CLOUD MANUFACTURING PLATFORM ARCHITECTURE

Lei Ren[(a) (b)]

[(a)] School of Automation Science and Electrical Engineering, Beihang University, Beijing 100191, China;
[(b)]Engineering Research Center of Complex Product Advanced Manufacturing System, Ministry of Education, Beijing 100191, China

leo.renlei@gmail.com

ABSTRACT

With a new trend of service orientation, high efficiency and low consumption, and knowledge innovation in global manufacturing, networked manufacturing is facing great challenges. Cloud Manufacturing, as a new service-oriented agile manufacturing paradigm over networks, deriving from the idea of Cloud Computing, can provide on-demand collaborative services supporting whole life circle manufacturing applications by sharing virtualized manufacturing resources via cloud networks. The achievement of this promising paradigm depends on powerful Cloud Manufacturing platform which meets the requirements of both resource providers and consumers. This paper presents a design of Cloud Manufacturing platform architecture which includes resource perception layer, virtual resource layer, middleware layer, application supporting layer, and user interface layer. The design can give comprehensive support to achieve the goal of Cloud Manufacturing. We also discuss the key technologies in Cloud Manufacturing platform, which presents a map for future research of this new area.

Keywords: cloud manufacturing, cloud computing, cloud simulation, cloud manufacturing platform, networked manufacturing

1. INTRODUCTION

The evolution of contemporary manufacturing has adapted itself to the development of economy globalization that gives rise to the requirements of quick response to global market. Current manufacturing is no longer limited to traditional production and fabrication, but a life-circle management of product covering analysis, design, simulation, experiment, fabrication, business management, after-sale service, etc. The competition in global manufacturing calls for dynamic alliance of manufacturing companies distributed in geographically different locations all over the world, resulting in virtual manufacturing organizations across Internet and intranet. The combination of manufacturing with information technology, such as distributed manufacturing networks and computer supported collaborative work, has proven a powerful means to support effective global manufacturing management of whole life circle of product (Zhan *et al.* 2003). In recent years, network manufacturing technology based on distributed computing, such as Application Service Provider (ASP) (Flammia 2001), Manufacturing Grid (Fan *et al.* 2004), etc., has become one of the essential advanced techniques to support the collaboration of distributed manufacturing companies over networks. For example, Manufacturing Grid can integrate and schedule manufacturing resources dispersed in networks such as material, device, information, business process, human, etc. to support complex collaborative manufacturing tasks.

However, current available network manufacturing technologies are facing new challenges. Form a perspective of business mode, current solutions do not provide incentives for manufacturing service providers in ASP or Gird because of the absence of pricing and accounting mechanism according to QoS evaluation and actual usage of resources. Thus, it is difficult to promote the market-oriented network manufacturing for both manufacturing service providers and consumers at market equilibrium.

Other than the problem of business mode, there are still technical roadblocks as well. One is that the encapsulated manufacturing services based on service-oriented architecture (SOA) mainly offer support for the soft-resources such as CAD/CAE software. The current SOA-based manufacturing techniques (Sun *et al.* 2008) cannot penetrate through the underlying infrastructure especially for the hard-resources such as critical fabricating devices in production chain. Therefore, the partial SOA solution cannot achieve efficient integration of manufacturing resources.

Additionally, as the green manufacturing (Gomes *et al.* 2004) is getting increasingly important for energy saving, manufacturing applications make an urgent demand for high efficient and low consumption of resources management especially in the large-scale and complex manufacturing domains. Complex manufacturing applications often need to perform collaborative computing tasks and deal with a vast amount of data, which calls for dynamical aggregation of distributed resources at the peak computing point. While current network manufacturing techniques always cannot meet the need of resources for peak computing, the average utilization of resources is much low because a majority of common manufacturing tasks only consume a few resources.

Moreover, a large number of knowledge accumulated in manufacturing domains has gained little effective utilization in current network integration solutions. The knowledge covers a wide range of domain-specific ontology, expert experience, simulation models, etc., which can supply semantic support for manufacturing service management and business process optimization to achieve intelligent manufacturing. Yet, current network manufacturing techniques cannot make full use of knowledge to implement intelligent integration and management of manufacturing resources.

