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Analysis of the Status Quo of Intelligent Manufacturing Research Based on CiteSpace

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Abstract: Intelligent manufacturing is a human-machine integrated intelligent system composed of intelligent machines and human experts. Using CiteSpace as a tool, the paper analyzes and visualizes the intelligent manufacturing related literatures collected by Web of Science, summarizes the research status of intelligent manufacturing in recent years, and elaborates on the research hotspots in this field in recent years; The "Advanced Manufacturing Partner Program" strategy, Germany proposed the "Industry 4.0" plan, the European Union promulgated the "Digital European Industrial Plan" and the "China Made 2025" issued by China, summed up the problems faced by the intelligent manufacturing industry at this stage and made corresponding suggestions.

Keywords: Intelligent manufacturing, manufacturing, Intelligent, Industry 4.0, CiteSpace

1. INTRODUCTION

Since the middle of the 20th century, with the integration and application of a new generation of information technology (such as cloud computing, Internet of Things, big data, etc.) and manufacturing, digital manufacturing has emerged. International scholars' theoretical research on manufacturing development mainly includes dual structure theory, leading industry theory and Marginal industry development theory. The study found that the growth rate of manufacturing during the period of industrialization in a country was higher than that of the same period and led to the prosperity of other industrial sectors, and played an important role in the engine of economic growth. At the same time, in order to meet and adapt to the needs and trends of socialization, personalization, service, intelligence, greenization and other manufacturing development[1], countries around the world have successively put forward their own national level of manufacturing development strategy, after the 2008 financial crisis, with the introduction of the US Industrial Internet, Germany's "Industry 4.0" [2], and the British "Industrial 2050 Strategy". The importance of manufacturing as a country's development foundation has once again been vividly interpreted. At the same time, under the background of the "manufacturing of a strong country" and "network power" strategy, the government of china has also introduced the development strategy of manufacturing countries such as "Made in China 2025" and " Internet accelerated speed". How to comprehensively improve the quality and level of manufacturing development has become an important topic for scholars and experts.

Therefore, it is urgent to explore the intelligent transformation, upgrading path of manufacturing industry, promotion of accuracy, rapid action, automation of processing and manufacturing. Intelligent manufacturing is the development direction of the future manufacturing industry.However, there are few results in scientific analysis and visualization using literature measurement. This article uses Web of Science to retrieve data and use CiteSpace for statistics. Analysis, high-frequency keyword analysis and cluster analysis, on the basis of in-depth study of key documents, summarizes the research status of intelligent manufacturing in recent years, and elaborates on the research hotspots in this field in recent years, combined with current international policies and related the guidance, looking forward to the future development direction of intelligent manufacturing, and thus provide some reference for relevant research scholars.

2. DATA SOURCES AND RESEARCH TOOLS

Web of Science is a citation index database in the ISI database. It includes more than 8,000 of the world's most influential high-quality journals reviewed by peer experts. The Web of Science core collection database is selected in Web of Science. Search time is December 29, 2018, search term: keyword =Intelligent manufacturing; time span is 2006-2019; get 1432 records, through manual screening, select the top 50% of ENGINEERING disciplines of ESI journals in the ESI journal list the journal eventually got 142 records (shown in Table 1). The analysis tool used in this paper is CiteSpace5.3.R7. It is suitable for multi-dimensional, time-sharing and dynamic complex network analysis[3].In CiteSpace, the number of nodes in each period is referenced by the label and node size of the node year ring. The key nodes in the network are highlighted by circles. By drawing a scientific knowledge map, it is possible to show the development trend and evolution of a discipline or knowledge domain in a certain period of time.

