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Industry 4.0: A survey on technologies, applications and open research issues

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ABSTRACT

Originally initiated in Germany, Industry 4.0, the fourth industrial revolution, has attracted much attention in recent literatures. It is closely related with the Internet of Things (IoT), Cyber Physical System (CPS), information and communications technology (ICT), Enterprise Architecture (EA), and Enterprise Integration (EI). Despite of the dynamic nature of the research on Industry 4.0, however, a systematic and extensive review of recent research on it is has been unavailable. Accordingly, this paper conducts a comprehensive review on Industry 4.0 and presents an overview of the content, scope, and findings of Industry 4.0 by examining the existing literatures in all of the databases within the Web of Science. Altogether, 88 papers related to Industry 4.0 are grouped into five research categories and reviewed. In addition, this paper outlines the critical issue of the interoperability of Industry 4.0, and proposes a conceptual framework of interoperability regarding Industry 4.0. Challenges and trends for future research on Industry 4.0 are discussed.

1. Introduction

Modern industry industrial development has lasted for several hundred years and has now the era of Industry 4.0 comes. The concept of Industry 4.0 was initially proposed for developing German economy in 2011 [60,87]. According to Lukač [45], the first industrial revolution begins began at the end of the 18th century and is was represented by mechanical production plants based on water and steam power; the second industrial revolution starts started at the beginning of the 20th century with the symbol of mass labor production based on electrical energy; the third industrial revolution begins began in the 1970s with the characteristic of automatic production based on electronics and internet technology; and right now, the fourth industrial revolution, namely Industry 4.0, is ongoing, with the characteristics of cyber physical systems (CPS) production, based on heterogeneous data and knowledge integration. The main roles of CPS are to fulfill the agile and dynamic requirements of production, and to improve the effectiveness and efficiency of the entire industry. Industry 4.0 encompasses numerous technologies and associated paradigms, including Radio Frequency Identification (RFID), Enterprise Resource Planning (ERP), Internet of Things (IoT), cloud-based manufacturing, and social product development [5,19,36,37,41,42,55,60,75,81,82,86,88].

The goals of Industry 4.0 is are to achieve a higher level of operational efficiency and productivity, as well as a higher level of automatization [81]. As Roblek et al. [60] and Posada et al. [58] point out, the five major features of Industry 4.0 are digitization, optimization, and customization of production; automation and adaptation; human machine interaction (HMI); value-added services and businesses, and automatic data exchange and communication. These features not only are highly correlated with internet technologies and advanced algorithms, but they also indicate that Industry 4.0 is an industrial process of value adding and knowledge management.

Despite of the dynamic nature of the research on Industry 4.0, however, a systematic and extensive review of recent research on Industry 4.0 is not available. Accordingly, this paper conducts a comprehensive review on of Industry 4.0 and presents an overview of the content, scope, and findings of Industry 4.0 by examining existing literatures in all databases within the Web of Science and Google Scholar. Altogether, 88 papers related to Industry 4.0 are grouped into five research categories and are reviewed. In addition, this paper outlines the critical issue of the interoperability of Industry 4.0, and proposes a conceptual framework of interoperability regarding Industry 4.0. Challenges and trends for future research on Industry 4.0 are discussed.

The rest of the paper is structured as follows: the methodology of this study is introduced in Section 2. Section 3 groups the selected paper into five categories and reviews them in details.

