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Development of a Hybrid Manufacturing Cloud

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ABSTRACT

Cloud manufacturing is emerging as a novel business paradigm for the manufacturing industry, in which dynamically scalable and virtualised resources are provided as consumable services over the Internet. A handful of cloud manufacturing systems are proposed for different business scenarios, most of which fall into one of three deployment modes, i.e. private cloud, community cloud, and public cloud. One of the challenges in the existing solutions is that few of them are capable of adapting to changes in the business environment. In fact, different companies may have different cloud requirements in different business situations; even a company at different business stages may need different cloud modes. Nevertheless, there is limited support on migrating to different cloud modes in existing solutions. This paper proposes a Hybrid Manufacturing Cloud that allows companies to deploy different cloud modes for their periodic business goals. Three typical cloud modes, i.e. private cloud, community cloud and public cloud are supported in the system. Furthermore, it enables companies to set self-defined access rules for each resource so that unauthorised companies will not have access to the resource. This self-managed mechanism gives companies full control of their businesses and boosts their trust with enhanced privacy protection. A unified ontology is developed to enhance semantic interoperability throughout the whole process of service provision in the clouds. A Cloud Management Engine is developed to manage all the user-defined clouds, in which Semantic Web technologies are used as the main toolkit. The feasibility of this approach is verified through a group of companies, each of which has complex access requirements for their resources. In addition, a use case is carried out between customers and service providers. This way, optimal service is delivered through the proposed system.

1. Introduction

Today's manufacturing systems are required to have a number of unique features, including, to name a few, high intelligence for autonomy, adaptability for dynamically changing environments, re-configurability for agile collaboration, and sustainability for environmental benefit [1]. In response to these requirements, a number of manufacturing paradigms have been proposed, such as flexible manufacturing [2], lean manufacturing [3], and sustainable manufacturing [4]. Looking back at the revolution of manufacturing paradigms, the focus of manufacturing systems has shifted from production maximisation to cost reduction, from production process standardisation to mass customisation, and from production-centric to service-orientated. In particular, advanced IT technologies have accelerated industry automation and intelligence. Looking into the future, the manufacturing industry will keep chasing for a high level of intelligence, adaptability and sustainability.

Recently, cloud computing emerged as one of the major enablers for the manufacturing industry; it can transform the traditional manufacturing business model, help it align product innovation with business strategy, and create intelligent factory networks that encourage effective collaboration. Realising the potential benefits that cloud brings, the concept of cloud manufacturing has been introduced [5–7]. Cloud manufacturing is an emerging service-oriented manufacturing paradigm that provides organisations with the ability to visualise their resources and offer them as consumable services over the Internet. In cloud manufacturing, distributed resources are encapsulated into cloud services and managed in a federated way. Clients use cloud services according to their requirements. The services a client may request include product design, manufacturing, testing, management, and possibly all other stages of a product life cycle.

Although cloud manufacturing is a nascent manufacturing paradigm, it has attracted a surge of research interest from academia and industry, bringing about a number of novel business models and academic publications. Most of the practices either

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(1) analyse the future picture of manufacturing industry in cloud environment or (2) propose a prototype system for a particular business situation. Despite all the hype surrounding cloud manufacturing, the reality is that it is not a simple task to adapt the cloud approach to a traditional manufacturing business paradigm. Companies are facing a number of obstacles in adopting a cloud approach, i.e., differing stages of maturity within the cloud adoption continuum and the need to avoid compromising the cloud's benefits with uncoordinated adoption. More specifically, different companies have different business conditions and thus require different cloud solutions. However, there is no feasible mechanism to enable an agile switch between different cloud modes, i.e. private cloud, community cloud and public cloud. Many cloud systems are proprietary as they are built on specific tools and description frameworks developed by a particular vendor for its particular cloud offering. This makes it prohibitively complicated and expensive to adapt a proprietary cloud solution to a new business environment.

