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Interoperability as a key enabler for manufacturing in the cloud

M. Mourad*, A. Nassehi, D. Schaefer

Department of Mechanical Engineering, University of Bath, Bath, BA2 7AY, United Kingdom

* Corresponding author. Tel.: +44-1225-386115; fax: +44-1225-386928. *E-mail address:* m.h.n.mourad@bath.ac.uk

Abstract

The emerging cloud paradigm has a prominent effect on manufacturing. The move from hardware bound systems to requirements based service provision is enabling the transition to cloud manufacturing. A networked manufacturing service provision system requires vast amounts of information to be exchanged in a non-ambiguous and timely manner to meet production requirements. In this paper, interoperability is identified as a key enabler for cloud manufacturing and a framework for realisation of interoperability across heterogeneous computer aided manufacturing systems is proposed. Using this framework, manufacturing resources can be shared by a large number of clients based on requirements and priorities.

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1. Introduction

Cloud Manufacturing, has been introduced as the emerging manufacturing service-oriented paradigm. This paradigm utilises cloud computing technology along with Internet-of-things and state-of-the-art manufacturing technologies to integrate manufacturing resources and capabilities to offer on-demand, reliable and affordable manufacturing services for the entire manufacturing product life cycle [1]. Through the intelligent integration of manufacturing resources and capabilities, a shared pool of resources is created in the cloud manufacturing platform, promoting cloud users to acquire manufacturing tasks as a service [2]. The integration of the deployed manufacturing resources and capabilities is achieved through virtualisation, as resources are enabled for access as cloud services [3]. Manufacturing resources (i.e. equipment, materials, software, knowledge, and skills) and manufacturing capabilities (i.e. design, production, management, and communication) are advertised and shared on a large unified network using the internet.

Interoperability is therefore one of the essential requirements for enabling cloud manufacturing application [4], providing a framework of open standards and application protocols to enable easy migration and integration of manufacturing applications and data between different cloud service providers [5].

In this paper, the current architectures for forming cloud manufacturing systems are discussed together with their enabling technologies. An interoperable framework for cloud manufacturing resource sharing system (C-MARS) is then defined, aiming to execute various part designs with different features, through the intergeneration of heterogeneous manufacturing resources. formerly, in section 4 a discussion of challenges in the implementation of the framework, followed by the conclusion and future work in section 5.

2. An overview of cloud manufacturing

Cloud manufacturing requires collaboration between various technologies in order to enhance its capabilities to execute complex, large-scaled manufacturing services and tasks [6]. The fundamental technologies used are cloud computing and the Internet-of-things, as the former provides computing as a service to enable computer based manufacturing applications to be dissociated from hardware and the latter allow resources to be formed into networked technology structures [7]. Multi-layered architectures with modular approach are commonly used to build cloud manufacturing systems[4]. Ding et al [8] proposed a compact three layered architecture that further decomposed into more specific layers: A cloud service provider layer that is divided into manufacturing resource layer, virtual interface layer, and virtual resource layer to collect and virtualise hardware and software manufacturing resources on three subsequent layers, a cloud service centre layer which supports the system with the available services and functions by publication, retrieval, aggre-

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gation and scheduling; and, a cloud service demander layer that handles the interface between the system and different cloud users. Jiang et al [9] introduced a five layered structure of basement layer; access layer; functional layer; portal layer; and, application layer, supported by cloud-agent technology within the functional layer to control and coordinate various service transactions within the cloud manufacturing system. This was followed by Wang and Xu [10] who approached the intelligent-agent technology within the smart cloud manager layer to analyse, optimise and control the cloud manufacturing service interactions between the user layer and the manufacturing capability layer. Lv [11] analysed a four layered architecture based on multi-view model that integrates different views (function view, resource view, information view and process view), each view depicts different aspect of the cloud manufacturing architecture. Figure 1 summarises the typical layered structure of cloud manufacturing systems and provides examples of components in each layer. The application layer encompasses cloud enabled applications such as new product development where the initial order for part production is issues. The application interface layer which is the topmost layer of the cloud manufacturing middleware, manages the order received from the application layer and coordinates with the core service layer to match the part requirements with virtual resource capabilities. The core service layer then passes the order to the virtual machine tool on the virtual resource layer that corresponds to one or several cloud enabled physical machine tools. The order which is now translated into executable instructions on the physical machines is executed and the produced parts are delivered to the user who initiated the order.