Cloud Computing (Armbrust *et al.* 2009) provides a new business paradigm for service-oriented distributed computing, which together with techniques of virtualization (Lei *et al.* 2012), Internet of Things (IoT) (Wolf 2009), Semantic Web (Acuna and Marcos 2006), and High Performance Computing (HPC) (Benioff and Lazowska 2005) appears to be promising solutions to tackle the problems above.

To address these concerns, Cloud Manufacturing (Zhang *et al.* 2012) provided a new model of service-oriented distributed manufacturing based on the idea of Cloud Computing. Cloud Manufacturing provided a promising business mode for both manufacturing service providers and consumers by the way of on-demand sharing and provision of distributed resources. Besides, Cloud Manufacturing leverages IoT and virtualization techniques to ensure that both soft-resources and hard-resources could be plugged in and virtualized into services. Also, virtualization and HPC give a support for high efficient utilization of virtualized resources. Further, Cloud Manufacturing focuses more on knowledge-based semantic integration to achieve intelligent manufacturing.

The achievement of this new paradigm depends on powerful Cloud Manufacturing platform which meets the requirements of both resource providers and consumers. This paper presents a design of Cloud Manufacturing platform architecture comprising resource perception layer, virtual resource layer, middleware layer, application supporting layer, and user interface layer. The design can give comprehensive support to achieve the goal of Cloud Manufacturing. We also discuss the key technologies in Cloud Manufacturing platform, which presents a map for future research of this new area.

2. RELATED WORK

Network manufacturing technology put emphasis on information integration, process integration, and enterprise integration to establish resources sharing environment across Internet and intranet. ASP, SOA-based manufacturing and Manufacturing Grid are among most popular ones. ASP presented an information system outsourcing paradigm in that application service providers, as vendor, could supply services for users through networks. SOA-based manufacturing typically used web services as a unified standard to implement integration of distributed and heterogeneous manufacturing resources. Manufacturing applications (mainly refer to software) are encapsulated into loosely coupled, interoperable, and protocol-independent services based on WSDL, SOAP and UDDI. Manufacturing Grid defines a set of standard protocols and middleware to provide interoperable services built on different manufacturing nodes, which can concurrently support access to different resource types such as computing, storage, software, etc, which thus can disassemble large-scale and complex tasks into networked and loosely coupled nodes acting in concert to complete parallel computing processes (Fan *et al.* 2004). In contrast to Cloud Manufacturing, current available solutions for network manufacturing introduced above do not build a successful business operation paradigm that support effective pricing and accounting mechanism, and they cannot attain high utilization of manufacturing resources by taking advantage of virtualization and knowledge-based intelligent management.

There are a variety of different definitions for Cloud Computing. For example, it refers to a large-scale distributed computing paradigm that is driven by economies of scale, in which a pool of abstracted, virtualized, dynamically-scalable, managed computing power, storage, platforms, and services are delivered on demand to external customers over the Internet (Foster *et al.* 2008). Cloud Computing is considered as a new business paradigm describing supplement, consumption and delivery model for IT services by Utility Computing (Mladen 2008) based on the Internet. The typical examples of public Utility Computing include Google AppEngine, Amazon Web Services, Microsoft Azure, IBM Blue Cloud, Salesforce. So far, Cloud Computing is regarded as the sum of IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service) (Buyya *et al.* 2009). Cloud Computing providers can deliver on-demand services covering IT infrastructure, platform, and software vie virtualization and service encapsulation technology. Thus, it can meet the needs of ever-rising scale of computing and storage of consumers and lead to decrease in IT investment cost at the same time. Cloud Computing introduces a promising business model and technical approach to the problems network manufacturing facing. For example, virtualization technology can support deep encapsulation of a logic entity of IT infrastructure (e.g., CPU, memory, disk, and I/O) and software into a pool of virtual machines, thus it can achieve high efficient and low consumption of resources. While current virtualization technology in Cloud Computing can build virtualized entities for soft-resources in network manufacturing, it cannot solve the encapsulation of hard-resources (e.g., lathe and fabricating equipment) problems that is essential to efficient manufacturing collaboration. Also, manufacturing need more support of knowledge including product design models, expert experience, production process logic, collaboration rules, etc. which is not emphasized in Cloud Computing.

