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A Cloud-Based Collaborative Manufacturing Resource Sharing Services

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Abstract: The spring up of cloud computing gives product manufacturing a new solution and chance to realize resource sharing and cooperative work between enterprises for global manufacturing. A collaborative manufacturing resource sharing platform is built based on cloud services, which implements to effectively describe information, resources and knowledge during manufacturing process by abundant semantics. The cloud services are the combination of cloud computing and ontology technique. Cloud computing utilizes virtualization technology to encapsulate collaborative manufacturing resources as services to shield the distribution of collaborative manufacturing. The cloud service integration model is built based on ontology technique. The cloud service integration model implements the uniform representation of heterogeneous information and helps to shield the heterogeneity of manufacturing resources systematically. Finally, a case study of the whole design of a decelerator is presented to validate the feasibility and effectiveness of the approach.

Key words: Collaborative manufacturing, resource sharing, cloud services, cloud computing, ontology technique

INTRODUCTION

Globalization is changing the ways of competition between manufacturing enterprises. If the manufacturing enterprises want to survive, they must do well in the market competition; they must make better use of their resources; they must improve their technologies and finally they must recruit capable people and unite them as one. All these requirements pose increasing need on how to organize all these people, so that they can study together, fulfill their diverse individual tasks and at the same time achieve the same goal. Therefore, it is urgent to find a new institutional management model that can evolve a company from a closed form management to an open one, which will enable the company to meet fast-changing market demand by better cooperation between company employees. We believe only such kind of manufacturing companies can maintain a reasonable level of competitiveness to survive (Xu, 2009). Collaborative Manufacturing (CM) is the inevitable trend of the enterprise development under the network economy. The goal of CM is to improve the innovative capability of product lifecycle and to realize the lower cost and higher efficiency of product designing and manufacturing process. Since, collaborative manufacturing resources are distributed, morphology diversity and autonomy. There exist some questions like resource uniform description; rapid and accurate acquisition needed resource and network security. Due to the above questions, the promotion and development of CM is restricted.

In recent years, cloud computing is becoming more and more popular as an enterprise computing model, which can provide various services according to the needs of users (Jiang *et al*., 2011). The term ‘cloud’ in cloud computing means a ‘remote datacenter’. Cloud computing has a two-part definition. The first is access, via the Internet using a Web browser, to computing resources that are administered remotely and are dynamically allocated and deallocated according to the needs of the users. The second is paying for the actual use of the computing resources (Yuan *et al*., 2010). Cloud computing is an integrated supporting environment both for the sharing and integration of resources in enterprises. It utilizes virtualization technologies to encapsulate collaborative manufacturing resources as services to shield the distributed and heterogeneous nature of collaborative manufacturing systematically. In short, the

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manufacturing enterprises and individuals enabled by the more efficient cooperative capability of enterprise cloud computing systems could obtain diverse manufacture services from the internet and intranet more conveniently.

Cloud computing brings new ways of Web services for Web users and enterprises. The benefits of cloud computing include: 1) Security, it provides the most reliable, most secure data storage center. Users no longer need to worry about data loss, viruses and other problems, 2) Convenience, it posts lower equipment requests and is convenient to use, 3) Data sharing, it can easily share data between different devices and applications and 4) Infinite possibilities, its use of the network provides a virtually unlimited range of possibilities. (Janssen and Joha, 2010). Currently, cloud computing has been applied to data queries, information sharing, resource integration, data security and other fields. A method of managing security of virtual machine images in a cloud environment is proposed by Wei *et al.* (2009a). In this study, an image management system is implanted, which controls access to images, tracks the provenance of images and provides users and administrators with efficient image filters and scanners that detect and repair security violations. A multi-dimensional index method for cloud data management is proposed by Zhang *et al.* (2009), which improves query efficiency by an order of magnitude compared with alternative approaches and scales well with the size of the data. Csorba *et al.* (2010) proposes an ant system for service deployment in private and public clouds. This system decomposes the problem of deploying into a mapping problem and paves the way for a deployment logic that is capable of finding near optimal mappings in a cloud computing environment. Wu and Yang (2010) proposed a concept of cloud manufacturing. Cloud manufacturing is the combination of cloud computing and Service-Oriented Architecture (SOA). The resource sharing is implemented in cloud manufacturing environment. The combination of cloud computing and collaborative manufacturing environment provides new ideas and opportunities to address current problems faced by modern manufacturing enterprises. It can be viewed as an extension to the virtualization and collaborative manufacturing systems and it essentially brings a transformation of production model and belongs to a new service-oriented computing model.

