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The Overview of Cloud Manufacturing Technology Research

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ABSTRACT *: Cloud manufacturing (CM) is a new, service-oriented and web-based manufacturing model. Through the virtualization and servitization of manufacturing resources and manufacturing capabilities, it is aimed to achieve large-scale gains, multi-win-win situation and highly efficient sharing and collaboration of distributed resources. Based on the currently related cloud manufacturing researches, this paper introduces the background of cloud manufacturing, then describes and analyzes its definition, system composition and operational principle, system architecture, typical characteristics, key technologies. Current application status of cloud manufacturing is summarized from different angles. Finally, the conclusion and outlook is given.*
Keywords *–Cloud Manufacturing, Cloud Service, Manufacturing Mode, Manufacturing Resource, Sharing, Collaboration*

I. INTRODUCTION

Manufacturing industry has always been a pillar industry of China's industrial development, the basic condition of the realization for industrialization, an important manifestation of the comprehensive national strength and technical level, the significant guarantee of national security [1]. Since the reform and opening up, China's manufacturing industry, a strong impetus to the process of industrialization and modernization, has been developing sustainably and rapidly, but compared with the world advanced level, manufacturing industry of our country is still a big but not strong in the capability of independent innovation, resource utilization efficiency, the level of industrial structure, the degree of information, quality and efficiency, etc. [2]. Manufacturing industry, as an important and difficult fusion of the industrialization and information, its structure adjustment, transformation and upgrading, quality and efficiency improving is bound to vigorously promote the integration of informatization and industrialization [3].

In recent years, with the development and application of new information technology, such as cloud computing [4], internet of things [5], intelligence science, high performance computing and so on, the level of manufacturing informatization has been improved continuously. Represented by Application Service Provider (ASP), Manufacturing Grid (MG), Agile Manufacturing (AM), etc., the emergence of networked manufacturing modes, have promoted the ability of rapid response to the market demand in the manufacturing industries, enhancing the core competitiveness of enterprises, the large-scale collaborative manufacturing. So many fruitful results in the fields of resource service, task management, workflow management, etc. have been achieved. However, there are some problems in the current networked manufacturing modes, such as service mode, manufacturing resource sharing and distribution technology, security and so on, which restrict its further development and application. Thus, a new service-oriented networked manufacturing model called Cloud Manufacturing (CMfg) was put forward [6].

Through the realization of sharing and collaboration of manufacturing resources, capabilities and knowledge, based on the full use of cloud computing, Internet of things, the Internet, knowledge services, virtualization and other technologies, cloud manufacturing is aimed to revitalize the stock of manufacturing resources, improve the utilization of resources and reduce the cost of the use of social resources. That is means, to some extent, to develop low-carbon economy, take the road of green manufacturing [7].

II. RESEARCH STATUS OF CLOUD MANUFACTURING

After the concept of cloud manufacturing put forward, it has a widely impact in all walks of life (government, industry, academia, research). Under the support of the national "863 Plan", some technical talents and innovative research teams from the field of cloud manufacturing have carried out lots of relevant researches, involving the definition of cloud manufacturing, system composition and operation principle, system structure, typical characteristic, key technologies, practical application. By the end of the current, some significant achievements of the researches and applications of cloud manufacturing have been obtained.

2.1 Definition of cloud manufacturing

At the beginning of 2010, cloud manufacturing was put forward by the Ministry of science and technology at the meeting of scientific and technical work about manufacturing informatization for the first time [8]. Integrating cloud computing, internet of things, high performance computing, service computing and other

