The Cloud Service Framework Oriented Additive Manufacturing

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Abstract. This paper proposes a 4-layer device virtualization system framework based on multi peer nodes. First, the different layers of deployment and the operation processes of the system are discussed, then the resource management and the information flow are described. Finally, the interface and task assignment of the proposed system is discussed using experiments and the effectiveness and stability of the system is demonstrated.

1. Introduction

Additive Manufacturing (AM) is a very competitive mode of production that fabricates products layer by layer. It has been widely used in various fields such as medical, rapid prototyping and mold. However, despite the rapid development of the AM industry, it is also facing the further development bottleneck. Firstly, the processing cost of industrial equipments is higher, which makes companies adopting AM technology bear the market pressure. Secondly, the AM technology is still under rapid development, the devices are expensive and require regular upgradation which further increases the cost for the companies. Finally, it is still limited in terms of the application field which leads to a low manufacturing equipment utilization. These factors increase the burden of 3D printing manufacturers, but also hinder the further application and manufacturing process development of AM technology. Currently, the major challenge is reducing the manufacturing cost and broadening the application field of the AM industry.

Cloud manufacturing is new manufacturing paradigm developed using the ontology technology to describe, abstract and encapsulate the manufacturing resources. It utilizes the virtualization technology in order to integrate the manufacturing resources and provides the manufacturing services interface to create a public service platform. A direct connection between the consumers and the manufacturing resources can be an effective method to improve the level of manufacturing intelligence and to reduce the production costs. The software and hardware resources can be integrated using the cloud manufacturing and service mechanism to achieve the rapid expansion of manufacturing capacity, to improve the utilization of AM equipment and to optimize the manufacturing process [1]. Compared to conventional processing methods, the AM process is simple and has high degree of automation and concentration which makes it more suitable to provide services in the form of a cloud platform. Therefore, building an additive manufacturing cloud platform is an effective method to promote industrial development and reduce costs.

This paper proposes a method of constructing manufacturing resource pools against AM manufacturing equipment and related software. The core ideas is to first abstract the hardware and software resources of AM and package them into a suitable size of manufacturing services and related technical services connected by the independent intelligent agent to form an isomorphic resource node. Then use the collaboration between the nodes to build a scalable virtual resource pool of heterogeneous and integrated manufacturing resource. Based on above mentioned idea, this paper proposes a multi-layer architecture of Additive Manufacturing Cloud Platform (AMCP) for individual service providers of 3D printing and AM enterprises from the aspects of resource management and information flow. The authors have also built a commercial 3D printing service website to demonstrate the call interfaces and task assignment of the AMCP.

2. Related Work

Currently, cloud manufacturing mainly focuses on the construction of the virtual resource pools and on the development of temporary production processes in accordance to the manufacturing needs to optimize the performance and the cost [2]. Among them, the virtualization of manufacturing resources is the basis of realizing resource scheduling based on the manufacturing demand [3]. This article will divide the study of cloud manufacturing resource virtualization into three aspects including resource access, resource mapping, resource scheduling, in order to clarify the features of current cloud manufacturing research and cloud platform.

The most important issue of AM resource virtualization is 'resource access' which promotes the work of AM equipment standardization. In this regard, Li *et al.* [4] used the FBG sensors and the embedded network NC system to realize the perception and access of lathes and milling machines, Ren *et al.* [5] utilized the access adapter for the standard access of the heterogeneous resources, Tao *et al.* [6] realized the access of the hard manufacturing resources by means of Internet of Things (IoT), Xu *et al.* [7] realized the access of the CNC machine tools with agents that adopt MTConnect protocol system. Most of above mentioned studies concentrated on the access of traditional hard manufacturing equipments. In the process of AM, resource access not only includes hardware, but also contains software and manual processes of AM region.

In mapping form between the physical resources and the virtual services, Ren *et al.* [5] and Xu *et al.* [7] proposed one to one, one to many and many to one approaches to achieve the conversion from physical resources to virtual services. Gao *et al.* [8] established fuzzy mapping between resource description and resource need. These studies provided references in terms of static mapping between the virtual and physical resources, but didn't consider the service matching and the optimization of a dynamic environment. The proposed AMCP uses one to one mapping mode during the transformation from the physical resources to the virtual services which decreases the difficulty of system management.