2.1. Service management

The management of services within cloud manufacturing is considered to be a critical issue, as it requires effective managing and coordinating between the manufacturing resources and manufacturing capabilities to execute on-demand services through the cloud [4]. Additionally, integration of resources and capabilities can occur between different clouds, as Zhang et al [1] identify, there may be two types of clouds (public clouds and private clouds) and therefore resources interact depending on the business needs. In order to ensure service performance of cloud manufacturing, various methods have been proposed: Wang and Liu [12] analysed the ontology of virtualised manufacturing resources; Liu et al [13] deployed a multi-agent system to implement manufacturing resources sharing within

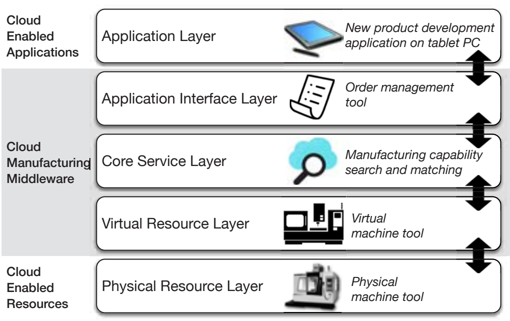

Fig. 1. Generic cloud manufacturing architecture with examples for each layer

a three different cloud manufacturing models to suit different sized enterprises (small, medium, large); Jiang et al [9] similarly introduced agent technology to reflect capabilities and behaviour in manufacturing resources, thus integrating its services within the cloud manufacturing; and more recently, Tao et al [14] addressed the uncertainty issue in the service composition and optimum selection of manufacturing resources, by applying an algorithm based on the adaptive chaos operator.

2.2. Interoperability

ISO16100-1 defines interoperability as the ability to share and exchange information using common syntax and semantics to meet an application-specific functional relationship across a common interface. Wang and Xu [15] proposed a four layered architecture for cloud manufacturing to address interoperability: (i) manufacturing resource layer; to abstract manufacturing capabilities into self contained modules, in order to be launched depending on user request. STEP/STEP-NC was applied to enhance the portability and longevity of the manufacturing resource data modelling, subsequently, data is backed up in the storage cloud database that is embedded within the layer; (ii) virtual Service layer; it organises the service request information into a compliant format; (iii) the global Service layer; promote Enterprises to gain a logic control over the work-flow and processes of the service; (iv) and, the application layer that provides the interface between the cloud user and the ICMS. Wang et al [16] addressed interoperability for manufacturing task description within the cloud manufacturing, by applying an ontology based framework. Lu et al [17] addressed interoperability through a Hybrid Manufacturing Cloud architecture that promote users to utilise different cloud modes; public, community, and private clouds. Enabling cloud users to have full control over the related resource sharing authorisation to enhance trustworthy and patent protection. Li et al [18] linked the cloud manufacturing models with STEP standards and application protocols. What is achieved previously in addressing interoperability within the cloud manufacturing field is the proposing of theoretical frameworks for the manufacturing tasks description, the switching between different cloud modes (public, community, and private cloud), and the approaching of a generic frame work of how information flows within the cloud manufacturing system. Consequently, a development of a interoperable cloud manufacturing framework that is able to identify the major machine tool types (i.e.manufacturing resources), their controller type and capabilities (i.e. table size, number of axis, maximum tool size, etc.) is required. This will ensure that only parts which are manufacturable being allocated to the available resources and additionally, can accept new models of manufacturing resources autonomously (Independent resource model that is only defined by available resources). Furthermore an investigation is still required to identify the communication and interaction protocols of the collaboration structure that merge service providers and service users within cloud manufacturing system. As the current literature lacks of adequate studies regarding the improvement of cloud manufacturing architecture, collaboration techniques, and resource sharing. Consequently, the development of state-of-the-art models, algorithms and techniques is a necessity in order to extend traditional manufacturing industries to be adopted within the cloud environment. Additionally, logical and real experimentation is needed to develop good practices for validation, in order to enhance the integrity of cloud manufacturing by developing rational cloud manufacturing models frameworks. In the current state there are redundant data representation and description of manufacturing resources and capabilities due to proprietary semantics and data formats. Many extensive efforts were proposed to establish standardised information representation of manufacturing resources and capabilities within an integrated manufacturing system, aiming for seamless data transfer and exchange. STEP, WSDL, ontology techniques and XML are deployed for the identification and application of standardised data models and structures for manufacturing resources and capabilities utilised through the product life cycle processes. Hence, this deployment approach can pave the way for the development of cloud manufacturing to realise the integration of the current manufacturing information systems. The manufacturing enterprises currently adopting service-orientated approaches to integrate manufacturing resources based on cloud computing paradigm, thus, state-of-the-art methodologies is crucially required to enhance the integration of various manufacturing resources. Additionally, there is a need for intelligent integration rather than just the current automation as it that offers autonomy in achieving manufacturing tasks. Further development in the integration of manufacturing control systems which can enhance the cloud manufacturing paradigm. Extensive work has been made in relation to the development of open communication standards among shop floor connectivity to enhance machine to machine interaction (intercommunication), thus flexibility and coordination through manufacturing product life cycle is realised.