Along with the advance in Cloud Computing, the Internet of Things (IoT) has become a promising technology that provides possibility to interconnect all physical things vie wireless sensors, RFID, embedded technology, etc. besides the IT infrastructure over the Internet. So, IoT can offer an approach that ensures the hard-resources plugged into Cloud Manufacturing and then virtualized to services.

Semantic Web gives a standard formal model describing knowledge by ontology such as OWL and provides support for semantic service computing such as OWL-S (Martin, *et al.* 2007), which can thus be adopted to manufacturing knowledge modeling and intelligent service management.

Under the pushing of large-scale and complex manufacturing applications such as Boeing787 aircraft, High Performance Computing (HPC) will offer powerful support for massively scalable data processing and parallel computing to achieve high efficient collaborative manufacturing through the whole life-circle of product in Cloud Manufacturing.

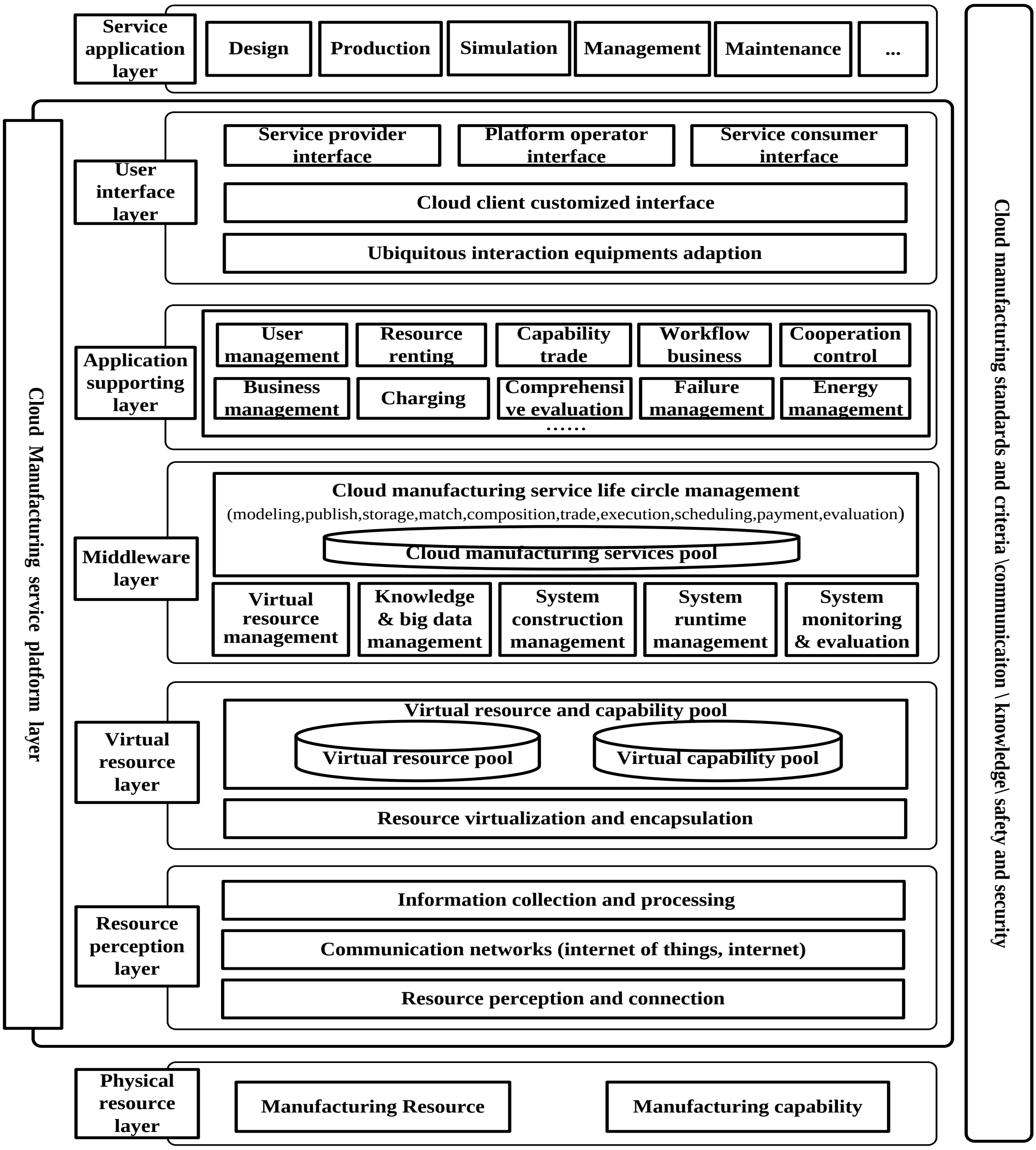

Figure 1: Cloud Manufacturing platform architecture

3. CLOUD MANUFACTURING PLATFORM

Figure 1 shows the layered architecture of Cloud Manufacturing platform. It consists of five layers: *resource perception layer*, *virtual resource layer*, *middleware layer*, *application supporting layer*, and *user interface layer*. Cloud Manufacturing platform can integrate a broad range of manufacturing resources as Figure 1 illustrates, and provide support for whole life circle manufacturing applications.

3.1. Physical Resource Layer

The *Physical Resource Layer* includes *manufacturing resource and capability*. This is an abstraction of a variety of manufacturing units distributed in geographically different places.

Manufacturing resource comprise a variety of underlying resources including three classes: hard-resource, soft-resource, and IT infrastructure. Hard-resources refer to manufacturing equipments such as fabricating device, milling machine, etc., which should be first plugged into cloud networks by means of wireless sensors or IoT so as to build up cloud terminals that could be accessed and controlled. Soft-resources involve all kinds of CAD/CAE/CAX software, simulation tools, model/algorithm repository, and domain knowledge. Some special software, such as Matlab, Adams, Easy5, Protel, and CodeV, is essential to domain-specific applications. Moreover, manufacturing applications always need domain knowledge to support product life-circle management. A great number of legacy models or algorithms for mechanism, control, dynamics, thermodynamics, and so on are indispensable to knowledge-based manufacturing. Besides hard-resource and soft-resource especially for manufacturing, physical resources also comprise IT infrastructure such as computing cluster, storage center, network device, and other IT hardware.