During the cloud manufacturing process, the key technology of establishing a virtual manufacturing resource pool is to achieve a unified management for the virtualized manufacturing resources and capabilities through dynamical scheduling. Based on the resources intermediary contract net mechanism, Ma *et al.* [9] achieved the adaptive management and scheduling of cloud manufacturing services. Whereas, Tai *et al.* [10] optimized the scheduling of manufacturing resources and capabilities based on the genetic ant colony algorithm. The AMCP uses agent collaboration, status monitoring and rule engine to realize the dynamical scheduling of AM services.

Contra pose to the traditional manufacturing equipment, the above mentioned studies proposed solutions from their point of view. Compared with the traditional manufacturing processes, AM that has high degree of equipment automation, simple process and has high concentration, is easier to implement the virtualization of resources to build a business services cloud platform which is network-based, integrated and transparent to the users. But throughout the design and production processes of AM, more flexible customization process is required which limit the application of the existing methods.

3. AMCP Framework

A large number of distributed heterogeneous AM equipments and related software have been established to achieve a unified foreign service and dynamical management and to solve the integration issue. Based on the idea of autonomic computing [11], the AMCP maintains the manufacturing resource access through a number of rules-driven peer resource management nodes and establishes a decentralized, scalable and distributed manufacturing resource pool through independent collaborative behavior between the nodes. This paper builds the AM resource management and service based on a series of management rules and presents a multi-layer framework to complete the interface management, workflow management, resource management, security management, policy management, environmental monitoring and perception and access of manufacturing resources.

3.1 System Framework.

The overall structure of the AMCP framework is shown in Fig. 1.

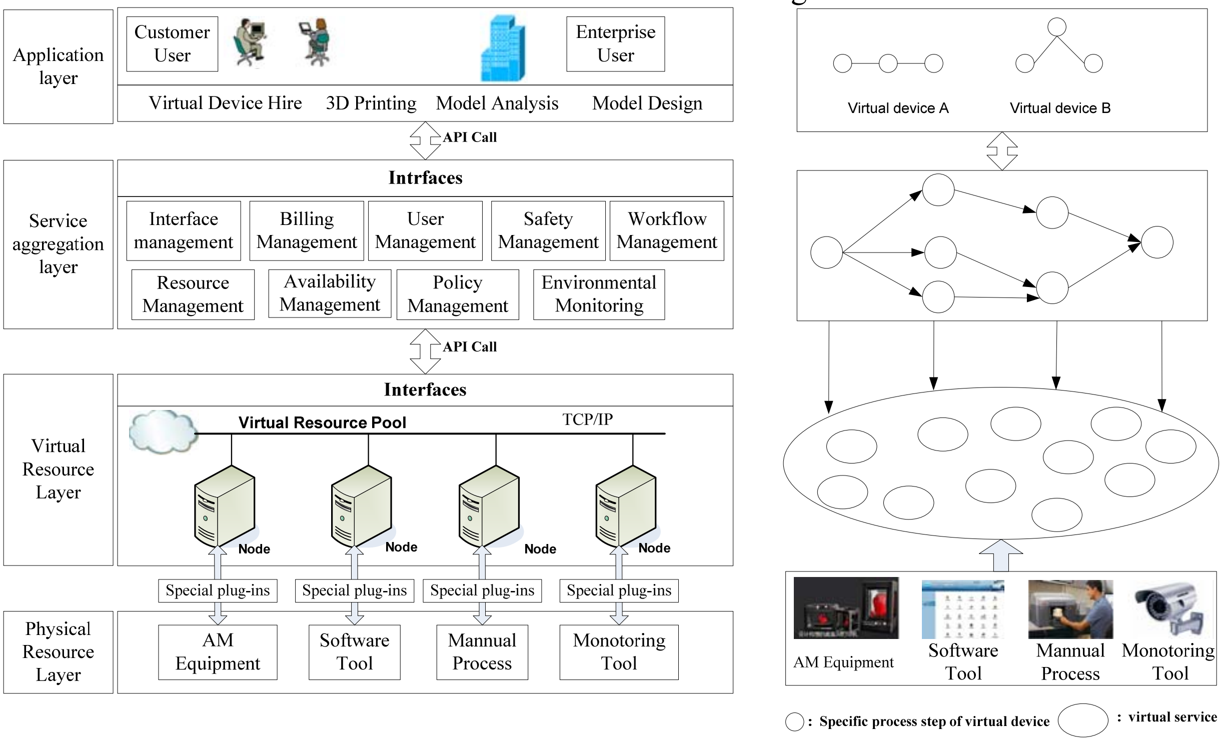

Fig.1 AMCP framework

The function of the application layer is the abstract level of describing the 3D printing applications, such as providing a 3D printing commercial service website and virtual 3D printer drivers that can be loaded to a desktop PC or a mobile device system. This layer completes the specific production tasks through integrating the virtual manufacturing service interfaces of the AMCP.