information technologies [9], it provides an important way for the manufacturing industry to transform from production-oriented to service-oriented. At first, because of cloud manufacturing is still a brand new concept and model, there is no standard definition. Two definitions have been proposed earlier and widely recognized in all walks of life. One definition of cloud manufacturing given by the Chinese Academy of Engineering Li Bohu [10] is: Cloud manufacturing is a new intelligently networked manufacturing model, which is service-oriented, highly efficient, consumes less energy, and is knowledge-based. It integrates the existing informatization manufacturing, cloud computing, internet of things, semantic web, high performance computing, etc. Based on the extension and innovation of the current networked manufacturing and service technologies, all kinds of manufacturing resources and capacities will be virtualized, unified and centralized intelligently for management and operation, to achieve intelligentialize, multi-win-win situation, general suitable and highly efficient sharing and collaboration. The other one is defined by Yang Haicheng [11], the chief engineer of the China Aerospace Science and Technology Corporation, Cloud manufacturing is an integrated product, integrating advanced information technology, manufacturing technology, state-of-the-art internet of things technology and so on, is the embodiment of the concept of manufacturing as a service. He believes that cloud manufacturing is frontier concept in contemporary information technology, including cloud computing, etc., expanding the idea "software as a service" into "manufacturing as a service. Under the extensive networked environment of resources, China's manufacturing industries are supposed to provide high added value, low cost products and global manufacturing services.

Subsequently, on the basis of the in-depth study of the characteristics and connotation of cloud manufacturing, Li Chunquan et al.[12] proposed a relatively comprehensive and detailed definition of cloud manufacturing: Cloud manufacturing is a new service-oriented manufacturing mode, which is web-based, relying on cloud computing theory and framework, based on the networked manufacturing technologies and methods, to take on-demand services as the core, take resource virtualization, multi-granularity and multi-scale access control as a means, take resource sharing and task cooperation as the goal, take distribution, aggregation of heterogeneous, autonomous domain resource or resource aggregation as cloud node, take network for the media, and then to construct an open and dynamic collaborative work environment by transparent, simple and flexible ways, providing universal, standard and normative manufacturing services.

2.2 Composition and operating principle of cloud manufacturing system

Cloud manufacturing is a new manufacturing model, which is based on manufacturing resources and capabilities virtualization, in order to achieve large-scale gains, multi-win-win situation and distributed resource sharing and collaborative [13]. Li Bohu et al. earlier proposed a cloud manufacturing system, its operating principle, shown in Figure 1. In Figure 1, it can be seen that the system has three major components: manufacturing resources and capabilities, manufacturing cloud, the whole manufacturing lifecycle applications. In addition, this system also includes a core support (knowledge), two processes (import and export), and three user types--resource providers, cloud operators and resource users. Based on the whole manufacturing lifecycle activities, it essentially reflects the supply and demand service relationship, which is between cloud manufacturing resource providers, cloud manufacturing platform operators and cloud manufacturing resource demanders [14].

First of all, the various manufacturing resources [15] such as manufacturing equipment, computing equipment, software, materials, etc. and capacities are encapsulated as cloud services. This process is called manufacturing resources “import”. According to different manufacturing requirements, cloud services are combined to form a manufacturing cloud. The cloud provides the whole manufacturing lifecycle applications with diverse services. This process is called “export”. Knowledge plays a central role in supporting the entire operating process of cloud manufacturing. It ensures that hard and soft manufacturing resource could be intelligently embedded and virtualized encapsulation during import; it assists functions such as intelligent search of cloud services during manufacturing management; and it facilitates smart cooperation of cloud services over the whole manufacturing lifecycle. Thus it can be seen, in a cloud manufacturing system, knowledge-based integration across the whole lifecycle is possible.

