Industry 4.0 and its applications in the Healthcare Sector: a systematic review

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Abstract: Industry 4.0 (I4), the Fourth Industrial Revolution, is having a strong impact in all industrial sector but, although less evident, it is also bringing important results in other fields such as Healthcare Systems. In fact, Hospitals can be effectively considered smart factories because they are “factory” which “context-aware assists people and machines in execution of their tasks”. Hospitals are very difficult entity to manage and the application of Industry 4.0 technologies could have a deep impact on them. However, a systematic and extensive review of recent research on it has been unavailable. Accordingly to that, this paper conducts a literature review on the combined use of the key words “Industry 4.0” and “Health 4.0”. Altogether, 46 papers related to such topics are grouped into eight research categories and reviewed. The aim of this paper is to investigate the applicability, the advantages and the weakness of Industry 4.0 paradigms in the Healthcare sector. In fact, on the one hand they could ensure and increase the safety of patients, the quality of life and other health care activities. On the other, the recent entry into application of the General Data Protection Regulation, May 2018, has required strong rules and limitations on the data management. All the data belonging to the healthcare sector could be defined as sensitive data. The value of this work is a critical analysis on the actual applications of Industry 4.0 in the Healthcare Sector with a focus on the Italian context.

Keywords: Healthcare, Industry 4.0, Internet Of Things, Big Data, Privacy.

1. Introduction

The concepts associated with Industry 4.0 and with the recent industrial revolution that has been emerging globally are not exclusive to manufacturing production processes, but can be applied to several areas such as logistics, transportation, energy and specially healthcare. This paper aims to provide an overview of the state of the art of recent Industry 4.0 applications in the healthcare sector, and to evaluate the role of enabling technologies in the transformative process of today's Hospital 4.0.

Hospital 4.0 or Smart Hospitals can be considered health care facilities that aim to optimize resources and processes through better organization of information, patients, clinical and administrative staff. In the same way, it is possible to speak of Smart Patients, i.e. ordinary people who purchase special devices capable of monitoring their own health conditions and who constitute the so-called Health Internet of Things (IoT) or Smart Health. As Healthcare continues to become more competitive, the ability to assess tradeoffs between resource utilization, service, and operating costs grows in importance, such as with respect to appointment access, waiting room delays and telephone service. Bendato et al. (2015), Patrone et al (2017) and Cassettari et al. (2013) discussed the use of stochastic simulation analysis for studying and improving health processes and other complex systems. The guiding factor of Smart Health and, consequently, also of Hospital 4.0 is the application of the Internet of Things (IoT) to medicine. In addition to the IoT, the application of predictive algorithms and artificial intelligence, capable of processing large amounts of data, plays a fundamental role in this context. The 4.0 Hospital is therefore seeing the birth of a new way of conceiving the hospital, where the process of delivery of healthcare, medical monitoring, waiting rooms and operations schedules change radically to adapt and successfully serve patients and clinicians. The main healthcare challenges are:

- Self-diagnosis systems for patients: patients through wearable devices can monitor their health status and thus managing to self-diagnose a good number of diseases and health conditions without having to go to the clinic or hospital

- Patient monitoring: In today's hospitals, the ability to have continuous or intermittent life parameter assessments available is a key element. The additional requirement is to make the system as space-saving as possible and, from a 4.0 perspective, to guarantee remote access by doctors. The future prospect is to build automated hospitals, in which a complete imaging system is set up as soon as the hospital is checked in

- Digital data archive: the aim is to integrate the devices with the digital medical records, in order to guarantee a constant and automatic update of the patient's vital conditions and of the care and therapies to which he is subjected
- Acceptance of Artificial Intelligence (AI): AI is beginning to play an increasingly important and crucial role in diagnoses and therapies
- Coordination and collaboration: the same patient can often be treated and examined by different professionals, and constant interaction is therefore necessary in order to enable the exchange of useful information. For this reason, sharing information is fundamental

The strengths of a principle of hospital modernization, based more and more on the constant integration of the IoT in daily tasks, must be linked with a large amount of risks, mainly associated with the problem of safety but also a problem related to the need for a generational change, so that the technology is something easy to use. The following sections of the paper will provide first a basic introduction of Health 4.0 and successively respective studies are highlighted.

