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## Intelligent Manufacturing in the Context of Industry 4.0: A Review

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### ABSTRACT

Our next generation of industry—Industry 4.0—holds the promise of increased flexibility in manufacturing, along with mass customization, better quality, and improved productivity. It thus enables companies to cope with the challenges of producing increasingly individualized products with a short lead-time to market and higher quality. Intelligent manufacturing plays an important role in Industry 4.0. Typical resources are converted into intelligent objects so that they are able to sense, act, and behave within a smart environment. In order to fully understand intelligent manufacturing in the context of Industry 4.0, this paper provides a comprehensive review of associated topics such as intelligent manufacturing, Internet of Things (IoT)-enabled manufacturing, and cloud manufacturing. Similarities and differences in these topics are highlighted based on our analysis. We also review key technologies such as the IoT, cyber-physical systems (CPSs), cloud computing, big data analytics (BDA), and information and communications technology (ICT) that are used to enable intelligent manufacturing. Next, we describe worldwide movements in intelligent manufacturing, including governmental strategic plans from different countries and strategic plans from major international companies in the European Union, United States, Japan, and China. Finally, we present current challenges and future research directions. The concepts discussed in this paper will spark new ideas in the effort to realize the much-anticipated Fourth Industrial Revolution.

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### 1. Introduction

Industry 4.0, a German strategic initiative, is aimed at creating intelligent factories where manufacturing technologies are upgraded and transformed by cyber-physical systems (CPSs), the Internet of Things (IoT), and cloud computing [1,2]. In the Industry 4.0 era, manufacturing systems are able to monitor physical processes, create a so-called “digital twin” (or “cyber twin”) of the physical world, and make smart decisions through real-time communication and cooperation with humans, machines, sensors, and so forth [3]. Industry 4.0 combines embedded production system technologies with intelligent production processes to pave the way for a new technological age that will fundamentally transform industry value chains, production value chains, and business models.

In the context of Industry 4.0, manufacturing systems are updated

to an intelligent level. Intelligent manufacturing takes advantage of advanced information and manufacturing technologies to achieve flexible, smart, and reconfigurable manufacturing processes in order to address a dynamic and global market [4]. It enables all physical processes and information flows to be available when and where they are needed across holistic manufacturing supply chains, multiple industries, small and medium-sized enterprises (SMEs), and large companies [5,6]. Intelligent manufacturing requires certain underpinning technologies in order to enable devices or machines to vary their behaviors in response to different situations and requirements based on past experiences and learning capacities [7]. These technologies enable direct communication with manufacturing systems, thereby allowing problems to be solved and adaptive decisions to be made in a timely fashion. Some technologies also have artificial intelligence (AI), which allows manufacturing systems

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to learn from experiences in order to ultimately realize a connected, intelligent, and ubiquitous industrial practice.

Similar concepts to intelligent manufacturing include cloud manufacturing and IoT-enabled manufacturing. In order to fully understand intelligent manufacturing in the context of Industry 4.0, this paper reviews 165 papers from the Scopus and Google Scholar databases and clearly presents key concepts such as intelligent manufacturing, IoT-enabled manufacturing, and cloud manufacturing. Next, this paper discusses key technologies such as the IoT, CPSs, cloud computing, big data analytics (BDA), and information and communications technology (ICT) that are used to support intelligent manufacturing. Worldwide movements in intelligent manufacturing are then discussed, including cases from government bodies and giant companies in the European Union, United States, Japan, and China. Finally, future perspectives are highlighted for the inspiration of industrial practitioners and academia.

Published data from 2005–2016 regarding intelligent manufacturing have been gathered from the Scopus database (Fig. 1), which shows a steady increase in papers on this topic. Fig. 1(a) shows the published documents on intelligent manufacturing from 2005 to 2016. From 2005 to 2006, the number of articles increased sharply, from around 100 to 150; from 2007 to 2014, the number then increased at a stable rate. From 2014 to 2015, another significant

increase occurred, with 225 documents being published in 2015. Fig. 1(b) shows the top sources publishing works related to intelligent manufacturing. The top five serials are the *International Journal of Advanced Manufacturing Technology* (83), *Computer Integrated Manufacturing Systems* (69), *Journal of Intelligent Manufacturing* (49), *International Journal of Production Research* (46), and *Expert Systems with Applications* (33). Fig. 1(c) lists the top universities or research institutes publishing in this research area. The top five universities are Shanghai Jiao Tong University (42), Beihang University (31), Zhejiang University (29), Chongqing University (20), and Tsinghua University (20). Fig. 1(d) shows the top scholars publishing in this area, and Fig. 1(e) lists countries or regions that are active in this field, of which China, the United States, and the United Kingdom are the top three.