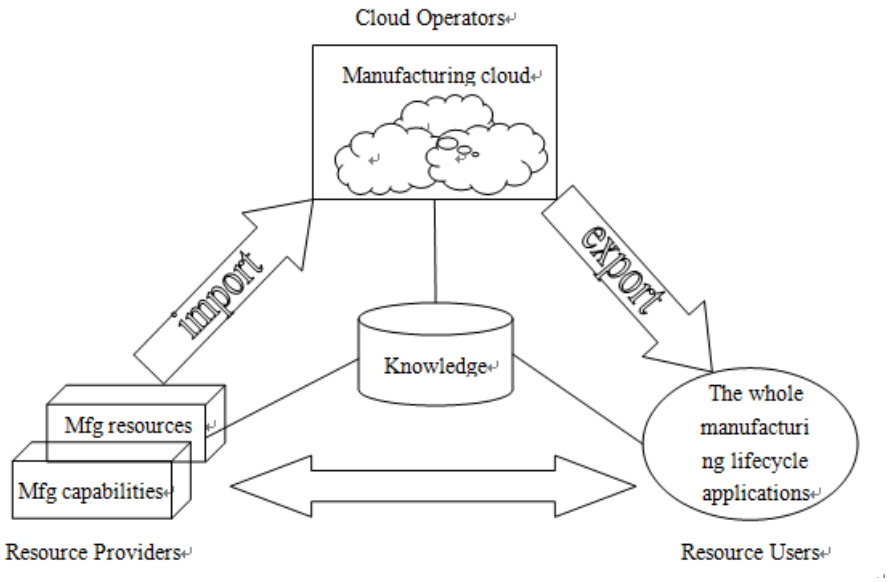

Fig.1 The operating principle of cloud manufacturing [16]

2.3 Architecture of cloud manufacturing

In January 2010, based on a service-oriented cloud manufacturing system model, which is an oriented multi-user commercial operation model, Li Bohu et al. [10] proposed a cloud manufacturing service platform system structure. The system includes five layers: all kinds of physical resources will be connected with network in physical resources layer; physical resource connected with network will be virtualized and encapsulated into cloud services in virtual resource layer; cloud task management, data management, service management and other activities will be implemented in core resource layer; interfaces of application and management tools will be provided to some professional manufacturing applications in application interface layer; the portal which is used to access to the cloud manufacturing system and the man-machine interface will be provided to cloud manufacturing user in application layer. After more than a year, on the basis of existing literatures and new researches, academician Li Bohu [17] further discussed hierarchical architecture of the cloud manufacturing, including the resource layer, middleware layer, the core services layer, portal layer and application layer, and expanded the corresponding contents of each layer.

In March 2010, Yang Haicheng [11] preliminarily put forward a system structure of 5 layers of cloud manufacturing. Physical resource layer includes computers, software, information resources, processing equipment and so on; the physical resources will be virtualized and formed a logical resource as a whole in logical resource layer; resource interface layer is mainly used to provide oriented-services and resource adapters; the abilities such as calculation, simulation, processing, testing, etc will be provided in service content layer; manufacturing problems layer involves new product development, complex problem solving, large-scale simulation, etc. He pointed out that many aspects problems of the system structure need to be researched.

The above two kinds of cloud manufacturing architecture is earlier proposed in the research field of cloud manufacturing and recognized from all walks of life. It presents a basic train of thought for research workers in this field in the future and other representative cloud manufacturing architecture researches are shown in Table 1.

Researchers	Year	Layer Nos.	Hierarchical classification	Object oriented
Li Bohu et al. [17]	2010	5	physical resources, virtual resources, core resources, application interface, application	overall system
Li Haicheng [11]	2010	5	physical resources, logical resources, resource interfaces, service, manufacturing issues	overall system
Yin Chao et al. [18]	2011	9	basic support, platform integration operating environment, platform tools, resources, platform service components, service modules, business model, transaction, user	mid-small enterprises cluster
Zhan Decheng et al. [19]	2011	4	virtual manager, service software support platform, service platform, service standard set	group enterprise cluster
Liu Siyan et	2012	4	physical resources, logical services, integrated	micro and

al. [20]			services, terminal applications	small enterprises
Huang Biqing et al.[21]	2013	12	resource, integrated operation platform, basic support, durable service, engine, tool, service component, service module, business model, business, enterprise service bus, user	mid-small enterprises cluster
Yan Hongbo et al. [22]	2014	6	resources, access, services, core services, application interfaces, users	overall system
Xiang Zhen et al. [23]	2015	5	infrastructure as a service, platform as a service, software as a service, service management, the user to access	numerical control processing enterprises

Table 1 Overview of cloud manufacturing system architecture

2.4 Typical characteristics of cloud manufacturing

The characteristics of cloud manufacturing were described and analyzed from different angles in Ref. [23-27], shown in Table 2. In general, the characteristics of cloud manufacturing can be summarized as following: complexity, dispersibility, targeted, networked, dynamic nature and uncertainty, etc.

