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Industry 4.0 and human factor: How is technology changing the role of the maintenance operator?

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Abstract

Industry 4.0 is revolutionizing not only the manufacturing industry but also maintenance strategies.
As consequence of the introduction of Industry 4.0 technologies, new skills are demanded to maintenance operators that has to be able to interact, as instance, with Cyber Physical Systems and robots. In this paper, we first investigate the state-of-the-art of Industry 4.0 technologies that are transforming operations and production management and finally we discuss how the role of maintenance operators is changed in a such digitalized environment.
We found that, the maintenance Operator 4.0 should be able to find relevant information and predict events by a proper use of Big Data analytics, in addition to the ability of interacting with computers, digital databases and robots. Finally, the ability to rapidly adapt his skills to innovations is also strongly demanded.

1. Introduction

The fourth industrial revolution (Industry 4.0) is supported by the so-called "nine pillars" of advanced technologies, that are able to transform the conventional factory into a "smart factory" [1,22,43] in particular through

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the introduction of the most representative technologies that are Cyber Physical Systems (CPS) and Internet of Things technology [21,23].

Such digitalized era is characterized by coupling manufacturing processes with information and communications technology (ICT) [25], resulting in the development of intelligent factories able to meet new management goals in a more flexible way [9,11,12,41].

Industry 4.0 also involved relevant changes in human resource management and tasks [22,39] and, therefore, it is possible to identify new skills that are demanded to operator, or, as one might call it, the "Operator 4.0".

On the other hand, such digitalized environment has raised complexities related to dynamics of processes and products, as well as the way in which operators have to manage and use new technologies [17].

The concept of the Operator 4.0 was already explored by Romero et al. [44], considering a context of human-CPS interaction towards "human-automation symbiosis work systems for a socially sustainable manufacturing workforce". The same authors also highlighted the evolution of the Operator in 4 main steps, that are: 1) Operator 1.0, "defined as humans conducting 'manual and dextrous work' with some support from mechanical tools and manually operated machine tools", 2) Operator 2.0 that "represents a human entity who performs 'assisted work' with the support of computer tools", 3) Operator 3.0 that "embodies a human entity involved in 'cooperative work' with robots and other machines and computer tools, also known as - human-robot collaboration", and 4) Operator 4.0 that represents "the 'operator of the future', a smart and skilled operator who performs 'work aided' by machines if and as needed".

In this study, we aim to define changes for maintenance Operator 4.0 in a "smart factory" and, in order to do this, a first literature review of recent articles has been needed. In fact, as reported by recent scientific studies [4,10,16,29,35-38], a comprehensive literature review allows to identify gaps in knowledge and provides theoretical foundations for the proposed study.

2. Methods

As first step to investigate how the role of the maintenance Operator 4.0 is changing, a literature review was needed to know the state-of-art of Industry 4.0 technology. As research source, only journals indexed by Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com) have been taken into consideration. We used Boolean operators to combine the following exploration keywords: "industry 4.0", "maintenance", "operator 4.0" or "human factor". Furthermore, through the use of key concepts raised from the first literature exploration, such as "augmented reality" and the "Big Data Analysis", further searches have been performed. We collected a total of 18 papers published from 2015 to 2020.

Articles with title and abstract that matched the aim of our study have been first collected and, after analyzing the entire contents of the article, they were assessed for considering their final inclusion in our database. On the other hand, conference papers and articles in languages different from "English" were excluded. Results section defines the state-of-art of Industry 4.0 technologies and how such technologies are remodeling the figure of maintenance operator within a "smart factory". Table 1 summarizes the literature review process.

Table 1. Summary of the systematic literature review process.

Step 1 and **Step 2**	**Electronic databases**
Finding and evaluation of articles	Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com)
	Search Period
	2015 - 2020
	Inclusion Criteria
	Articles with title and abstract that matched the aim of our study have been first collected and, after analyzing the entire contents of the article, they were assessed for considering their final inclusion in our database. **Exclusion Criteria**
	Articles and conference papers and in languages different from "English"
	Search Strings
	"industry 4.0" AND "maintenance"
	Other combinations with:

		"operator 4.0", "human factor", "augmented reality", "Big Data Analysis", etc…
Step 3 *Assessment of findings*	**Analysis phase** Iterative collection of articles within the database	
Step 4 *Reporting of findings*	**Synthesis phase** Relevant aspects are extracted from database and discussed	

3. Results

3.1 Industry 4.0 technology: state of art

As aforementioned, Industry 4.0 is based on the introduction of the "nine pillars" of technologies. Such pillars are: 1) Industrial Internet of Things (IIoT); 2) Big Data; 3) Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) 3D printing and 9) Cyber Security.

The Industrial Internet of Things (IIoT) refers to all Cyber Physical Systems (CPS) introduced in smart factories. Such systems are interconnected using internet, in this way it is possible to establish a communication network able to exchange real time data, without any human interaction [20,42].