3. Cloud manufacturing resource sharing system (C-MARS) Framework

The illustration of the theoretical framework is described in this section, so that to explore the cloud-resource systems in manufacturing and investigate the execution of manufacturing process plans on heterogeneous-decentralised manufacturing resources (Mresources), as shown in figure 2 high-level illustration of the system framework functions in acquiring cloud manufacturing services . As the cloud manager accepts the

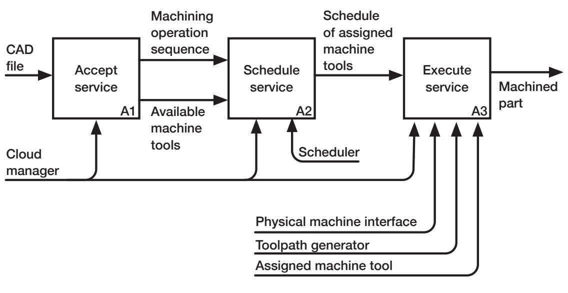

Fig. 2. Cloud Manufacturing Resource Sharing System (C-MARS)

CAD file and forwards the scheduling input parameters to the scheduler then the machining tasks is sent to the assigned machine tools for service execution. Explicitly, the service processing function is abstracted in to four main functions; order review, scheduling, generating tool-path and order processing. Each with a specific constraints and physical aspect for mechanisms; as the order review function is mainly executed by the cloud manager component that compare the service order with the deployed manufacturing capabilities within the cloud manufacturing sharing system (C-MARS), consequently, the confirmed order is scheduled by the scheduler component that sequences the assigned resources with the requested order, furthermore, the scheduled order is passed through the tool-path generator component to compile tool-path for the assigned resources, henceforth the order processing function is initiated by the physical machine interface component. In this section, the structural and functional, views of the theoretical framework are specified.

3.1. Functional view

The cloud manufacturing resource sharing system (C-MARS) model as shown in figure 3 will work by; (1) initiating a service request by a customer for manufacturing a designed part (uploading a CAD file through a web interface). operation.

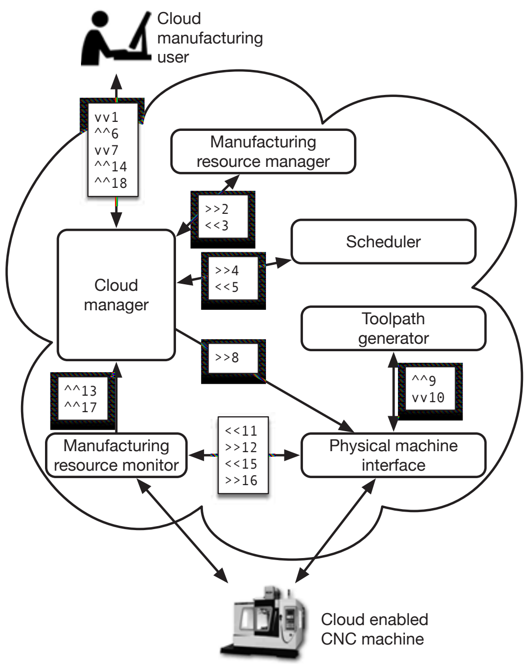

Fig. 3. C-MARS Functional view

The file will be sent directly to the Cloud Manager (identifies the design features) that consequently will compare the machine capabilities available with the part requirements in the CAD file and (2) request the needed machine capability profile from the Manufacturing Resource Manager, that will reply to the Cloud Manager with a (3) list of the available machines tools that can machine the features of the part (based on the capability profile requested by cloud manager).