Research perspectives	Main viewpoints	Proposer and time
macroscopic perspective	Oriented service and demand, uncertainty, user participation, transparency and integration, active, support multiple users, support payment according to the need of use, low threshold, outsourcing, agile, specialization, based on capacity sharing and transactions, knowledge-based, group innovation, green and low carbon manufacturing	Tao Fei et al. (2011) [24]
user interface	generalization and naturalness, intelligentialize and mobility, virtualization and loose coupling, personalized and the whole lifecycle can be customized	Ma Cuixia et al. (2011) [25]
manufacturing mode	manufacturing resources, self organization, cooperation, on-demand, etc.	Meng Xiangxu et al. (2011) [26]
manufacturing resources and capabilities	On the basis of the digitization (common feature), physical association, virtualization, servitization, coordination, intelligentialize	Li Bohu et al. (2012) [27]
micro perspective	massive resources, isomerism, complexity and coarse granularity, user highly participation and diversity, strong self-healing property	Zhu Linan (2014) [28]

Table 2 Typical characteristics of cloud manufacturing

2.5 Key technologies of cloud manufacturing

The structure, operation, maintenance and management of cloud manufacturing are a complex systematic engineering, involving many theoretical and technical problems need to be solved urgently. The present researches mainly concentrate in five aspects [6,12-15,26,29], shown in Figure 2. Later, on the basis of the in-depth study of the key technologies related to cloud manufacturing, Li Bohu et al summarized a more complete cloud manufacturing technology system [10], including : overall technology, cloud manufacturing resource embedded and perceptive technology, the virtualization and servitization technology of cloud manufacturing resource and capacity, the virtualized cloud manufacturing service environment construction and management technology, the virtualized cloud manufacturing services environment operation technology, the virtualized cloud manufacturing service environment assessment techniques, the cloud manufacturing credible and safe manufacturing service technology, the cloud manufacturing general suitable human-computer interaction technology. The content of each technology was further expanded.