The service aggregation layer provides the service interfaces and the internal calls for the virtual resource pools, and as a Host Side to control the internal services, it calls the entire life cycle of services including the workflow management, the security control, the logistics, etc. This layer still uses the rules-driven peer node structure. The number of starting nodes depends upon the service requests quantity of the application layer. Once, this layer receives service requests from the application layer, the request is places into a request queue and the workflow is generated by reading the task queue, then under the drive of the workflow manager, the task requests are sent to the resource management nodes of the next layer whose network segment information is known in the form of broadcast. According to the response time of the resource management nodes against task requests queue (the queue uses cache to maintain the current active node), the resource management node responding first is the master node, and the service callings are controlled by the master node.

The virtual resource layer is the core level that constructs the virtual resource pool comprising of multiple homogeneous resource management nodes. The connection between the resource management nodes is via TCP / IP networks. The responsibility of this layer is down to connect all the physical resources to establish scalable virtual resource pool, and up to provide the service-level interface to services aggregation layer. In addition, the layer is also responsible to collaborate among the resource management nodes to achieve resources aggregation and to constitute a scalable dynamic virtual resource pool.

The physical resource layer covers all the manufacturing-related hardware and software resources. These resources are the objects managed and integrated by the AMCP framework. Considering the manufacturing process of the AM's entire life cycle and management simplicity, the AMCP divides the AM resources into four categories, AM hardware devices, software tools, manual processes, and monitoring equipment.

3.2 Resource Management.

3.2.1 Resource Access.

The procedure of accessing the four kinds of AM resources by the resource management node is as follows. The different virtual services can be encapsulated into virtual devices that have special functions. The AM resource access procedure is as follows: First, aiming at different kind of AM resources, make use of open source systems, OLE embedding and separate process way to form a controlled interface of device resources and a dynamic link library plug-in. The plug-in contains the device control interface, resource description and interface description. XML language is used to describe the plug-in functionality and input/output interface. Different technology is utilized to achieve resources connection in the plug-in. Second, deploy the resource management node on the computers that are connected to devices. The resource management node starts reading the plug-in library and generates a set of unified form services according to the description of the plug-in and the interfaces. The generated services are then registered in the Knowledge Base of the resource management node. After the resource management node starts, the master node broadcasts data to the network segment, updating the public policy and the environmental data, and using the way of operator logins to set up the local management strategies (price, priority, manual).

3.2.2 Resource Mapping.

One to one model is used by the AMCP to perform mapping from the physical resources to virtual services. First, the entity resources are easily transformed into easily manageable virtual services, while the services are being searched and matched, the rules engine of the resource management node determines which virtual service will be called. Second, depending on the deferent process, multiple virtual services are encapsulated into virtualization devices with deferent function; If AMCP uses one to many mapping model, the event manager of the resource management node needs to adopt the multi-level reasoning mechanism which increases the difficulty of AMCP management.

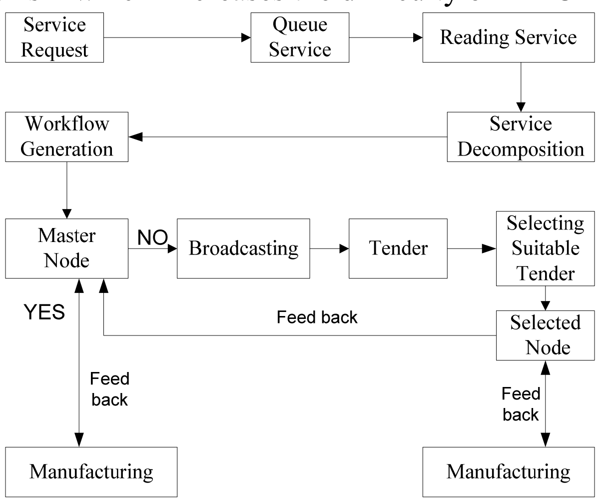

Fig.2 Service collaboration

3.2.3 Resource Schedule.

In the resource scheduling as shown in Fig. 2, when a fabrication request is received, the master node of the AMCP virtual resource layer determines whether to perform specific tasks based on the policies and the status of the services connected to itself. If the service of the master node can independently complete the fabrication task, then the AMCP goes directly into the manufacturing process if the master node cannot independently complete the fabrication task, the master node initiates collaborative requests to resource management nodes around. Specifically, the collaborative process is as follows: The master node broadcasts the task information to the surrounding resource management nodes in the form of tenders. Once the tender is received, the resource management node will decide whether to participate in this task according to its capabilities and status, if it decides to participate, then it will send a tender to the master node to indicate its ability and status. Thus the master node will receive multiple tenders and will then choose the most suitable one to execute the task under its monitoring. At the same time the monitoring information will be fed back to the service aggregation layer.

