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Multi-granularity resource virtualization and sharing strategies in cloud manufacturing

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ABSTRACT

Cloud Manufacturing is a new and promising manufacturing paradigm. Resource virtualization is critical for Cloud Manufacturing. It encapsulates physical resources into cloud services and determines the robustness of the cloud platform. This paper proposes novel multi-granularity resource virtualization and sharing strategies for bridging the gap between complex manufacturing tasks and underlying resources. The proposed approach considers three factors, including workflow, activity, and resource that significantly influence stepwise decompositions of a complex manufacturing task. Resource aggregation functions are constructed to classify resources over different granularities. Resource clustering algorithms are presented for mapping physical resources to virtualized resources. Cloud service specifications are designed to describe virtualized resources and are implemented through a prototype. A case study is illustrated to validate the proposed approach.

1. Introduction

Cloud Manufacturing, proposed by B. Li et al. (2010, 2011), is a new and promising manufacturing paradigm, one to which researchers and industries worldwide (Xu, 2012; Vincent Wang and Xu, 2013; Wu et al., 2013; Wang, 2013) are paying close attention. Cloud Manufacturing is effective because it promotes enterprise competence, enhances product innovation, and improves resource utilization. Resource virtualization is a core idea of Cloud Manufacturing that contains manufacturing resource virtualization and manufacturing capability servitization (Ren et al., 2011; Zhang et al., 2012; Tao et al., 2011b). Distributed manufacturing resources (e.g., manufacturing equipment, materials, software, knowledge, and skills) and manufacturing capabilities (e.g., design capability, production capability, experimentation capability, management capability, and communication capability) are utilized as a logical resource pool and assigned to users on demand. Therefore, two characteristics of Cloud Manufacturing are integration of distributed resources and distribution of integrated resources. The architecture of Cloud Manufacturing, illustrated in Fig. 1 consists of four layers (Resource Layer, Virtual Layer, Global Service Layer, and Application Layer).

The Resource Layer includes physical resources, which take two forms – manufacturing resources and manufacturing capabilities. Physical resources can be identified and accessed to Cloud Manufacturing systems by RFID (radio frequency identification), WSN (wireless sensor networks), CPS (cyber physical system), or GPS (Global positioning system). The Virtual Layer is responsible for transforming heterogeneous physical resources to isomorphic logical ones (i.e. cloud services), that sequentially performs three operations: (i) modeling for cloud manufacturing resource information; (ii) clustering physical resources to virtualized ones; and (iii) describing virtualized resources as cloud services. A cloud service is an encapsulation of one or more physical resources and can be shared by all users in the cloud platform. The Global Service Layer provides various operational activities for managing cloud services (Zhang et al., 2010; Yin et al., 2011; Zhan et al., 2011; Huang et al., 2013). Cloud services can be dynamically located, monitored, allocated, and reconfigured to satisfy a user's requests. The Application Layer orients to all areas and industries in a manufacturing domain. Users (equipment manufacturers, group users, individuals) share cloud services through interfaces, such as portals, personal computer terminals, and mobile devices. Providing diversified manufacturing services according to user requirements, still pose many problems yet to be solved in Cloud Manufacturing:

- Resource virtualization in Cloud Manufacturing is difficult. Cloud manufacturing resources are generally provided by distributed enterprises. They are heterogeneous in storage format, description method, and management strategies. Invocation of cloud manufacturing resources is greatly affected by

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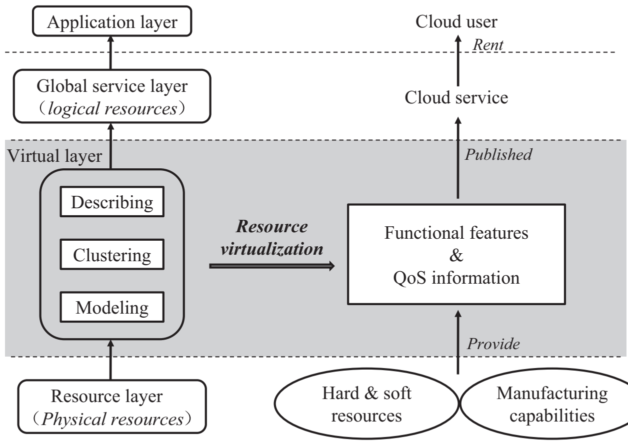

Fig. 1. The architecture of Cloud Manufacturing.

physical distance and geographical constraints. Furthermore, cloud manufacturing operational activities are concerned with the functional features provided by cloud manufacturing resources and a variety of required quality of service (QoS) information, rather than the resources themselves.