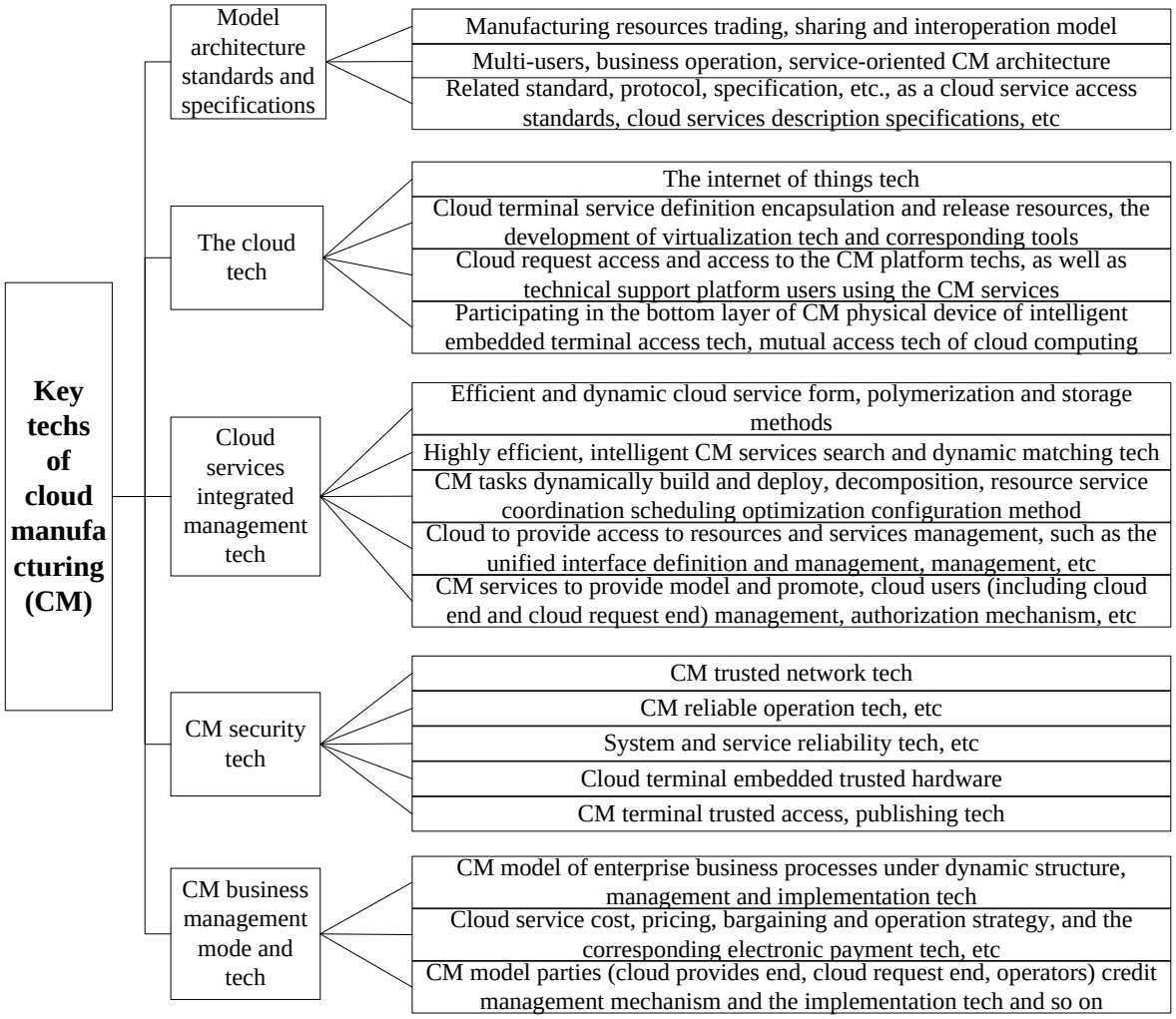

Fig. 2 Study on key technologies of cloud manufacturing

III. APPLICATION STATUS OF CLOUD MANUFACTURING

At present, although the theory of cloud manufacturing is in the primary stage, the cloud manufacturing mode have been promoted and applied in many enterprises and institutions in China and abroad.

3.1 Application of foreign cloud manufacturing

Western developed countries have carried out lots of work related to the cloud manufacturing and made a series of achievements. In 2000, the United States established a networked platform called MFG.COM, which has become the world's largest manufacturing industry trading platform, providing the global manufacturing partners fast and efficient service. By the end of 2012, there are nearly 20 million manufacturers provide services to consumers on this platform [30]. Local-Motors.com, which is the networked platform of the United States off-road racing car factory, adopts the way of service crowdsourcing, and all the individualized design and manufacturing process in the whole car production process are crowdsourced to small and medium-sized enterprises. Ponoko [31] is an on-demand production service provider. Its cloud platform used for product customization provides accessible manufacturing resources to the designers and realizes the condition of product development. Considering the cost of raw materials and the using time of production equipment, products are priced. In addition, manufacturing cloud project was launched by the EU seventh framework in August 2010. With the support of application--software as a service, the configurable manufacturing services will be provided to the users and product customization, which is multi-user oriented and web-based, will be realized [32].

3.2 Application of domestic cloud manufacturing

Domestic research and promotion work of cloud manufacturing service platform is mainly concentrated in group enterprises and small and medium-sized enterprises.

3.2.1 Cloud manufacturing service platform for aerospace complex products

Considering some characteristics such as the long development cycle of complex aerospace products, involved more discipline fields and the uneven distribution of the group's internal resources, Aerospace Science and Industry Corporation II Hospital and Beijing University of Aeronautics and Astronautics jointly set up a cloud manufacturing service platform for aerospace complex products [27,33]. At present, some prominent advantages such as high performance computing (more than 20 trillion times) resources have been accessed, multi-disciplinary and large-scale analysis software and related resources are stored (more than 300T), the high-end CNC machining equipments are equipped and the professional ability of cellular manufacturing system and various manufacturing stages, have achieved the integration of the group's manufacturing resources and capabilities, greatly reduced the cost and improved the group's resource utilization, informatization and competitiveness.