Table 1. List of selected journals

Number	Quantity of paper	The journal source	Subject	ESI 50% (Yes/No)
1	45	*Robot Cim-Int Manuf*	Engineering	Yes
2	21	*IEEE Transactions on Industrial Informatics*	Engineering	Yes
3	15	*Journal of Cleaner Production*	Engineering	Yes
4	10	*Chinese Journal of Mechanical Engineering*	Engineering	Yes
5	8	*IEEE Sensors Journal*	Engineering	Yes
6	6	*Annual Reviews in Control*	Engineering	Yes
7	5	*Measurement*	Engineering	Yes
8	5	*Mechatronics*	Engineering	Yes
9	5	*Sensors and Actuators a Physical*	Engineering	Yes
10	4	*Control Engineering Practice*	Engineering	Yes
11	3	*Applied Intelligence*	Engineering	Yes
12	3	*Automation in Construction*	Engineering	Yes
13	3	*Energies*	Engineering	Yes
14	3	*Fuzzy Sets and Systems*	Engineering	Yes
15	3	*Journal of Power Electronics*	Engineering	Yes
16	3	*Rapid Prototyping Journal*	Engineering	Yes

3. INTELLIGENT MANUFACTURING BASE CASE

3.1 Annual output of papers in the field of intelligent manufacturing

The change of the number of academic papers with the year is one of the important indicators to evaluate the development trend of a certain subject area. It is of great significance to draw the literature distribution and analyze it to measure the stage and development trend of the field.

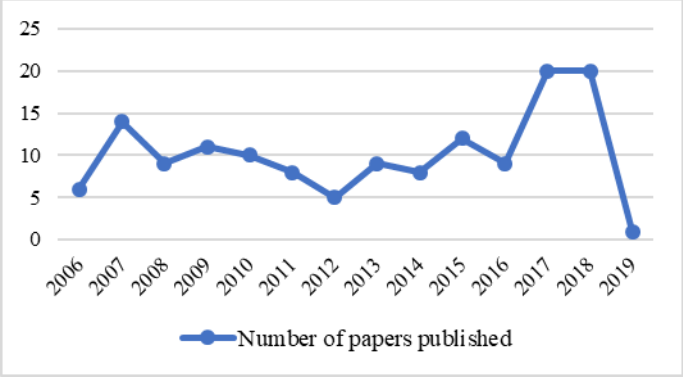

Figure 1. Annual output of papers in the field of intelligent manufacturing

Figure 1 shows the publication volume results of intelligent manufacturing in the top 50% of ESI journals in the list of ENGINEERING disciplines in Web of Science database from 2006 to 2019.From figure 1, it can be seen that before 2011, the number of intelligent manufacturing papers was small and relatively stable, with about 10 papers per year. Since 2014, the number of intelligent manufacturing papers has shown an exponential growth. In 2017,the number of intelligent manufacturing papers increased by 122% compared with that in 2016.Intelligent manufacturing has become a research and practice hotspot in manufacturing industry.

3.2 Related journal analysis

Through the volume of relevant journals to understand the subject areas involved in the Smart Manufacturing Institute, the amount of documents can indicate how close the field is to smart manufacturing. Journals with a large number of papers on the subject of smart manufacturing include ROBOTICS AND COMPUTER INTEGRATED MANUFACTURING,IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, JOURNAL OF CLEANER PRODUCTION, CHINESE JOURNAL OF MECHANICAL ENGINEERING,all of which are more than 10 papers. Involved in the fields of aviation manufacturing, computer technology, manufacturing systems, automation,among which ROBOTICS AND COMPUTER INTEGRATED MANUFACTURING has the largest number of publications, 45 papers. This journal is on disseminating the application of research to the development of new or improved industrially-relevant robotics, manufacturing technologies, and innovative manufacturing strategies; IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS has reached 21 papers，This journal focuses on the following main topics: Flexible, collaborative factory automation, Distributed industrial control and computing paradigms, Internet-based monitoring and control systems, Real-time control software for industrial processes, Java and Jini in industrial environments, Control of wireless sensors and actuators, Systems interoperability and human machine interface.