Here manufacturing resource differs from manufacturing capability in that the former is used to describe “what I have” while the latter indicates “What I can do”. So the capability should be described with more semantics than typical resource. In fact, it is the manufacturing capability trade that the providers and consumers are dealing with. Indeed, manufacturing capability roots in manufacturing resource merged together with human intelligence and knowledge to supply design capability, production capability, experiment capability, simulation capability, and management capability that are inevitable to life circle manufacturing.

3.2. Resource Perception Layer

The *Resource Perception Layer* is responsible for making the manufacturing resources and capability plugged into manufacturing clouds. The terminals are connected into clouds over comprehensive networks such as IoT, internet, and mobile networks. The so called plug-in needs special intermediate hardware devices which provide adaptive interfaces for diverse manufacturing machines connected in. Meanwhile, a wide variety of sensors play an important role to transform passive machines into intelligent active ones. For example, pressure sensors and temperature sensors can be used to perceive the real-time states of chemical plant installations and the perception information makes it possible for remote controller in clouds to give an alarm and do better scheduling. RFID and other wireless sensors give support for tracing materials in logistics.

Another indispensable function in this layer is information collection and processing because there should be enormous data generating constantly by sensors. The mass data need de-noising to generate clean data, and the trimmed data need to do further organization and classification to provide valuable information desired by applications.

3.3. Virtual Resource Layer

Virtual resource in Cloud Manufacturing differs from Cloud Computing in that it extend the definition to a large degree. Virtualization in Cloud Manufacturing refers to transforming physical manufacturing resources and capability into logic and abstract ones with standard interfaces to handle inputs and outputs. This layer is responsible for this transformation. Then the virtual ones decouple themselves from the physical ones. As a result, there would be a large number of virtual units that make the management of manufacturing resources and capability more flexible.