3.2.2 BISWIT cloud services platform [34]

In order to realize the close collaboration of the external resources and core business such as enterprises manufacturing process and others in small and medium-sized enterprises, Enwei Collaborative Technology Co., Ltd. has developed a cloud manufacturing service platform called BISWIT, which has already provided more than 500 small and medium-sized enterprises cloud services for enterprise management. The users can obtain a series of tools support such as manufacturing resource registry, resource demand publishing, searching for resources supply and demand, resource capacity assessment, collaborative manufacturing management and transaction settlement management in the BISWIT.

3.2.3 Cloud manufacturing platform for mould industry

The existing problems for mould industry such as independent research and development ability is insufficient, low proportion of technical personnel in most enterprises, the lack of sophisticated detection equipment, the enterprise management level is not high and lack of modern method and means for product development, Li Bo et al. [35] from Huazhong University of Science and Technology proposed a cloud manufacturing platform for supporting the collaboration of mould industries. This platform provides mould manufacturing enterprises company registry, intelligently searching for manufacturing service and capability, service trade, service evaluation and other functions, thus it is beneficial to integrate resources and abilities within the region, to improve the competition of the industry, to promote the manufacturing industry to a higher level development. In addition, according to the characteristics of Ningbo mould industry, Zhejiang University and other companies developed a set of cloud manufacturing service platform system, in which a variety of forms of enterprise alliance are established, to ensure the successful operation of the service platform and system, to help mould enterprise expand to the service industry, and expand to upstream and downstream direction of the industry development [36].

In addition, there are many researchers from other aspects research and develop the applications of cloud manufacturing platform. For example, Song Tingxin et al. [37] have developed a software system of cloud manufacturing service platform for small and medium-sized enterprises, validated in components manufacturing industry of car / motorcycle industry and in supply chain of steel industry. Through online and offline service, it effectively integrated manufacturing service resources of the industry and achieved the effective management of cloud manufacturing service. For the features of fault diagnosis, Li Qiang et al. [38] put forward a cloud manufacturing service platform, which is validated in Baotou steel seamless that it is effective for manufacturing service platform to diagnose faults. Gao Pei [39] proposed a cloud manufacturing design platform for personalized customization cranes. It realizes the high collaboration between personalized customization of the users and each service provider, shortens the period of design and production of crane product, improves the utilization ratio of resources and increase the income of the enterprises.

IV. CONCLUSION AND OUTLOOK

In this paper, the definition, system composition and operation principle, system architecture, typical characteristics, key technology and application status of cloud manufacturing is simply described and analyzed, which is aimed to pave the way for the subsequent research. As a new networked manufacturing mode, cloud manufacturing provides the manufacturing industry an effective means and support to further improve the level of networked, socialization, greenization, servitization and intelligentize. Therefore, whether it is from a theoretical or practical viewpoint, cloud manufacturing has great significance.

Today, cloud manufacturing has left the clouds. In many manufacturing fields such as the mould manufacturing, 3D printing and product developing, it plays a huge role, but many scientific issues and key technologies need to be further researched in other aspects, such as cloud manufacturing business operation mode, the composition problem of cloud manufacturing services, cloud manufacturing intellectual property issues, cloud manufacturing information management, big data analyzing in the cloud manufacturing, cloud

manufacturing and 3D printing technology, cloud manufacturing safety and credible manufacturing and so on. In the future, with the cloud manufacturing mode becoming more and more complete, the cloud manufacturing will play an important role in social development. It will be forcing the productive service industry and manufacturing industry to create a new business model, promoting the strategic adjustment of economic structure of our country, and playing an important role in transforming China from a manufacturing of quantity to one of quality.

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