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Cloud based 3D printing service platform for personalized manufacturing

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Recently, the rapid development of 3D printing technology and continuous breakthroughs in new material technology has increased the application of 3D printing in a wide range of fields, such as automobile industry, medical treatment, education, and food industry. Nowadays, several 3D printing companies use additive manufacturing (AM) to produce new product prototypes rapidly. For example, according to the Wohlers Report 2018, the global AM sector has grown at an annual average rate of 24.9% from 2013 to 2017, and the industry's total value was $7.34-billion in 2017 [1]. 3D printing facilitates the automation of rapid prototyping and product customization. Compared with traditional production methods, manufacturing companies that use 3D printing technology for customized production must improve their flexibility and agility to meet the new challenges of intelligent manufacturing to the 3D printing industry. Lipson proposed that thousands of 3D printers with different characteristics would be similar to an ant factory: each manufacturing company like an ant, alone, by itself, may be small. However, like billions of ants with factories, the combined whole will be greater than the sum of its parts [2]. The fusion of cloud manufacturing and 3D printing will be a popular business model in the future, and from a design perspective, this fusion will promote innovation by reducing the threshold for designing. Thus, this study aims to build a 3D printing service platform to support users in experiencing manufacturing life cycle activities of 3D printing. Existing 3D printing business platforms, e.g., Shapeways and 3dhubs, do not cover the whole production life cycle. For example, in the existing 3D printing service platform, the 3D model has not yet formed an automated process from design to printing [3]. In short, the 3D printing production process of existing commercial platforms is not intelligent enough, and the transition between some processes needs to be completed manually. However, in this 3D printing service platform, by using servitization integration technology based on cloud computing, 3D printing product processing will be connected automatically in series. From a technical perspective, the 3D printing service platform has new functions and tools compared with existing commercial platforms, such as a 3D model generation tool, an equipment map, and an on-demand pricing tool. Therefore, this platform effectively integrates the entire production process (design, task scheduling, on-demand production, cloud inspection, and post-processing) of 3D printing products.

Proposed framework and key technologies of 3D printing service platform. (1) Cloud manufacturing concept model. The 3D printing service platform realizes platform resource management and

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platform service application maintenance via three roles defined in the cloud manufacturing conceptual model [4]: resource provider, cloud operator, and resource users. The resource provider provides manufacturing resources to the platform. The cloud operator operates and maintains the platform and feeds detected equipment fault information back to the resource provider. Resource users customize and purchase required products through the service applications provided by the platform. According to this new cloud manufacturing model, the 3D printing service platform can obtain the resources and service capabilities required to satisfy the personalized customization needs of customers.

(2) Advances of 3D printing service platform. The proposed 3D printing service platform is divided into five layers, i.e., the physical devices layer, access adaption layer, publishing tools layer, management tools layer, and application layer [5]. The main idea of framework design is to run through the entire life cycle of the production process for 3D printing products in the form of servitization [6]. The production process of the entire life cycle of a product comprises five basic processes, i.e., design, task scheduling, on-demand production, cloud inspection, and post-processing. Through servitization, platform users can directly experience each process. To satisfy the developing requirements of the 3D printing service platform, we studied five key technologies in the production process of 3D printing products, including model generation and design, on-demand production and cloud inspection, and developed corresponding application modules in the application layer of 3D printing service platform.

(3) Key technologies of 3D printing service platform. Based on customized production in cloud manufacturing, the following five key technologies relative to the 3D printing service platform are discussed: 3D model generation based on deep learning, sketch retrieval, print task scheduling, equipment map and on-demand pricing, and monitoring health status of equipment. These technologies are described as follows:

• 3D model generation base on deep learning. In the online design module of the platform's application layer, users can use the 3D model generation tool to upload photos of personalized 3D models they need to print. Based on the deep learning algorithm of generative adversarial networks, photos from different angles are automatically transformed into a standard 3D printing model file using the efficient computing power of cloud computing clusters.

• Sketch retrieval. The sketch retrieval tool can match a sketch of a user's online drawing to a closed outline view of the 3D model in the model library. We have developed an aggregation and retrieval mechanism for the 3D printing model. The sketch retrieval tool can effectively manage the 3D printing model library to realize the reuse and sharing of 3D printing models. Thus, users can achieve precise matching between sketches and professional 3D models.

• Print task scheduling. The print task scheduling tool can dynamically match 3D printing tasks with specific 3D printers in the distributed environment [7]. In addition, this tool can optimize the layout of multiple 3D models assigned to the same printer, match printing tasks, and form multiple products in a working cycle. Thus, this tool realizes reasonable planning of 3D printing tasks and improves the utilization rate of 3D printing equipment.

• Equipment map and on-demand pricing. In the preview resource and cost estimation modules of the platform's application layer, equipment map and on-demand pricing tool enable users to view the actual location of 3D printers in a map. In addition, the cost estimate function of this tool provides a list of real-time reference prices based on the basic order information of currently available 3D printers, printing supplies, time, and delivery distance. This tool allows users to view information about the printing device on the cloud platform and select appropriate 3D printer resources according to the reference price list.

• Monitoring health status of equipment. The preview processing module of the platform's application layer includes a 3D print adapter with a universal access function. The adapter was developed based on Arduino [8]. This tool also enables users to observe the operation of 3D printers online. It can realize auxiliary monitoring of the health status of equipment, and when the equipment triggers a fault threshold warning owing to an abnormal state, the automatic push function of the adapter pushes the information to the relevant equipment management personnel for inspection and maintenance purposes. Therefore, the tool can reduce losses caused by equipment failure and improve the printing efficiency.

Conclusion. A cloud-based 3D printing service platform is introduced based on cloud manufacturing. The framework of this platform is also discussed. We have provided a detailed interpretation of the platform's design concept and key technologies. We conducted some research work in the production process of 3D printing products, including model generation and design, on-demand production, cloud inspection and other links, and developed corresponding application modules. In

order to realize the concept that centralized management of distributed resources, this platform's related research work and application modules will be improved in the following study. We will try to effectively integrate the 3D printing production process information collected by these application modules to make 3D printing service platform become more intelligent.

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Supporting information Videos and other supplemental documents. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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