This paper proposes a Hybrid Manufacturing Cloud (HMC) that enables companies to create different cloud modes for their periodic business goals. Three typical cloud modes, i.e. private cloud, community cloud and public cloud are supported in the system. More importantly, it enables companies to define their own resource-sharing rules for each resource so that unauthorised companies have no access to the resource. This self-managed mechanism gives companies full control of their businesses and boosts their trust with enhanced privacy protection. The rest of the paper is organised as follows. Section 2 provides a brief overview of the cloud manufacturing research and discusses business practices in different deployment modes. Section 3 discusses the research challenges in developing a hybrid cloud manufacturing system. A Hybrid Manufacturing Cloud is then proposed in Section 4 accompanied by the system architecture. Section 5 discusses the main business processes in HMC, including a guide on how to migrate to the cloud for different business conditions and business interaction workflows in the system. The implementation of the proposed system is introduced in Section 6. System infrastructure, unified ontology and resource-sharing control are presented with an integrated case study. To demonstrate the feasibility of the proposed system, one use case is presented in Section 7. This use case verifies the process of purchasing manufacturing services, retrieving authorised resources and delivering optimal services. Section 8 gives the final words and highlights future work.

2. Cloud manufacturing

Cloud technology has been adopted in some key areas of manufacturing such as IT, pay-as-you-go business models, and production scaling-up and down per demand. Cloud manufacturing represents a more entrenched way of implementing cloud concepts in manufacturing businesses. It can transform the traditional production-oriented business model into a service-oriented business model, enhance business management efficiency, and create intelligent factory networks that encourage effective collaborations. This section provides a summary on cloud manufacturing research by discussing key benefits for manufacturing business, existing system architecture, key functionalities, adoption models and deployment modes.

2.1. Business benefits

Cloud manufacturing provides a unique solution that can easily accommodate businesses of all sizes. A cloud manufacturing system is expected to provide functionalities to two key stakeholders: the vendors that provide their resources and services for consumption; and the customers that consume the available services for their own requirement. These services can range from the conception of a product all the way up to its disposal. In other words, cloud manufacturing allows complete Product Lifecycle Management (PLM) processes to be provided as consumable cloud-based services.

This business model enables service-oriented manufacturing, mass customisation, and large-scale collaboration via rapidly scalable and deployable manufacturing resources over the network. The main characteristics of the proposed model include on-demand self-service, ubiquitous network access, rapid scalability, resource pooling, and virtualisation [8].

These characteristics offer enterprises flexibility to manage their businesses. With the cloud approach, there is no need for enterprises to make costly capital investments in purchasing manufacturing equipment, maintaining their shop floor, and even recruiting specialised engineers. Instead, they could have instant access to the most efficient, innovative business technology solutions on a pay-as-you-go basis. Derived from the above characteristics, a number of significant and long-lasting business benefits can be attained, including:

- *Financial flexibility*: Cloud manufacturing enables the shift from capital expenses to operating expenses. The transformation to metered rather than upfront costs offers increased budget flexibility through management of more variable costs, and a much clearer mechanism for cost-allocations across the business.
- *Business agility*: Heavy capital investment in manufacturing industry provides little business agility, which has a major impact on the profitability of an enterprise. With cloud adoption, this risk can be significantly reduced as the cloud offers the flexibility of terminating service provision based on feedback from the dynamic market and changing business goals with ease.
- *Instant access to innovation*: Technology innovation and business go hand in hand, which has created unprecedented growth across all industries. Although leading edge technologies are critical to business growth and competitiveness improvement, most small and medium enterprises (SMEs) cannot benefit from IT (Information Technology) advancements because of the upfront capital investment. However, shifting to the cloud liberates an organisation's intellectuals and finances to focus on technology innovation and business upgrades rather than buying or maintaining costly resources.

2.2. Existing architecture and frameworks

Since the inception of cloud manufacturing, there has been a surge of research interest in developing system frameworks for cloud manufacturing platforms. Adamson et al. [9] provides a comprehensive summary of existing architecture and frameworks of cloud manufacturing. Although these platforms differ in complexity, extendibility, and application prospect, they share some similarities and provide some guidance for future work. A cloud manufacturing system typically comprises of a resource layer, an application layer, and other layer(s) for translating manufacturing resources to manufacturing service regardless of its architecture. So far, there has been no report on a fully developed cloud manufacturing system. However, those partially developed systems [7,8,10,11] carry key features of cloud manufacturing and provide some technical insight into implementing cloud manufacturing.

2.3. Key functionalities of cloud manufacturing systems

Cloud manufacturing is an aggregation of various technologies, including data acquisition, service-oriented approach, cloud computing and so forth. Some of these can be seen as core technologies, others as supporting functions. Although key functions of