It is possible to find in literature multiple contribution and applications of what it has been qualify with the label "Health 4.0". We selected articles using ScienceDirect by searching "Health 4.0" and combined keywords such as "Industry 4.0" plus "Healthcare", “Internet of Things” plus “Healthcare”. The survey gave a result of 46 research articles identified in this field. Most of the papers analyzed are recently published. 11 papers of the 46 reviewed were published in 2017, 17 in 2018, denoting an increment in publications related to such topic. 6 research articles cited in this review paper have been published in 2019. Analyzing the Subject Area and Category identified by Scopus the Authors observed that the computer science area provides the maximum contribution of 41% in total research publications. However, the overall engineering field contributes 35%, decision sciences and mathematics contributing 14%, business, management and accounting 6%, materials science 4%. We classified the scientific contributions found in the literature into eight categories, depending on the type of enabling technology to which they refer: Cyber Physical Systems, Internet of Things, Edge/Cloud Computing, Addictive Manufacturing, Robotics, Artificial Intelligence, Virtual Reality, Augmented Reality. The survey carried out made it possible to highlight the upcoming future developments expected, the potential linked to technological advancement but also the limits connected to the use of new enabling technologies in this field.

2. Cyber physical systems (CPS)

A cyber physical system (CPS) is a complex system that integrates computation, communication, and physical processes. Figure 1 shows a conceptual illustration of communications between organizations in Industry 4.0. (Lee et al. 2017).

Figure 1: communications between organizations in Industry 4.0 (Lee et al. 2018)

CPS are not yet introduced to the medical domain but the process has begun. As healthcare-related data are consistently explosive, there are challenges for data management, storage, and processing (Thuemmler et al., 2017). With the assistance of cloud computing and big data, healthcare data from CPS (e.g., huge files, complex structures, and different features) can be efficiently managed (Zhang et al., 2017). Lin proposed a NoSQL-based approach for rapid processing, storage, indexing, and analysis of healthcare data, to overcome the limitation of a rational database. In another study, Takeuchi and Kodama (2014) presented a personal dynamic health system based on cloud computing and big data to store daily healthcare related information collected by mobile devices. In addition, they also proposed a health data mining algorithm to find out the correlation between a health condition and lifestyle. Although the innovations are in the healthcare field, there are some issues that need to be solved, particularly the heterogeneous data fusion and the open platform for data access and analysis (Chandola et al., 2013). For example, although studies are focused on the interconnection between body area networks (BANs) (Chen et al., 2011) and the cooperation between BANs and medical institutions (Chen et al., 2010), it is difficult to fuse the multisource heterogeneous data and the corresponding managements without unified standards and systems.

3. Internet of Things (IoT)

The Internet of Things (IoT) represents a technologically optimistic future where objects will be connected to the internet and make intelligent collaborations with other objects anywhere, anytime. IoT offers a seamless platform to connect people and objects to one another for enriching and making lives easier (Farahani et al. 2017). Remarkably, due to the rapid proliferation of wearable devices and smartphones, the IoT-enabled technology is evolving healthcare from conventional hub based system to more personalized healthcare systems (PHS) (Qi et al., 2017).

The most significant developments in IoT in the Healthcare sector are:
- Reduction of first aid waiting times: IoT technology, together with specific machinery, has allowed a great improvement in the reduction of...
waiting times. In fact, in America, recently, a system called AutoBed has been developed reducing about 50% the patient waiting times (by about 50%) (Abas et al., 2018).

- Health and remote monitoring: Remote health monitoring, often referred to as "teledicine", could add a lot of benefits reducing costs. In fact, this system would ensure the possibility of eliminating some unnecessary visits and improve the quality of life of the patient through a constant analysis of vital parameters; finally, Telecare takes care of frail and elderly patients who are controlled through alarms of activation of emergency services and calls for "support" by the centers (Demartini et al, 2019, Martini et al., 2018a and 2018b Patrone et al., 2018, 2019a, 2019b and 2019c).

- Ensure the availability and accessibility of critical hardware: The transformation of hospitals inevitably requires the use of new generation software and hardware, which are often exposed to great risks. The e-alert is a solution created by Philips, based on the IoT, which aims to solve this problem. Instead of waiting for the problem to occur, the technology protects and monitors the medical hardware through sensors that measure the environmental parameters against the thresholds and, in the event of deviations, warn staff members before the problems increase (Papa A., 2018)

- Monitoring of staff, patients and inventory: a key part of hospital management is security, and should be the main focus of any hospital. However, there is no security without an efficient resource tracking system (including staff, patients, devices). An inexpensive and highly useful solution in this area is the use of real-time tracking devices, which allow you to track resources and monitor daily operations and activities within the hospital (Kamel et al., 2013 and Yoo et al., 2018).

