects ideally for paying corporate clients or community service or at least with realistic market constraints. They are responsible for all the aspects of the project including capturing requirements, planning, design, choice of material and technology. The learning factory concept has proven its abilities to provide high-quality hands-on educational experiences beneficial for both universities, industry and students (Lamancusa et al. 2008) (Elbestawi et al. 2018).

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CONCLUSION

The integration of services, people and machine through IT is at the core of Industry 4.0. This new manufacturing paradigm promises strong advances in terms of product customizability, productivity, costs and energy reduction. Industry 4.0 is based on a set of technologies acquiring data from the physical world, transmitting them over the different actors of the value chain and adding value to them through analytics and simulations. The future of the workforce lies in individuals actively involved in the growth of the company, able to communicate with a large variety of stakeholders, committed to lifelong learning and with highly specialized skills but also able to understand the "big picture" of the value chain. To prepare the workforce for this new paradigm, universities should adapt their curriculum, deploy new teaching methods and enhances collaboration with the industry.

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