3.3 Literature co-citation network analysis

The literature co-introduction concept was proposed in 1973 by the former Soviet intelligence scientist Illina Masakova and the US intelligence scientist Henry Small. They believe that if two papers A and B are cited by one or more subsequent papers, it is considered that the documents A and B are co-introduced, and the number of papers citing A and B is co-introduction. The greater the co-introduction, the closer the relationship between documents A and B, or the more relevant the literature A and B. In this paper, the cited reference and keyword are selected for the node type; the threshold is set to TOP50; the time interval is 2 years; the operation method selects pathfinder. Import the 142 data sources identified in the previous section into Citespace, and run Citespace to generate a literature on the intelligent manufacturing domain (shown in Figure 2).

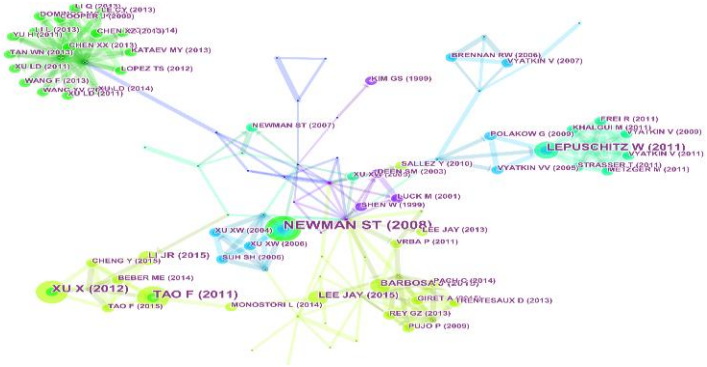

Figure 2. Intelligent manufacturing research literature co-citation network map

There are 174 nodes and 396 connections in the figure. The nodes in the figure are composed of rings of different colors. The larger the radius is, the higher the citation frequency is; the warmer the color of rings is, the

closer the time of citation is to the present. If the node has a dark outer ring, the citation frequency has been or is still increasing sharply.

3.4 High frequency keyword clustering

High-frequency keywords can generally reflect research hotspots in the subject area. Use CiteSpace for keyword co-occurrence analysis and high-frequency keyword clustering. The larger the key nodes, the higher the frequency of occurrence. By clustering high-frequency keywords, a network map (shown in Figure 3) is obtained and the results are output. As shown in Figure 3. The high-frequency keywords of the past 14 years in 2006-2019 are: Cloud computing, Holonic multi-agent methodology, Bom-based life cycle assessment, Software architecture, Cloud environment, Intelligent mechatronic system, Turning operation.

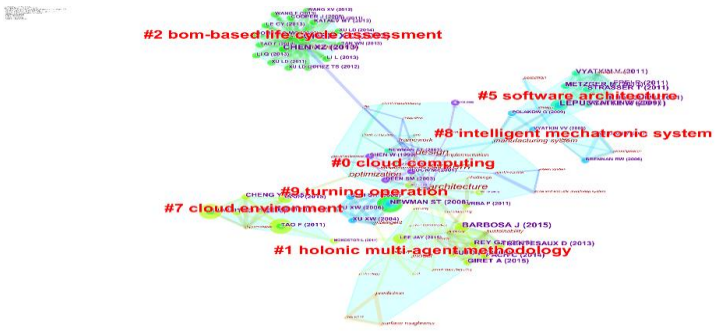

Figure 3. High frequency keyword co-occurrence

The clustering of 7 keywords is obtained by clustering the keywords as shown in Table 2, where Cluster ID is the cluster number; Size is the size of the class; Silhouette is the clustering effect, the closer to 1 the clustering effect is better; Lable(LLR) (Chen Chaomei's research results show that the clustering label of the LLR word selection algorithm has a relatively high representativeness and comprehensiveness.[4]) Get the class label, and mean(year) represents the average year of the literature in the cluster, which can be used to judge The distance of the literature cited in the cluster. Here, each cluster only lists the first three keywords. From the table, we can see the number of literature research corresponding to each cluster, and the representative research vocabulary and research hotspot of each cluster.