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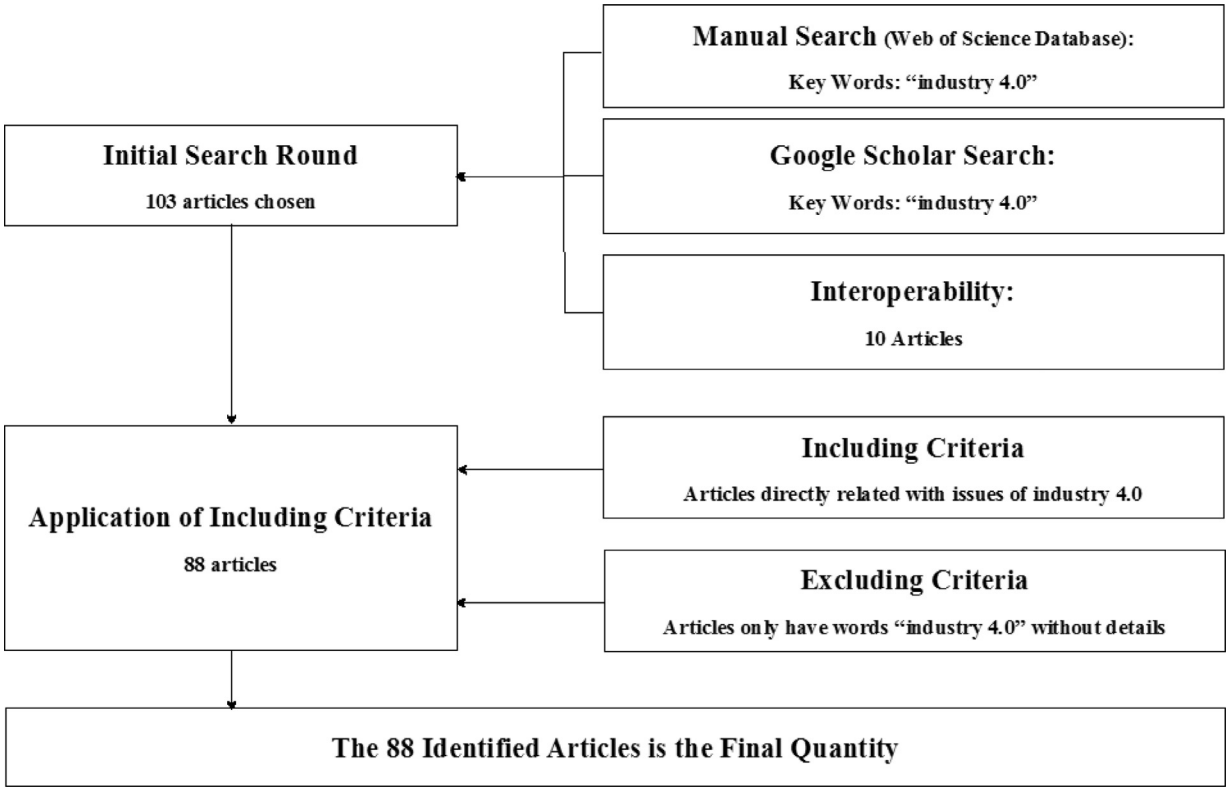

Fig. 1. Literature selecting and identifying procedures.

Challenges and directions for future research are introduced in each category. A framework of interoperability for Industry 4.0 is proposed as well. Section 4 summarizes and concludes this paper.

2. Methodology

This study follows the two-state approach initiated by Webster and Watson [92] to conduct a literature review. This approach has the capability of locating rigorous and relevant research, and then guaranteeing the quality and veracity of the articles finally selected [84]. The process of this approach is shown in Fig. 1.

At the first stage, "Industry 4.0" was chosen as the keyword to search published papers from 2011 to 2016 collected by Web of Science and Google Scholar. The search returned 103 results, which indicates that Industry 4.0 is an emerging research topic. Next, citations of these 103 papers were extracted from Google Scholar. At the second stage, these 103 papers were carefully reviewed and unrelated papers were dropped. At the end, 88 papers were left. The distribution of publication years of these papers and their citation numbers are shown in Fig. 2.

From 2011 to 2016, the annual average number of published papers on Industry 4.0 was 13 and the average annual citation is 157. The annual number of published papers increased from one in 2011 to 33 in 2016. A quick increase occurred in 2014 from one in 2013 to 11. Annual citation of these papers reached a peak in 2014, with the number of 461. The changes in the number of published papers and citations indicate that Industry 4.0 began to attract attention in literature from 2014. The 88 papers are then grouped into five research categories, as shown in Table 1.

The distribution of the categories indicates that more attention has been paid to technologies / tools and applications regarding Industry 4.0 in recent literature. This indicates that Industry 4.0 is not only an integration of CPS, ICT, Enterprise Architecture (EA), and IoT, but that it is also an interoperability process.

Table 1
Research categories of the selected 88 publications.

Research categories	Number of publications
Concept and perspectives of Industry 4.0	18
CPS-based Industry 4.0	12
Interoperability of Industry 4.0	11
Key technologies of Industry 4.0	20
Applications of Industry 4.0	27
	Total: 88

3. Industry 4.0: the state of the art

This section summarizes the content of selected 88 papers, which are grouped into five research categories. Potential directions for future research are discussed in the research category, as well.

3.1. Concept and perspectives of Industry 4.0

Scholars have defined Industry 4.0 from diverse perspectives in this research category (Table 2). For instance, according to the Consortium II, Fact Sheet [14], Industry 4.0 is "the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes." Henning and Johannes [25] define Industry 4.0 as "a new level of value chain organization and management across the lifecycle of products." Hermann et al. [26] define Industry 4.0 as "a collective term for technologies and concepts of value chain organization." They note that, within the modular structured Smart Factories of Industry 4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. They point out that over the IoT, CPS communicate and cooperate with each other and humans in real time, and that the Internet of Services (IoS), both internal and cross organizational services, is offered and utilized by participants of the value chain. So far, there is no unanimously adopted definition of Industry 4.0.