These articles are sourced from the Scopus and Google Scholar databases with a focus on key concepts such as intelligent manufacturing, IoT-enabled manufacturing, and cloud manufacturing. By analyzing these key technologies and related worldwide movements, future perspectives are highlighted.

## 2. Major concepts

The manufacturing industry is the basis of a nation's economy and powerfully influences people's livelihood. Emerging technologies

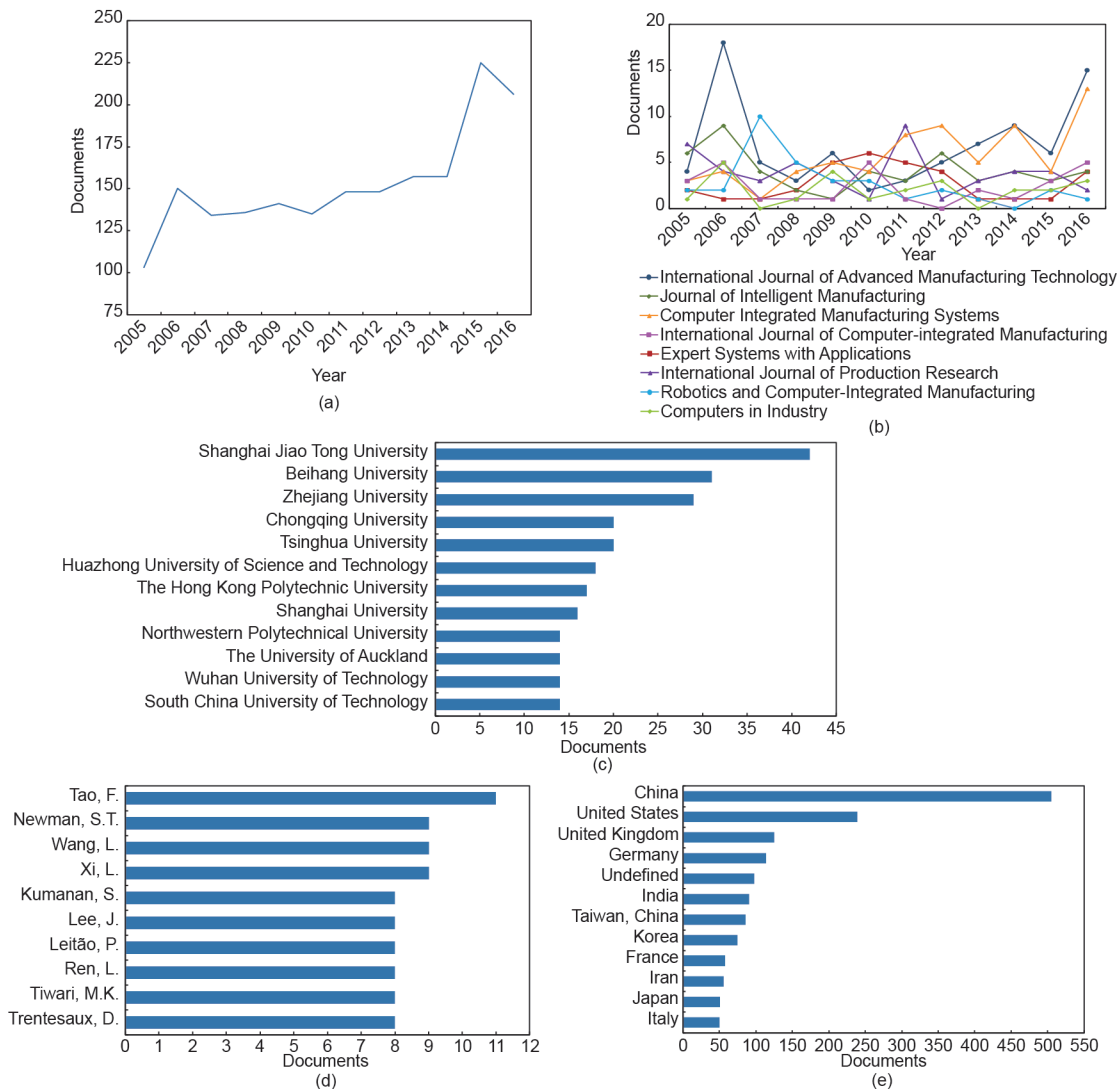


Fig. 1. Statistics from Scopus database (search keywords: “intelligent manufacturing”; Date: 31 March 2017). (a) Published documents per year; (b) published documents by source; (c) published documents by affiliation; (d) published documents by author; (e) published documents by country/region.

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