Table 2. Keyword co-occurrence clustering schedule

Cluster ID	Size	Sihouette	Lable(LLR)	Mean(Year)
0	28	0.742	cloud computing, self-adaptive intelligent shopfloor, cyber-physical system	2007
1	20	0.853	holonic multi-agent methodology, sustainable intelligent manufacturing control system, cloud manufacturing	2015
2	19	0.998	bom-based life cycle assessment, manufacturing resource, iot-based intelligent perception	2012
5	11	0.944	software architecture, to-peer communicating controller, plc-based software	2010
7	8	0.943	cloud environment, manufacturing service, intelligent manufacturing	2014
8	6	0.963	intelligent mechatronic system, flexible manufacturing, ontology-based reconfiguration agent	2008
9	6	0.98	turning operation, step compliant system, future industrial system	2007

3.5 The evolution time span and research progress of each cluster

Figure 4 is a timeline view of the intelligent manufacturing research keyword based on the publication year of the citation and the clustering number of the Y axis. The literature situation in each cluster can be clearly obtained. The more documents in the cluster, the more important the representative cluster domain is. It can be seen that #0, #1, #2, #5 have more literatures, #7, #8, #9 have a little less literatures. The timeline view shows the time span and research progress of each cluster's evolution. The domain represented by cluster 0 has a long time span. This most obvious group can summarize the development and structural changes in the field of intelligent manufacturing.

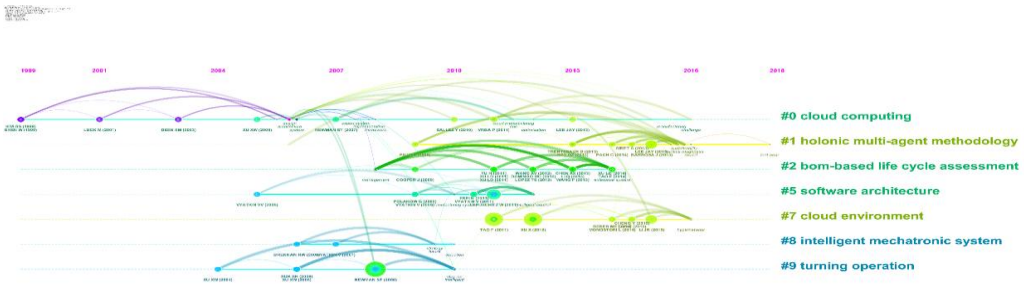

Figure 4. Keyword timeline view

3.6 Intelligent manufacturing research hotspot

Combining high-frequency keywords and keyword co-occurrence clustering and reading important node articles, the author believes that the research hotspots in the field of intelligent manufacturing are mainly concentrated in the following seven aspects: Cloud computing, Holonic multi-agent methodology, Bom-based life cycle assessment, Software Architecture, Cloud environment, Intelligent mechatronic system, Turning operation. At the same time, we listed the information of the literature cited more than 50 times, and gave the corresponding journal sources and clustering categories, as shown in Table 3.

Table 3. Literature information with more than 50 citations

Serial number	Frequency	Author	Published year	The journal source	Clustering categories
1	575	XunXu	2012	*Robot Cim-Int Manuf*	#0 Cloud computing
2	204	TaoFei	2014	*IEEE Transactions on Industrial Informatics*	#0 Cloud computing
3	183	TaoFei	2014	*IEEE Transactions on Industrial Informatics*	#2 Bom-based life cycle assessment
4	181	TaoFei	2013	*IEEE Transactions on Industrial Informatics*	#7 Cloud environment
5	77	Vyatkin Valeriy	2011	*IEEE Transactions on Industrial Informatics*	#5 Software architecture
6	98	Wan Jiafu	2016	*IEEE Sensors Journal*	#5 Software architecture
7	96	Shen Welming	2014	*Robot Cim-Int Manuf*	#5 Software architecture
8	56	TaoFei	2014	*IEEE Transactions on Industrial Informatics*	#2 Bom-based life cycle assessment
9	54	Herrero-Perez D	2016	*IEEE Transactions on Industrial Informatics*	#8 Intelligent mechatronic system
10	53	Zhang Yingfeng	2014	*Journal of Cleaner Production*	#9 Turning operation
11	52	Marik Vladimir	2007	*CONTROL ENGINEERING PRACTICE*	#5 Software architecture
12	50	Rauch Matthieu	2012	*ROBOTICS AND COMPUTER-INTEGRATED MANUFACTURING*	#9 Turning operation
13	50	Morel Gerard	2007	*CONTROL ENGINEERING PRACTICE*	#5 Software architecture