This study has proposed a collaborative manufacturing resource sharing method based on cloud services. The cloud services are the combination of cloud computing and ontology technique. Cloud computing utilizes virtualization technology to encapsulate collaborative manufacturing resources as services to shield the distribution of collaborative manufacturing resources. The cloud service integration model is built based on ontology technique. It effectively manages heterogeneous information and presents the exchange of semantics of product data among manufacturing resources. The cloud service integration model uses Web Ontology Language (OWL) (Wei *et al.*, 2009b) as a content language, which facilitates information sharing and retrieval. In short, the collaborative manufacturing resource sharing platform is implemented based on cloud services, which provides convenience for user to transparently use various manufacturing resources.

A LAYERED FRAMEWORK OF COLLABORATIVE MANUFACTURING RESOURCE SHARING BASED ON CLOUD SERVICES

This study proposed a collaborative manufacturing resource sharing platform based on cloud services, which is a service-oriented, knowledge-based network platform. Based on traditional cloud computing architecture, this platform is mainly decomposed into three layers: Cloud service provider layer, cloud service demand layer and cloud service center. And each layer is further subdivided into more detailed sub-layers. Figure 1 shows the proposed architecture.

The cloud service provider layer is further divided into manufacturing resource layer, virtual interface and virtual resource layer. The manufacturing resource layer has a collection of various physical elements used in a full product lifecycle. It has two types of resources: the hardware resources and the software resources. The hardware resources include manufacturing equipments, testing equipments and computing equipments and so on. The software resources include manufacturing process models, application software and data and so on. Manufacturing resources have many physical features, such as the morphological heterogeneity, geographical distribution and autonomy. To ensure that these distributed resources to remain independent autonomy and to support collaborative sharing of dynamic integrated manufacturing, we use virtualization technologies to transform physical manufacturing resources into virtual resources. Virtual resources provide a variety of services for the collaborative manufacturing resource sharing platform.

Cloud service center which provides a variety of core services and functions, manages cloud services and integrates diverse cloud services under the same platform. The cloud service management implements the publication, aggregation, retrieval and scheduling of cloud services. The product manufacturing process needs

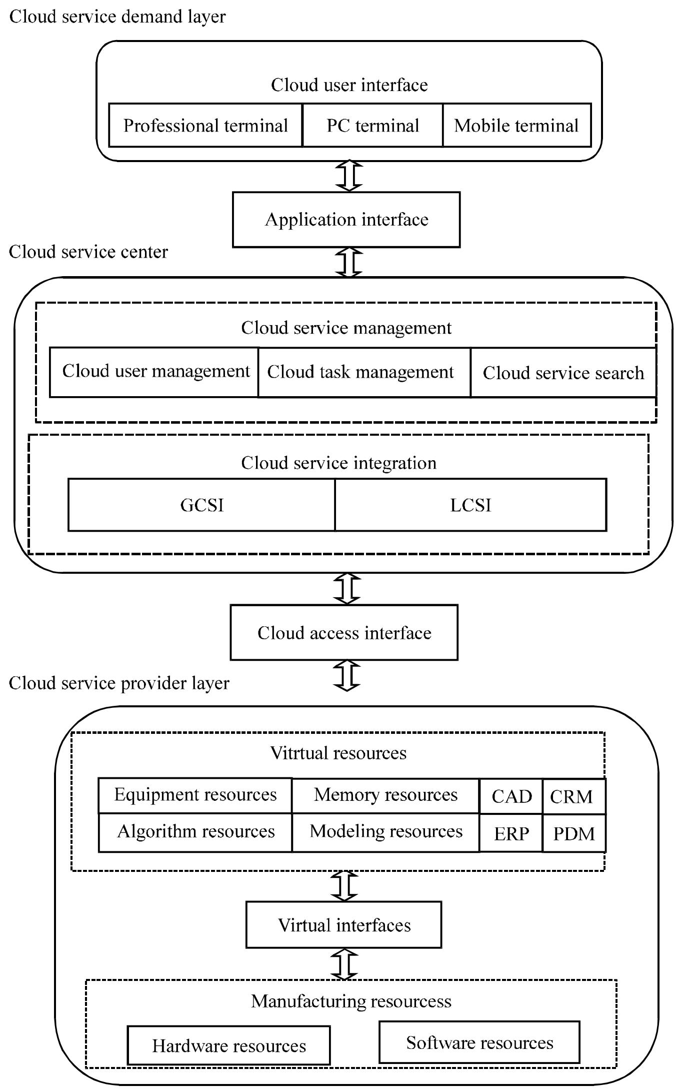

Fig. 1: A collaborative manufacturing resource sharing platform based on cloud services