4. Information Flow

We discuss the system information flow through the 3D printing website calls the manufacturing services of AMCP. When the 3D printing website initiates a call for manufacturing service API of AMCP. The service aggregation layer receives the order and puts it in the queue, and then calls the read service API to read service orders and identify the service categories, and then calls the analysis & verify API to ensure the order is valid and then calls the service decomposition API to generate the workflow. The workflow manager initiates a manufacturing request to resource management nodes of the virtual resource layer and chooses the master node. The master node of the virtual resource layer determines whether to perform specific tasks based on the policies and the status of the services connected to itself. If the master node service can complete the fabrication task independently, then the AMCP goes directly into the manufacturing process and calls a status monitoring service to make changed status information known by the master node at the same time. While executing the manufacturing task, the AMCP will call another status monitoring service to monitor the operating conditions of the 3D printer, and the monitoring information is fed back layer by layer to the master node, knowledge base and the end-users. Once the product is printed completely, it is delivered to the user by the logistics. If the manufacturing task cannot be completed by the master node independently, it will initiate a service collaboration (Fig.2) to select the most appropriate resource management node around itself, and then the task will be given to the selected node.

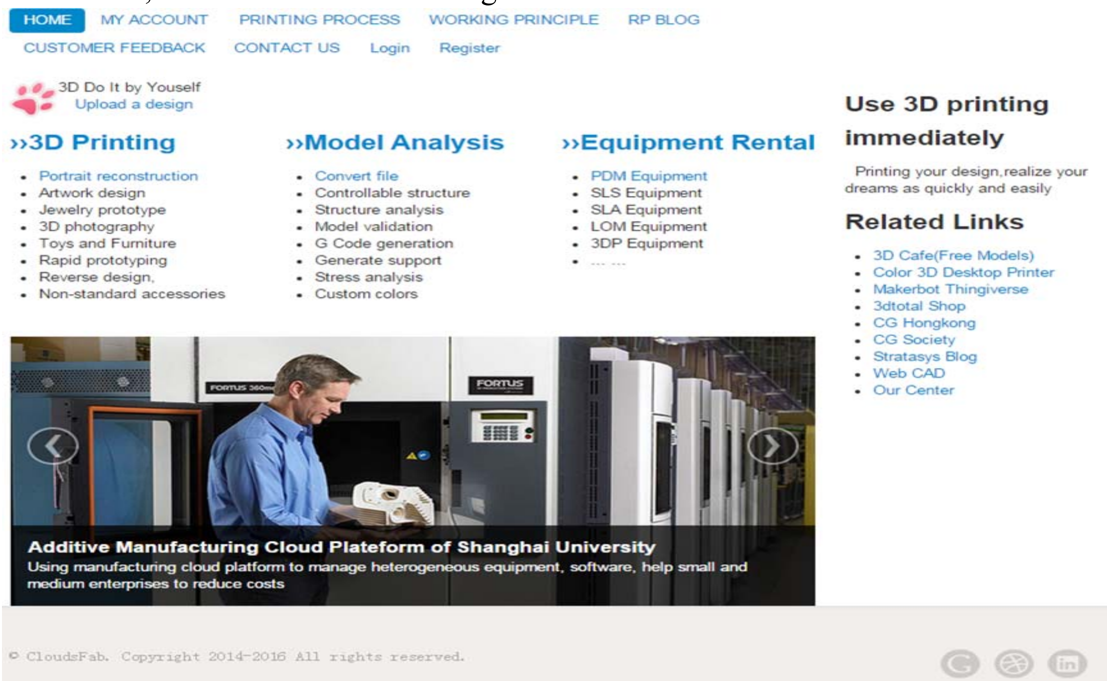

Fig.3 AMCP interface

5. Experiment

In order to evaluate the concept of the AMCP, two case studies have been carried out. The manufacturing capabilities are virtualized in the cloud manufacturing environment. The first case study shows the process of API service calling, and the second demonstrates how the AMCP deal with cloud service assignment.