In addition, in this layer there are two types of pools where the virtual units are assembled. One is virtual resource pool and the other is virtual capability. The pools seem like UDDI in SOA architecture. This layer provides needed basic functions for management of virtual units pool such as encapsulation, registration, query, update, etc. Moreover, this layer supports intelligent and optimal composition of virtual units for complex requirements single virtual unit cannot meet, such as a product design request that need diverse resources across multiple organizations.

3.4. Middleware Layer

Middleware Layer packaged commonly used functions in clouds into different modules that provide standard interfaces used by *Application Supporting Layer*. This layer comprises six types of middleware to realize virtual resource management, knowledge & big data management, system construction management, system runtime management, system monitoring & evaluation, and cloud manufacturing service life circle management, respectively.

The virtual resource management middleware is responsible for management of virtual resource and capability pools. The knowledge & big data management middleware acts as the provider of multi-domain knowledge to give intelligent support for both life circle of manufacturing applications and life circle of cloud services. Moreover, this middleware provides support for parallel storage and high performance processing of the big data generated by clouds. Most of the big data are semi-structured and unstructured, and cannot be organized, stored, and analyzed efficiently by means of traditional relational database management systems. The system runtime management middleware masters the customized runtime system. It need manage coordination among cloud services, involving workflow control, resource allocation, time and space synchronization. In addition, it handles runtime fault tolerance and implement live migration of tasks, e.g., finding substitute resources and then copy task contexts to new physical manufacturing nodes. System monitoring & evaluation middleware acquires customized system parameters and provides various qualitative and quantitative models for evaluation of performance, QoS, and etc. Cloud service management middleware offers support for management of the whole life circle of cloud services, and the functions including service modeling, publishing, storage, matching, composition, trade, execution, scheduling, payment, and evaluation.

3.5. Application Supporting Layer

The *Application Supporting Layer*, on basis on the middleware interfaces, encapsulates the functions frequently used by manufacturing applications into service components.

The user management component is used to manage user personal information, accounts and roles. The resource renting component helps resource requesters to find needed resources and rent them. The capability trade component acts as the intermediary agent between capability providers and consumers. The workflow business component is used to manage complex service composition. The cooperation control component is responsible for management of collaborative and interactive services. The business management component serves as a business manager to handle business affairs such as contracts. The charging component is used to compute the fees according to rates of resources and capability. The comprehensive evaluation component provides both interfaces for end-users to score and APIs for automatic evaluation by the platform. The failure management component is to deal with runtime faults to keep systems reliable. The energy management component aims at realize optimized utilization of energy.

3.6. User Interface Layer

The *User Interface Layer* play an indispensable role for end-users in Cloud Manufacturing systems. End-users have different roles in manufacturing applications and they also have diverse requirements concerning how to access mysterious clouds. It is the issue of ubiquitous usability (Jacob *et al*. 2008). This layer provides support for divers interaction terminal equipments such as PC, pad computer, smart phone, and PDA, so end-users may use cloud services without limitations of time and space.

Moreover, this layer offers cloud client customization for different end-users keep their individual interfaces, and the interfaces can be changed flexibly. To facilitate the three main roles of end-users, this layer provides three types of portals for service providers, platform operators, and service consumers.

4. SUMMARY

As a new promising research area, Cloud Manufacturing is facing great challenges. Design issues of Cloud Manufacturing platform play a significant role since it occupies an indispensable intermediate position between service providers and requesters. This paper presents a design of Cloud Manufacturing platform architecture and discusses the key technologies in each layer. This architecture includes resource perception layer, virtual resource layer, middleware layer, application supporting layer, and user interface layer. The design can support comprehensive connection and perception of hard-resource and soft-resource, and the registered resources in clouds are described with semantics to support knowledge-based match between supply and demand. In addition, the networked resources can be virtualized into logic ones for flexible composition and decomposition according to needs, as well as published as standard services for effective cooperation across different enterprises over heterogeneous environments. Moreover, it can provide on-demand collaborative services to establish customized networked systems according to consumer's requirements supporting whole life circle manufacturing applications by sharing virtualized manufacturing resources via networks in clouds. Therefore, the design can provide a solution to give comprehensive support to achieve the goal of Cloud Manufacturing.