- Multi-granularity virtualized resources for different purposes. Granularity refers to the average measurement of particle size, which is used in many areas of computer science, such as software engineering (Batory and O'malley, 1992), information retrieval (Yan et al., 2011), and parallel computing (Gerasoulis and Yang, 1993). Cloud Manufacturing is a multi-granularity system, in which granularity implies any number of functional features provided by a physical resource. For example, some resource providers describe functional features with fine granularity (such as kinematic trajectory, rotation, and angle) while others describe functional features with coarse granularity, such as drilling, milling, and grinding. However, no one knows the specific requirements of users in advance, which could result in gaps between resource providers and users. Hence, multi-granularity virtualized resources should be provided for the cloud platform to bridge such granularity gaps.

This paper proposes to address the problems of multi-granularity resource virtualization and sharing strategies. By analyzing the features of resources and tasks, the multi-granularity resource aggregation functions are constructed to estimate the correlation between resources. Resource clustering algorithms are presented to integrate the physical resources into virtualized resources which provide a solid foundation for resource discovery and selection.

The remainder of the paper is organized as follows. Section 2 reviews the literature relating to resource virtualization. In Section 3, related concepts are defined and a multi-granularity resource virtualization model is introduced. Resource clustering methods are proposed for multi-granularity resource virtualization and sharing in Section 4. The proposed methods are validated through a case study in Section 5, followed by conclusions in Section 6.

2. Literature review

Networked manufacturing (e.g., agile manufacturing, grid manufacturing, agent-based manufacturing, and holonic manufacturing) appeared in the 1990s, the primary goal of which was to improve the competence of enterprises and alleviate the limitations of geographical locations (Fan et al., 2005). Different from existing networked manufacturing paradigms, Cloud Manufacturing provides a seamless, stable and high quality transaction of cloud services (Tao et al., 2011a; Zhang et al., 2011). Therefore, syntactic integration and semantic interoperability are two critical issues to be addressed for resource virtualization.

2.1. Syntactic integration

Most existing resource virtualization techniques for networked manufacturing are mainly concerned with syntactic integration. Syntactic integration depends on effective resource modeling techniques and current web service standards. Steele et al. (2001) integrated engineering functions with an object-oriented resource model that linked information from different knowledge domains. Vichare et al. (2009) proposed a unified manufacturing resource model which represents various resource elements for CNC machining systems. Li et al. (2006) proposed several key techniques for sustaining a web-based part library system, such as the data dictionary, feature-based neutral representation, and a hoops-based visualization method. Shi et al. (2007) employed XML schema to encapsulate manufacturing resource information and adopted WSDL to model the accessing operations to manufacturing resources. Rodriguez et al. (2010) presented a novel classification method for eight web service discoverability anti-patterns, which is good for ranking more relevant services. Tao et al. (2013) investigated the formulation of service composition optimal-selection in Cloud Manufacturing with multiple objectives and constraints. A parallel intelligent algorithm was developed. Kong et al. (2011) modeled the uncertain workload and the vague availability of virtualized server nodes with a fuzzy prediction method. Shi et al. (2011) proposed a solution for enabling scalable support of realtime 3D virtual appliances in a cloud computing environment. Lombardi and Di Pietro (2011) proposed an architecture called the Advanced Cloud Protection System (ACPS) to guarantee increased security of cloud resources.

Although the methods mentioned above provide effective virtualization mechanisms to shield the heterogeneity of distributed resources, they only focus on resource sharing at the syntactic level. Unfortunately, cloud manufacturing resources are complex, diverse, and context-dependent. Existing web service standards cannot provide the effective means to explicitly represent these characteristics and interpret the resource semantics. Thus, required resources cannot be found and located automatically by existing semantic matchmaking algorithms. To automatically use such resources, these techniques would require a lot of cost and time.

2.2. Semantic interoperability

Semantic web techniques provide semantic interoperability for networked manufacturing. Ontologies (Uschold and Gruninger, 1996), as one of the important supporting technologies for the semantic web, model cloud services by means of accurate conceptualization, shared understanding and logical reasoning. Therefore, many researchers use ontology to provide open semantics for the accumulated domain knowledge in resource virtualization. Sun et al. (2012) presented a heavy-weight ontology-based construction method for interoperation models to support the reuse of subsystems in various collaborative contexts. Patil et al. (2005) proposed an ontology-based framework to enable semantic interoperability across different application domains. Li et al. (2013) investigated the resource virtualization and service encapsulation of a logistics center. A logistics resource expression model is designed with three levels: service encapsulation focuses on location; service function; and, service status information. Lin and Harding (2007) discussed ontology-based approaches for representing information semantics and developed a general manufacturing system engineering ontology model. Cai et al. (2011)