- Improved medicine management: New forms of prescription medicines are undoubtedly among the most advanced applications of IoT in healthcare. The project aims to create pills that contain microscopic sensors capable of sending signals to specific devices to ensure proper dosage and use of the drug. This means that it is no longer possible for patients to forget to take their prescription (Craig et al., 2018).

By applying IoT technologies to healthcare processes, the quality and cost of healthcare can be improved, (Rahmani et al. 2018). However, the advantages should be combined with the disadvantages, basically resulting from the huge amount of data and its relative management and security. Medical sensor nodes often have lower processing capacity, power, memory, and power supply than sensors for other types of networks; it should be added that, for monitoring based on these same sensors, it is necessary that transmissions are arranged to provide real-time information, a requirement that is even more important in multi-patient applications (Edoh, 2019); (Almotiri et al., 2016).

4. Edge/Cloud computing

The Cloud plays a strategic role within companies because the process digitization has made available a large amount of data (Big Data), whose optimal management by companies is a critical success factor for the future (Elhosency et al 2018). The Cloud has a very wide field of application, allowing the user a direct exploitation without the need to physically install something. For this reason, in most of the cases, the Cloud is free. The cloud, in general, contains a wide category of services (Estrela et al., 2018).

Manogaran et al. (2017) proposed a Meta Cloud-Redirection (MC-R) architecture with big data knowledge system used to collect and store the sensor data (big data) generated from different sensor devices. In the proposed system, sensor medical devices are fixed with the human body to collect clinical measures of the patient. The proposed system uses key management security mechanism to protect big data in industry 4.0.

Despite all the advantages of the cloud, it is important to know even the most common criticalities. The first concerns availability which depends on high-performance Internet connection. Another common problem refers to cloud service levels, which often do not match expectations. Other issues include loss of control and limited visibility over your infrastructure.

Edge computing paradigm has attracted many interests in the last few years as a valid alternative to the standard Cloud-based approaches to reduce the interaction timing and the huge amount of data coming from IoT devices toward the Internet. In the next future, Edge-based approaches will be essential to support time-dependent applications in the Industry 4.0 context. Pace et al. (2018) propose BodyEdge, a novel architecture well suited for human-centric applications, in the context of the emerging healthcare industry. It consists of a tiny mobile client module and a performing Edge gateway supporting multi-radio and multi-technology communication to collect and locally process data coming from different scenarios.

Figure 2: High-level architecture of BodyEdge
Pace et al. (2018)
5. Additive Manufacturing

The progressive reduction of the costs of 3D printing has generated, even if still on an experimental level, a great opportunity of application in the health field, where the possibility of printing personalized organs for transplantation has been reached (Zadpour and Malda, 2017). The opportunities inherent in the application of such a technology are many:

- Pre-surgical planning. There are application cases of 3D printing for pre-surgical planning in order to improve pre-surgical planning and thus achieve success of procedures considered impossible (Perica et al., 2017).

- 3D printing of medical devices. The basic purpose of printing disposable devices is basically to respond to the growing need for personalized care that recognizes the uniqueness of each patient (Shende and Agrawal, 2018).

- Orthopaedic implants. 3D printing and the evolution of additive manufacturing have played a key role in orthopaedic surgery; the fusion of the electron beam through a titanium alloy makes it possible to manufacture implants that meet the roughness requirements necessary for effective bone fusion (Lal and Patralekh, 2018).

6. Robotics

The main advantages of surgical robots are their precision and the possibility of performing minimally invasive operations and, furthermore, their ability to access all the anatomical areas of the patient, thus providing a high degree of versatility in the operating context. For example, the Da Vinci Surgical System is an entrant into the field of robotic technology. This system is undergoing considerable research and is being practically applied in general surgery, cardiothoracic surgery, urology and gynecology (McLeod and Melder, 2005). Its main application is the procedure for removing the prostate or replacing the heart valve, but it can actually be used for any localized surgical procedure. Although the advantages of the machine are many, it is not possible to consider the disadvantages, i.e. the very high costs (Fiani et al., 2018). The second robotics application area is the rehabilitation sector. Robotic rehabilitation has the prospect, nowadays, of promising a return to almost complete motor normality even after severe traumas and major disabling pathologies. Example of this application involves the use of exoskeletons that allow a re-education of the limbs, posture and movement. Also in this case high costs are the main disadvantages.