all kinds of manufacturing resources, for example Computer Aided Design (CAD), Product Data Management (PDM), Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) and so on. According to the different product design requirements, cloud service management is able to rapidly build a virtual production unit and formulate the personalized service flow. The manufacturing resources can be quickly and accurately selected according to service flow. Because of the manufacturing resources are uniformly encapsulated as cloud services, cloud service management actually operates cloud services. The cloud service integration could integrate various manufacturing resources and realize semantic interoperability between different manufacturing resources. Cloud service integration model is divided into global cloud service integration model (GCSI) and Local Cloud Service Integration model (LCSI). The design of GCSI and LCSI will be described in detail in the following sections. It is the key to implementing cloud service integration.

The cloud service demand layer provides the gateway support for high performance cloud services. Different users may use a series of manufacturing resources through the cloud service gateway website and all kinds of user interfaces.

CLOUD SERVICE INTEGRATION MODEL

Seamless integration of various manufacturing resources is impeded by semantic heterogeneity. In this study, the semantic interoperability of product lifecycle is implemented base on cloud service integration model. Cloud service integration model is divided into global cloud service integration model (GCSI) and local cloud service integration model (LCSI). Product manufacturing is a complex process, in which diverse activities are required to co-operate with each other. Such activities include research, product design, manufacturing and quality control. In different manufacturing stages, based on the different need, different manufacturing resources are used. In this study, manufacturing resources are divided into Generic Manufacturing Resources (GMR) and Specific Manufacturing Resources (SMR). For example, CAD tools are used in the product design stage. It include Pro/E, UG and CATIA and so on. Pro/E, UG and CATIA are called as specific manufacturing resources. The semantic interoperability between specific manufacturing resources is implemented by LCSI. At the same time, PDM, ERP and CRM also are used in product manufacturing process. CAD, PDM, ERP and CRM are called as generic manufacturing resources. The resource integration and sharing between generic manufacturing resources is implemented by GCSI. Fig. 2 shows overview of integration and sharing of manufacturing resources.

This study has adapted ontology technique to shield the heterogeneity of manufacturing resources. The benefits of ontology representation lie in its capabilities in explicitly defining concepts, attributes and relationships. The explicit concepts and structure can contribute to machine-readable and human-perceived meaning of semantic information to distributed, synchronous software sources. It encapsulate the SMR based on ontology technique, which may be defined as a simplified 6-tuple:

$$S^F_E \equiv \{C^F_E, A^F_E, P^F_E, SubC^F_E, LinkA^F_E, LinkP^F_E\}$$

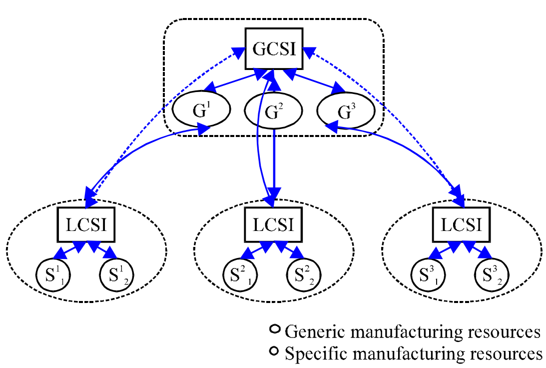

Fig. 2: Overview of integration and sharing of manufacturing resources

where, S^F_E is a set of concept defined in SMR. S^F_E defines all the concepts required, which describe an specific manufacturing resource. Concepts play an important organizational role in a taxonomy (subsumption hierarchy). The each concept has a distinct set of global ID, a taxonomy of them is always a tree. When a concept specializes another concept, it adds further global ID to those inherited from the subsuming concept. The concept can shield the semantic heterogeneity in highest abstract level.

A^F_E is a set of attribute defined in SMR. The attribute defines the basic property information of a concept contained. They represent roles that are constrained to concept. The attribute can be used as the basis of the identifying concepts.

P^F_E is a set of parameter defined in SMR. The parameter provides all parameters of the concept. Parametric feature modeling is one of the most advanced ways for product manufacturing, so we encapsulate the specific manufacturing resources following the parametric principles.