5.1 Interface Call.

Based on the 3D printing resources of the rapid manufacturing engineering center of Shanghai University, the AMCP packages them into cloud manufacturing services and establishes the Additive

Manufacturing Cloud Platform of Shanghai University (Fig.3) as a 3D printing service website to test the AMCP manufacturing service API. The website services by calling the AMCP quote API to finish the service quotes. Once the user chooses to go on printing, the website generates service order. After the user finishes the payment of the service order, the website calls the AMCP manufacturing API to transfer the service order to the service aggregation layer. The service order is fed back once it is successfully received by the service aggregation layer. After receiving the analysis and the verification of the service order, the service aggregation layer ensures the order is valid, and then transfers the service order to the workflow manager to generate a workflow. Finally, the AMCP enters the manufacturing process as described in section 4.

5.2 Task Assignment.

The task assignment is an important part in the workflow management. The AMCP workflow manager uses random assignment strategy during the task assignment. In theory, the probability that the workflow manager randomly assigns a task to a node of virtual resource layer successfully is 60%, namely, the probability of failure is 40%. The task type is software service. The average time to complete the task is $t = 2.02s$. The average time has been obtained through 1000 times test and the average time t includes the following time periods: $t1$ is the time taken by the workflow manager of the service aggregation layer to the event manager of the virtual resource layer, $t2$ is the time taken by the event manager to parse the task, $t3$ is the time to send a request to the rules engine by the event manager, $t4$ is the decision time by the rules engine to determine whether to execute or not, $t5$ is the time executing task, $t6$ is the time taken by the rules engine to the event manager and $t7$ is the time that the event manager takes to the workflow manager of the service aggregation layer. The key factors affecting the average time are the amount of resource management nodes, the amount that each resource management node queries the task queue in a second time, servers and the task size. As shown in Fig.4, using varying amounts of resource management nodes to deal with the task requests of service aggregation layer, the four squares are representing the amount of tasks that task queue is currently maintaining when 2 nodes deal with the task requests, the circle is representing the condition of 200 nodes, and the triangle is representing the condition of 1000 nodes. And the frequency that each resource management node queries the task queue is 10 times per second.

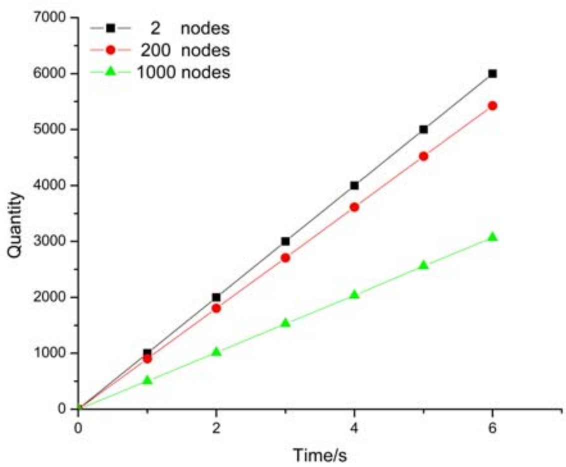

Fig.4 The task assignment test

The service requests increase with a growth slope of 1000 /s. When the number of resource management nodes increases, the difference between the two curves at the same time shows the size of AMCP throughput, additionally it shows that the average throughput is about 500 /s under the condition of 1000 nodes. Furthermore, the number of unassigned tasks maintained by the task queue is getting smaller and smaller which indicates that the task allocation method in this paper can effectively allocate the tasks without making the task queue longer. If the number of nodes increased and the processing algorithm of resource management node reduced unnecessary output, AMCP could get a higher processing efficiency.

6. Conclusion

Based on the AM characteristics, the authors have proposed a four-layer AM resource virtualization framework, namely the AMCP. Compared with the present studies, the AMCP that is based on the peer nodes has two advantages: First, the structure of decentralized resource management makes the system more flexible, configurable and scalable, it can quickly and effectively integrate and reuse a large number of AM software and hardware resources. Second, the rules-based resource management node supports self-management and coordination mechanism, which not only simplifies the actual configuration of the cloud platform and but also decreases the technical barriers and cost promoting the practical process of the 3D printing technology.

Further work will focus on the systematic test of the AMCP resource access, operation management and a third-party application integration. Based on this, the optimize resource scheduling algorithm and the implementation process with main concerns of solving the questions of resource aggregation, virtual device generation and security issues during the process of cloud service operations.

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