4. SUMMARY OF INTELLIGENT MANUFACTURING CLASSIFICATION

4.1 Cloud computing

Intelligent manufacturing has produced a revolutionary change, and evolving applications, such as product lifecycle management, are becoming a reality. Xu Xun et al. [5]reviewed Cloud computing is a new model which changes the way industries and enterprises do their businesses in that dynamically scalable and virtualized resources are provided as a service over the Internet and creates a brand new opportunity for enterprises. Tao Fei et al.[6]thought Internet of Things (IoT) and cloud computing (CC) can provide a new method for intelligent perception and connection from M2M (including man-to-man, man-to-machine, and machine-to-machine), and on-demand use and efficient sharing of resources, respectively. And they have been widely studied and applied in many fields. Wan, Jiafu et al.[7]analyzed Industrial Internet of Things (IIoT) and its related domains, such as industrial wireless networks (IWNs), big data, and cloud computing have been great advances. These emerging technologies will bring great opportunities for promoting industrial upgrades which

allow the introduction of the fourth industrial revolution, namely, Industry 4.0.

4.2 Holonic multi-agent methodology

The overall sustainability in industrial activities of manufacturing companies must be achieved at the same time that they face unprecedented levels of global competition. Giret Adriana et al.[8]structured that urgent is imposing radical changes in the way manufacturing systems are designed and implemented which need for sustainable development. Therefore, in an effective way there is a well-known need for tools and methods that can support the design and implementation of these systems.

4.3 Bom-based life cycle assessment

Tao Fei et al.[9]thought in order to address this problem, ESER life cycle assessment(LCA) based on Internet of Things (IoT) and bill of material (BOM) is proposed in this paper is a new method. There is a four-layered structure, perception access layer, data layer, service layer, and application layer. ESER LCA system based on IoT and BOM is designed and presented, as well as the key technologies and the functions in each layer. The main contributions of the proposed method are:1) realize effective data integration between the ESER evaluation system and the existing enterprise information systems based on BOM. And 2) facilitate real-time intelligent perception, and the collection of energy consumption and environmental impact data generated in the entire life cycle of manufacturing by using IoT technologies.

4.4 Software architecture

Shen, Welming et al.[10]reviewed The combination of Web services and software agents provides a promising computing paradigm for integration of inter-organizational business processes and efficient service selection. Sorouri, Majid et al.[11]structured a new software composition method for automated machines that exploits their mechatronic modularity which is demonstrated that desired behavior of a certain class of machines can be composed of behaviors of its mechatronic components, including operation controlled and decentralized scheduling. Pereira, Carlos Eduardo et al.[12]reviewed advances in software and microelectronics now allow embedded systems to be composed of a large set of processing elements, and this trend is towards significant enhanced scalability, functionality and complexity

4.5 Cloud environment

Cheng, Ying et al.[13]structured due to recent developments in big data, cyber-physical systems, industrial wireless and networks cloud computing. Perform data processing in the cloud, including the cloud layer architecture, the offline prediction and analysis method and the real-time active maintenance mechanism. Industry 4.0 has become more popular. Matsuzaki, Ryosuke et al.[14]reviewed a novel rubber-based strain sensor fabricated using photolithography was proposed. Tao, Fei et al.[15]structured recently some scholars has proposed Cloud manufacturing (CMfg) as a new service-oriented manufacturing paradigm. The services are managed in CMfg include not only computational and software resource and capability service which compared with cloud computing.