7. Artificial Intelligence

Diagnosis is the key process in the care and treatment of a patient: the usefulness is to recognize a disease, going to analyze specifically the symptoms and signs that, overall, can go to define the clinical picture of a disease. The role of enabling technologies is fundamental in diagnostic and leads to a real diagnostic process 4.0. Virtual reality, augmented reality and artificial intelligence have contributed to an improvement in the diagnosis of patients’ diseases. Industry 4.0 seems to be an essential part of tomorrow's medical field and smart factories, where software, technologies and processes provide efficient and world-class results with lesser time and cost (Javaid et al 2019).

Clinical decision support systems (CDSS) were one of the first successful applications of AI, focusing primarily on the diagnosis of a patient’s condition given his symptoms and demographic information. More recent advances in machine learning and AI build predictive models and make real-time inferences from a large patient population for purposes including alerts, stratifying risk, and predicting the length of stay. Several of these approaches focus on critical care, using physiological data that are routinely recorded in intensive care units. For example, Ying Zhang and Peter Szolovits (2008) developed an intensive care monitoring system to model individual patients’ vital signs and produce patient-specific models and alarm thresholds. Decision trees and neural networks were used to generate binary classifiers of the patient state and determine when to issue an alarm. Suchi Saria and her colleagues developed a physiological assessment score for preterm newborns, using time-series data captured from the newborn’s (Saria et al., 2010). The US healthcare system faces many challenges, including skyrocketing costs, high rates of drug-resistant and hospital-acquired infections. This approach lets healthcare providers accurately estimate the probability of an infant’s risk of such severe problems as infections and cardiopulmonary complications.

Artificial intelligence is not fundamentally an enabling technology, but it is the basis of some of them. In the medical field, Artificial Intelligence has proved to be an effective diagnostic tool for diseases and pathologies of patients, especially in the oncological field (Aruni et al., 2018). IBM’s Watson looks forward to being an intelligent surgical assistant. It is a harbinger of unlimited medical information, using natural language processing to clarify a surgeon’s doubts. It is currently being used to analyse electronic medical records and sequence tumour genes with the goal of formulating more personalised treatment plans (Ahmed et al., 2017). IBM Watson is a computerized system that has the ability to answer questions that are asked. In the health sector, Watson is prepared as a machine that, through the generation of hypotheses and the ability to learn, assists the doctor and is proposed as a decision support system (Nooman et al. 2017). The Watson device is accompanied by a series of diagnostic processes in increasing development (Razzaki et al., 2018).
deep learning.

8. Virtual Reality and Augmented Reality

Augmented reality (AR) and virtual reality (VR) are rapidly becoming increasingly available, accessible and importantly affordable. Both technologies are applied in many areas of the hospital sector, including the diagnostic sector: the diagnostic imaging technologies currently used are considerably advanced and provide the possibility of having a broad and clear clinical picture of the patient, without having to operate the patient to learn more; the evolution in this field, however, consists in the growing opportunity given by the new devices that "take" not only static images, but also moving so as to give the doctor an overview of the functioning of the organs in action not only at a precise moment but in an interval of time.

An example, although experimentally developed, is ProjectDR, a revolutionary device, developed by Watts et al. (2017) in Canada, in the field of diagnostic imaging. The machine is in fact able to look inside the patient's body but through an external projection so as to match actual and virtual reality. Outside of the diagnostics, ProjectDR will also provide wide perspectives in the surgical field, providing the possibility to perform simulations of great use in the pre-operative preparation.

Khor et al. (2016) provide an overview of the technologies and the potential areas of development in the surgical arena.

AccuVein and VeinViewer are two devices that make use of augmented reality to make a hemodynamic mapping (Figure 3). This allows to the doctors to observe peripheral veins, bifurcations and valves in real time and evaluate in real time the filling and the venous blood flow (Khor et al., 2016).

Figure 3: Hemodynamic mapping device

AR and VR can be used as a form of anaesthetic, which creates a sort of placebo effect. Mainly used in an Australian hospital, the idea is to "immerse" patients undergoing chemotherapy cycles in a VR world so as to have an escape from reality that is of relief, without having to resort to other medical prescriptions (Bhatt et al., 2017).

9. Conclusion

Industry 4.0 seems to be an essential part of tomorrow's smart factories and smart hospitals, where software, technologies and processes provide efficient and world-class results with lesser time and cost. The Internet of Things has substantially changed health care in a relatively short time. For example, connected devices allow older people to age in place safely for as long as possible. They help doctors confer with specialists across the world about complex cases, and they monitor patients' chronic diseases between office visits. Nonetheless, any advance in technology brings with it challenges to be overcome. The aim of this paper was to highlight, for each application area of 4.0 technologies, the status of the research and future possible developments.

10. References


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