Future work is to establish a Cloud Manufacturing application example for large-scale and complex product such as aircraft to evaluate the architecture.

ACKNOWLEDGMENTS

The research is supported by the NSFC (National Science Foundation of China) Projects (No. 61103096) in China, the National High-Tech Research and Development Plan of China under Grant No. 2011AA040501, and the Fundamental Research Funds for the Central Universities in China.

REFERENCES

Zhan H. F., Lee W. B., Cheung C. F., Kwok S. K., and. Gu X. J., 2003. A web-based collaborative product design platform for dipersed network manufacturing, *Jounal of Materaials Processing Technology*, 138, 600–604.

Flammia G., 2001. Application service providers: challenges and opportunities, *IEEE Intelligent Systems and Their Applications*, 16(1), 22–23.

Fan Y., Zhao D., Zhang L., Huang S., and Liu B., 2004. Manufacturing grid: needs, concept, and architecture. *Lecture Notes in Computer Science*, 3032, 653-656.

Sun H., Yu T., Liu L., and He Y., 2008. Service-oriented manufacturing grid system, *Computer Integrated Manufacturing Systems*, 14(1), 56–63.

Gomes C. F., Yasin M. M., and Lisboa J. V., 2004. A literature review of manufacturing performance measures and measurement in an organizational context: a

framework and direction for future research, *Journal of Manufacturing Technology Management*, 15(6), 511–530.
Armbrust M., Fox A., Griffith R., Joseph A. D., Katz R. H., and etc., 2009. Above the clouds: A Berbeley view of Cloud computing, *Technical report UCB/EECS-2009-28, Electrical Engineering and Computer Sciences*, University of California at Berkeley, Berkeley, USA.
Lei, R., Lin Z., Fei T., Xiaolong, Z., Yongliang, L., and Yabin, Z., 2012. A methodology toward virtualization-based high performance simulation platform supporting multidisciplinary design of complex products. *Enterprise Information Systems*, 6(3), 267-290.
Wolf W., 2009. Cyber physical systems, *Computer*, 42(3), 88–89.
Acuna C. and Marcos E., 2006. Modeling semantic web services: A case study, *Proceedings of the 6th International Conference on Web Engineering (ICWE)*, ACM Press, , pp. 32–39.
Benioff M.R. and Lazowska E.D., 2005. Computational Science: Ensuring America's Competitiveness, President's Information Technology Advisory Committee (PITAC).
Zhang L., etc. Cloud Manufacturing: a new manufacturing paradigm. *Enterprise Information System*(accepted). 2012.
Foster I., Zhao Y., Raicu I., and Lu S., 2008. Cloud Computing and Grid Computing 360-degree compared, in *Grid Computing Environments Workshop*, pp. 1–10.
Mladen A. V., 2008. Cloud Computing – Issues, Research and Implementations, *Journal of Computing and Information Technology*, 16(4), 235–246.
Buyya, R., Yeo C.S., Venugopal S., Broberg J., and Brandic I., 2009. Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. *Future Generation Computer Systems*, 25 (6), 599-616.
Martin D., Burstein M., Mcdermott D., and Mcilraith S., 2007. Bringing semantics to web services with owl-s, *World Wide Web*, Springer-Verlag.
Jacob R., Girouard A., Hirshfield L., and etc., 2008. Reality-based interaction: a framework for post-WIMP interfaces, *Proceedings ACM 26th SIGCHI conference on human factors in computing systems*, pp. 201–210.

AUTHORS BIOGRAPHY

Lei Ren, Ph.D. Dr. Lei Ren received Ph.D. degree in 2009 at the Institute of Software, Chinese Academy of Sciences, China. From 2009 to 2010 he worked at the Engineering Research Center of Complex Product Advanced Manufacturing System， Ministry of Education of China. He is currently a researcher at the School of Automation Science and Electrical Engineering, BeiHang University. He is also a senior researcher at the Engineering Research Center of Complex Product Advanced Manufacturing System， Ministry of Education of China now. He is a member of SCS and SISO. His research interests include high performance simulation platform, integrated manufacturing systems, Cloud Simulation, Cloud Manufacturing and Cloud Computing.