As stated by Kaisler et al. [24], Big Data is "the amount of data just beyond technology's capability to store, manage and process efficiently" [24]. In a smart factory, a relevant part of the overall digital data come from CPSs.

Horizontal and vertical system integration allows a full connection of all parts of the whole supply chain, through a highly dynamic system [30].

Simulations can be considered as the digital support to design production systems, and they can also elaborate real time data from CPSs [6].

Cloud technology refers to digital storage solution and cloud computing [43], making possible "on-demand" digital data exchange among CPSs and other smart devices [14,28].

Augmented Reality (AR) superimposes digital data on reality, allowing the interaction between humans and CPSs [15].

Robotic applications can have different purposes within a smart factory. They generally help operators in their task and are also able to interact with other cobots [34]. Robots represent another tool for acquiring and exchanging data during their activities.

Additive manufacturing refers to the 3D printing of physical objects. They can also use, as digital source, 3D CAD digital designs [7].

The ninth pill consists in Cyber Security, that aims to preserve digital data and smart devices from cyber-attacks [40].

3.2 The Maintenance Operator 4.0

As mentioned in the introduction section, Industry 4.0 context has amplified complexity and dynamics of operations and manufacturing processes, as well as changed protocols and human tasks [17].

Zolotová et al. [43] consider the transformation from operator to an Operator 4.0 possible through the increase of physical, sensing, and cognitive capabilities, and then able to support main aspects of maintenance processes.

According to Wittenberg [41], the main role of the Operator 4.0 is that of supervisor of the automated production, using enhanced monitoring systems. The same author also discusses how conventional interface for managing information is today unsuitable, because of the increased amount of available digital data.

Ansari et al. [2] define how to reach a proper collaboration between operators and CPSs for maintenance tasks, while Fantini et al. [13] establish a procedure to address situations where operators have to interact with CPSs.

According to Manyika et al. [27], for the Big Data Analysis, although it has a key role in the economical innovation, a general lack of operators able to obtain insight from Big Data has been observed, resulting in a deceleration for the technology establishment.

Operator 4.0 can increase own real-world perception by augmented reality technology, analyzing digital data collected in collaboration with robots, and this generally results in improved maintenance tasks in terms of control and execution [18].

Virtual reality is a powerful technology for both training and helping operators in decision-making for new maintenance procedures [43]. On the other hand, AR tablet are often used for maintenance purposes [3,18,32]. However, tablets have relevant limitations, such as battery power requirement and not being a hand-free technology. For this reason, wearable AR or head mounted devices (HMD) are becoming ever more popular [32].

As emerged from a survey dated 2016 [41], most of maintenance operators have a favorable consideration for smart devices, helping them to reduce uncertainties during tasks.

The maintenance Operator 4.0 can be defined as a smart operator with enhanced physical, sensorial and cognitive capabilities by means the integration with technologies of Industry 4.0. In Table 2, key aspects and critical aspects for the maintenance Operator 4.0 are summarized.

Finally, Fantini et al. [13] state how a proper design of workplaces is important to ease the human-automation symbiosis, while Koch et al. [26] discuss proper interfaces for an optimal interaction between operators and robots, including skills that are demanded.

Table 2. Key aspects and disadvantages for the maintenance Operator 4.0.

Maintenance Operator 4.0	
Relevant technologies and aspects	*- Improving operator training with the help of 3D printing or AR*
	- Interaction with autonomous robots
	- AR (wearable, HMD, glass data, tablets)
Critical Aspects	*- Interaction with a smart factory*
	- Need of hand-free technology
	- Human-automation symbiosis

4. Discussion and conclusion

The aim of this work was to define changes for maintenance operator in a "smart factory" and, in order to do this, a first literature review for defining state-of-art of Industry technology, has been performed.

We found that Industry 4.0 has introduced relevant changes concerning processes and manufacturing systems, through the introduction of the "nine pillars" technologies, and new skills are demanded to maintenance operator.

In such digitized environment, although complexity and dynamics of manufacturing processes have been increased, a maintenance operator can take advantages by technologies such as AR and CPSs that allow real-time feedbacks and a more effective training. However, the possibility to have a hand-free technology appears to be mandatory.

The Operator 4.0 should be able to find relevant information and predict events by a proper use of Big Data analytics [5,33], in addition to the ability of interacting with computers, databases and robots.

The maintenance Operator 4.0 has been deeply remodeled during last five years, having to be not only smart and able to interact with CPSs, cooperate with robots and other smart technologies, but also able to perform different tasks in an enhanced physical, sensorial and cognitive environment. According to Gilchrist [19] and Perez et al. [31], Operator 4.0 has to have the capability to rapidly adapt his skills to a digital world, where innovations are continuously introduced. Finally, it can be assumed a continuous improvement of the skills and performance of maintenance technicians in the near future. However, the training process will be accelerated thanks to the same Industry 4.0 technologies, such as smart devices and virtual reality.

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