Accordingly, the Cloud Manager will aggregate this information (comprehensive process sheet (i.e. operations type, cutting tools used, feed, speed, etc) with the information sent by the Manufacturing Resource Monitor (machine tools status update) to set the scheduling criteria and (4) send these sets of information to the Scheduler (machine tools type, machining operations, criteria (i.e. delivery time, specific machine tool). The Scheduler will assign the machine tools based on the criteria given and will (5) reply with assigned machine tools, machining operations and the part number. The Cloud Manager will then (6) send the schedule draft to the customer to (7) reply with the service confirmation.

Consequently, the Cloud Manager will (8) send (based on the Scheduler assignment) to the Physical Machine Interface of each assigned machine; the part features (CAD file) along with the process sheet of the related machining operation. Once the Physical Machine Interface of each of the assigned machine tools receives this information, it will (9) send the feature manufacturing sequence and the postprocessor type to the Toolpath Generator, (10) requesting an NC file (G code) for the related machining.

Accordingly, the Physical Machine Interface will notify the Manufacturing Resource Monitor with the machining operation (11) start and (15) end, in order for it to update the Cloud Manager of the machine tools status (13) and (17), to facilitate the Cloud Manager to notify the customer with machining operation (14) start and (18) end. (12) and (16) are automatic responses for receiving messages by the Manufacturing resource monitor.

3.2. Structural view

The model structure consists of eight main classes as shown in figure 4 to perform an assigned task. Each class represents a specific component in C-MARS structure, which describes the roles of each component allocated in the system. For instance; the **cloud manager component;** is considered to be the main core component of the model for offering (acquiring) model services, as it provides (a) task request for operation, (b) list of manufacturing resources assigned to the related job request, (c) The resource capabilities of the manufacturing resources assigned (deployed), and the job order of the deployed manufacturing resources to execute the requested task.

Additionally the **scheduler component;** which schedules the requested task with the manufacturing resources assigned by the cloud manager component, etc. Although, the scheduling tasks can be embedded within the cloud manager responsibilities. However, the separation of the scheduler component from the cloud manager, allows C-MARS to utilise various schedulers with different scheduling techniques rather than constrained with a specific scheduler.

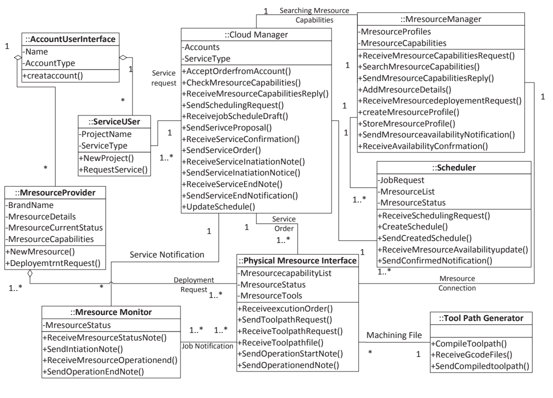

Fig. 4. class diagram of C-MARS model

4. Discussion and summary

The aim of the work proposed is to identify and specify the requirements to realise interoperable resource sharing system for cloud manufacturing. As the reviewed literature in section 2 showed that; extensive efforts have been done in order to integrate heterogeneous manufacturing resources and capabilities to develop a collaborative environment for manufacturing enterprises.

Although the majority of these efforts are not harmonized in the context of unified manufacturing integrated system that could be seamlessly deployed for the approaching technologies as cloud manufacturing. Although, they showed particular strengths in the interoperable integration of CAx chain systems, shop-floor connectivity, and additionally, the unified information representation of manufacturing resources.