$SubC^F_E = C^F_E \rightarrow 2^{CF}_E$ is the subsumption function, which associates each concept with directly subsumed concepts defined in SMR. 2^{CF}_E denotes the power set of C^F_E.

$LinkA^F_E = C^F_E \rightarrow 2^{AF}_E$ is the function that associates each concept with its attribute information.

$LinkP^F_E = C^F_E \rightarrow 2^{PF}_E$ is the function that associates each concept with its parameters list.

We encapsulate the GMR based on ontology technique, which may be defined as a simplified 9-tuple:

$$S^G = \{C^G, A^G, P^G, M^G, SubC^G, SubM^G, LinkA^G, LinkP^G, LinkM^G\}$$

where,

C^G : Is a set of concept defined in GMR
A^G : Is a set of attribute defined in GMR
P^G : Is a set of parameter defined in GMR
M^G : Is a set of add-attribute defined in GMR

The add-attribute provides additional properties to distinguish concepts. In GMR, the data are stored by different storage methods and defined based on different concepts, attributes and relations. There are essential differences between GMR. The attribute can not accurately distinguish concepts, so we need the add-attribute:

$SubC^G = C^G \rightarrow 2^{C^G}$ is the subsumption function, which associates each concept with directly subsumed concepts defined in GMR.

$SubM^G = C^G \rightarrow 2^{M^G}$ is the subsumption function that associates each concept of the GMR with directly subsumed add-attribute of the GMR.

$LinkA^G = C^G \rightarrow 2^{A^G}$ is the function that associates each concept with its attribute.

$LinkP^G = C^G \rightarrow 2^{P^G}$ is the function that associates each concept with its parameters list.

$LinkM^G = M^G \rightarrow 2^{A^G}$ is the function that associates each add-attribute of the GMR with its attribute.

We have developed a cloud service integration model that automatically merges the manufacturing resources. Cloud service integration model is divided into GCSI and LCSI. In the following subsections, we discuss the manufacturing resource merging algorithm based on GCSI and LCSI. LCSI and GCSI use meta-concepts which have explicit ontological semantics. The semantic heterogeneity emerges only among the concepts in the SMR and GMR that belongs to the same meta-concept and have the same parent concepts. LCSI could implement semantic interoperability between specific manufacturing resources, it may be defined as a simplified 7-tuple:

$$S^L \equiv \{C^L, A^L, P^L, SubC^L, Sub\_C^L, LinkA^L, LinkP^L\}$$

where, $C^L = \bigcap_{(i|1 \le i \le n)} C^F_{E_i}$, C^L is a set of meta-concept defined in LCSI. We observe that the essential concepts and attributes defined in SMR are similar though their parameters of the corresponding concepts may be different. So, C^L is intersection set of C^F_E. It is minimum and unique meta-concept set. The other concepts in SMR can be transformed into concepts in LCSI:

- $C^L = \bigcap_{(i|1 \le i \le n)} C^F_{E_i}$, A^L is a set of attribute defined in LCSI
- $A^L = \bigcap_{(i|1 \le i \le n)} A^F_{E_i}$, P^L is a set of parameter defined in LCSI

$SubC^L = C^L \rightarrow 2^{C^F_{E_i}}$ is the subsumption function, which associates each concept with directly subsumed concepts defined in LCSI.

$Sub\_C^L = C^L \rightarrow 2^{C^L}$ is the subsumption function, which associates each concept of the LCSI with directly subsumed concepts of the SMR.

$LinkA^L = C^L \rightarrow 2^{A^L}$ is the function that associates each concept with its attribute.

$LinkP^L = C^L \rightarrow 2^{P^L}$ is the function that associates each concept with its parameters list.

The GCSI has explicit ontological semantics and helps to shield the heterogeneity of generic manufacturing resources systematically. The GCSI may be defined as a simplified 11-tuple:

$$S^{PI} \equiv \begin{Bmatrix} C^{PI}, A^{PI}, P^{PI}, M^{PI}, SubC^{PI}, Sub\_C^{PI}, SubM^{PI}, \\ Sub\_M^{PI}, LinkA^{PI}, LinkP^{PI}, LinkM^{PI} \end{Bmatrix}$$