4.6 Intelligent mechatronic system

Sorouri, Majid et al.[11]reviewed demonstrated that desired behavior of a certain class of machines can be composed of behaviors of its mechatronic components. That is a new software composition method for automated machines that exploits their mechatronic modularity. Alsafi, Yazen et al.[16]structured this current mass customization era requires increased agility and flexibility in the manufacturing systems to adapt changes in environments and manufacturing requirements.

4.7 Turning operation

Mok, C. K. et al.[17]structured A architecture of the system consists of an interactive KB mould design system embedded in an Internet environment which is a prototype Internet-based intelligent design system for injection moulds. Zhang, X. et al.[18]reviewed proposes a Process Planning System (PPS),this system surface

roughness chosen as the process planning objective. Reviewing on recent research and development on STEP-NC. Yusof, Yusri. et al.[19]reviewed over the last decade, it is necessary for the changing economic climate to made global manufacturing. Forcing companies from East and West to collaborate beyond geographic boundaries in the design, assembly of products and manufacture.

5. RESEARCH CONCLUSIONS AND PROSPECTS

First, the theoretical framework and impact mechanism of intelligent transformation and upgrading of manufacturing industry should be further explored. The current research focuses on national strategic and macro policies, lacks accurate grasp and effective application of theoretical theory, quantitative analysis methods and evaluation systems involved in the transformation and upgrading of manufacturing. “Intelligence” involves the process of comprehensive and intelligent promotion of the multi-dimensional elements of manufacturing, such as manufacturing equipment, production, manufacturing, management and service. “Intelligent manufacturing” is the core content or path, but “intelligent” also emphasizes industrial ecology. Coordination of the environment. "Intelligent Ecosystem" is an effective carrier for implementing and promoting "intelligence".

Second, the research on intelligent transformation and upgrading of manufacturing industry urgently needs to build an analytical framework for intelligent ecosystems. At present, there are many perspectives on the intelligent research of manufacturing industry, and the system is complex. There are many researches on the technical level, management level, service level, talent level, innovation level, productivity level, knowledge level and social development level. These studies seem to be independent of each other, but they are interconnected and become organic systems. At present, the research has not fully clarified the complex systemic mechanism of intelligent transformation and upgrading of manufacturing industry. Therefore, it is urgent to use the niche theory to transform and upgrade the intelligent manufacturing industry from the perspective of intelligent ecosystem. The mechanism and path are fully analyzed to expand and enrich relevant theoretical research.

Third, the research on intelligent transformation and upgrading of manufacturing industry is relatively insufficient in key grasp and timing advancement. Previous studies have mainly focused on the identification and definition of common problems in the process of intelligent transformation and upgrading of manufacturing industry. There is a lack of systematic and standardized analysis of different manufacturing environments and socio-economic environments. The strategic direction of manufacturing “smart ecosystems” is mainly The overall grasp of the target and the strategy of tackling the problem is insufficient, and how to deal with the intelligent ecological subsystems of the manufacturing, product design, production, logistics, sales, service, management, etc. according to the different stages and characteristics of the “intelligence” of the manufacturing industry. Lack of systematic research and analysis, such as staged advancement.

Fourth, in the process of continuous improvement of cloud computing, systemic and standardized development of user services should be carried out, and the standardized service types of cloud computing should be strengthened through this method. And basic software, virtualization software, high-end storage devices, infrastructure software and data needs to be improved. The core technology of the Internet of Things needs to be strengthened such as mobile processors, sensors, and large servers. In the field of industrial robots, it is necessary to improve the industrialization and promote the precision manufacturing technology, promote the industrialization of robot control systems and sensors, and strengthen the application of intelligent manufacturing systems to improve the wide application of industrial robots.

In addition, this research also has some imperfections. First of all, all the literature is derived from the Web of Science database, and subsequent research can further expand the search scope of the literature, in order to more fully understand the development trends and cutting-edge hot spots in the field. Secondly, the author's

co-citation analysis is the co-cited case of the first author, and does not consider the situation of the collaborator, which may cause a certain degree of deviation.

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