The aim was applying open standards for non-ambiguous virtual representation and interoperability enhancement of various manufacturing resources and capabilities to be integrated within a specified framework. On the other hand, the existing architectures, models, and algorithms in relation to cloud manufacturing are insufficient for a large-scale evaluation environment, thus avert the development of the commercial application of cloud manufacturing. Additionally, the full integration of the legacy systems is not possible as the former proposed networked manufacturing systems has some significant limitations as; lack of protocols and standards, lack of operation models (i.e. management mechanisms for coordination of large data), and lack of flexibility in integration of manufacturing resources. Hence, former networked manufacturing systems lack the adaptability to acquire the future and the competitive needs of manufacturing enterprises. However, these legacy manufacturing systems yielded many applications that can be deployed/adopted within the cloud manufacturing system (i.e. scheduling, tool-path generators and process planning optimization, product design, resource optimal allocation, and resource service composition).

Hence, through the utilisation of the cloud computing technologies and the various manufacturing applications of the legacy systems; the cloud manufacturing paradigm potentially will be able to achieve the aim of centralised management of decentralised and disturbed manufacturing resources and capabilities to offer them as a service. Which implies to the challenge of integrating the essential components of a manufacturing system (i.e. unified manufacturing resource model, scheduler, tool-path generator, CAx systems) to realise interoperable cloud manufacturing system, and so that to provide manufacturing resources and capabilities as services on an on-demand basis through the utilising of the internet. And enable the cloud manufacturing system components to communicate and exchange data autonomously. This study has taken a step in the direction of identifying interoperability as a key enabler for cloud manufacturing application, through a framework for realisation of a interoperability across heterogeneous computer aided manufacturing systems. By the deployment of various information technologies as Internet-of-Things, cloud computing, service oriented architectures to integrate state-of-the-art techniques of manufacturing resource standardisation and servitisation. Hence, integration of heterogamous manufacturing resources along the product life cycle is enabled. The novel vision of the work approached is through development of the cloud manager component, the cloud manufacturing resource sharing system (C-MARS) framework will be able to execute various part design features on heterogeneous deployed manufacturing resources autonomously. furthermore, allowing added on capabilities of manufacturing resources to be deployed within the system. Therefore, the outlined approach embraces the integration of traditional and non-traditional manufacturing components, thus facilitates the adoption of the cloud manufacturing paradigm by current manufacturing enterprise (SMEs). This service oriented system should allow various stakeholders to access the necessary manufacturing information according to their requirements and priorities. additionally, enhance the expediency of the cloud manufacturing environment.

5. Conclusion and Future work

There are numerous interoperable systems of which cannot or do not communicate with each other efficiently in order to make seamless distributed manufacturing system through the product lifecycle from design to final part. The challenging question is it possible to integrate the essential components of a manufacturing system (i.e. unified manufacturing resource model, scheduler, tool-path generator, CAx systems) to realise interoperable cloud manufacturing system, and so that to provide manufacturing resources and capabilities as services on an on-demand basis through the utilising of the internet. And enable the cloud manufacturing system components to communicate and exchange data autonomously. The novel aspect of the proposed work is that through the cloud manager component it will be possible to understand the data that comes from the other different components within the cloud manufacturing system, creating an interoperable cloud manufacturing framework based on the integration of different manufacturing resources and capabilities through creation of the cloud manager that will enable the communication and interaction between the cloud manufacturing main components (i.e. scheduler, tool path generator, manufacturing resource manager, and physical machine interface). Additionally will be able to manipulate the data to make the cloud manufacturing components communicate with each other through the cloud manager component to execute service requests. In this study so-far, a theoretical framework is modelled to address interoperability within the cloud manufacturing components, as each component was conceptualised and related functions were explicitly analysed and identified to enable a well expressed modelled framework. In addition the proposed framework C-MARS will propose the object oriented approach in modelling the cloud manufacturing system. Furthermore, an extensive review of literature was acquired , along with the study of tools utilised and the related technology deployed for the application of cloud manufacturing. Future work will focus on:

- **Development of prototype software:** this phase encompasses the implementation of the approached theoretical framework model, as the model main components (i.e cloud manager component) will be explicitly expanded to a low level aspect, furthermore the compulsory components will be utilised, in order to develop and demonstrate a verified cloud manufacturing resource sharing system prototype software.
- **Design of Industrially inspired experiment cases:** In this step an industrially inspired experimental cases is selected and applied to demonstrate the capabilities of the developed software.

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