Where:

$$C^{PI} = \bigcup_{(i|1 \le i \le n)} C^{G_i}$$

$$A^{PI} = \bigcup_{(i|1 \le i \le n)} A^{G_i}$$

$$P^L = \bigcup_{(i|1 \le i \le n)} P^{G_i}$$

$$M^{PI} = \bigcup_{(i|1 \le i \le n)} M^{G_i}$$

$$SubC^{PI} = C^{PI} \rightarrow 2^{C^{PI}}$$

$$Sub\_C^{PI} = C^{PI} \rightarrow 2^{C^{PI}}$$

$$SubM^{PI} = C^{PI} \rightarrow 2^{M^{PI}}$$

$$Sub\_M^{PI} = C^{PI} \rightarrow 2^{M^{PI}}$$

$$LinkA^{PI} = C^{PI} \rightarrow 2^{A^{PI}}$$

$$LinkP^{PI} = C^{PI} \rightarrow 2^{P^{PI}}$$

$$LinkM^{PI} = M^{PI} \rightarrow 2^{A^{PI}}$$

The goal of cloud service integration model is to provide meta-concepts can consistently distinguish domain concepts of SMR and GMR and systematically structure them. Those high-level meta-concepts guide the SMR and GMR to have similar aggregation and granularity. The manufacturing resource merging process with the SMR is individually connected to the LCSI. The connections are made through a subsumption relation, Sub_C^L. The manufacturing resource merging process with the GMR is individually connected to the GCSI. The connections are made through two subsumption relations, Sub_C^{PI} and Sub_M^{PI}. Sub_M^{PI} associates each concept of the GCSI with directly subsumed add-attribute of the GMR. The LCSI and GCSI use OWL as a content language, which facilitates information sharing and retrieval.

EXPERIMENTAL CASE

In this section, a case study of a decelerator is presented to validate the feasibility and effectiveness of the collaborative manufacturing resource sharing method based on cloud services. For example, a user on the cloud service demand layer may want to construct a decelerator. Cloud service center gets this request. Cloud service center includes cloud service management and cloud service integration. The cloud service management rapidly

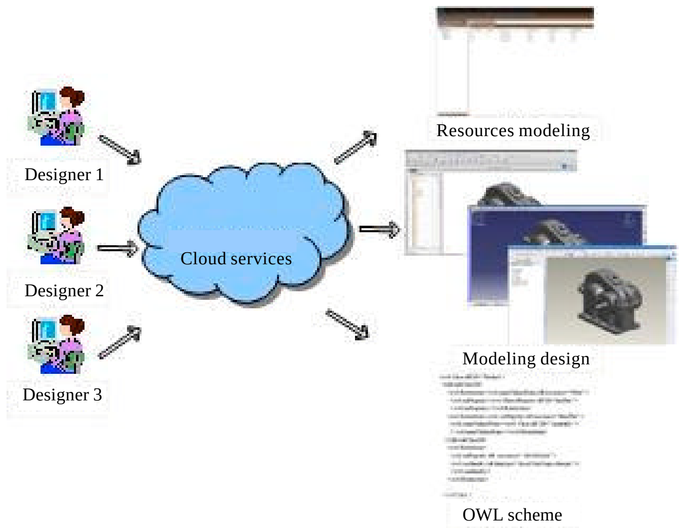

Fig. 3: Decelerator design in cloud service environment

builds a virtual decelerator construction unit and formulates the personalized cloud service flow. The cloud service flow is split into simpler sub-services by Activity Logic Graphics (ALG). Three designers using PCs provide sub-services. The twelve CPU cores in three computer nodes are virtualized, which are encapsulated into a resource pool. The six virtual machines are built in the resource pool, which can be installed on a variety of application software. Each virtual machine can dynamically assign resources in resources pool and complete a certain sub-services. The cloud service integration shields the heterogeneity of manufacturing resources and realizes semantic interoperability between different manufacturing resources. The three designers using different CAD tools design collaboratively the decelerator in cloud service environment as shown in Fig. 3.

CONCLUSION

In this study, we build a collaborative manufacturing resource sharing platform based on cloud services. The framework of the platform uses the three-layer based on traditional cloud computing architecture. And each layer is further subdivided into more detailed sub-layers. In which, the cloud service integration model is described in detail in cloud service center layer. Based on the cloud service integration model, the semantic interoperability is facilitated among different manufacturing resources and the ubiquitous service-oriented applications are supported. In short, the collaborative manufacturing resource sharing platform encapsulates collaborative manufacturing resources as services to shield the distribution and heterogeneity of collaborative manufacturing systematically. It provides an integrated supporting environment both for the sharing and integration of resources in enterprises.

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