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Technical Paper

A semantic web-based framework for service composition in a cloud manufacturing environment

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ABSTRACT

Cloud manufacturing has been recognised as a transformative manufacturing paradigm to enable rapid production of highly customised products in a networked environment, through on-demand consumption of cloud-based manufacturing services. The fundamental issue of on-demand manufacturing service provision is service composition, where distributed manufacturing resources are mapped to personalised service requests. This paper examines knowledge-based service composition and adaptive resource planning in a cloud manufacturing environment. The intention is to develop an integrated networked environment, allowing fast resource allocation for a given service request, subject to governance policies, resource access policies, resource availability information and etcetera. The research challenge in this is to explore a feasible service composition method that facilitates easy mapping between service requests and manufacturing resources based on restrictive rule sets in the cloud and availability information about a resource. The research work in this paper analyses the relevant research challenges, proposes a practical approach and implements the solution in the form of a web-based system. The proposed system utilises distributed knowledge for intelligent service composition and adaptive resource planning. A case study is also presented to validate the performance of the proposed approach.

1. Introduction

Cloud manufacturing is a service-oriented, high efficiency and low consumption, knowledge-based new mode of networked manufacturing and it has been recognised as a transformative model for future manufacturing [1,2]. The purpose of cloud manufacturing is to move from production-oriented manufacturing processes to service-oriented manufacturing process networks by modelling single manufacturing assets as services and provide them to the variable demand of customers [3–5].

The fundamental issue of providing on-demand manufacturing services in the cloud is the mapping of distributed manufacturing resources with personalised service requests; this process is called service composition [4]. Recognising the need to develop a feasible service composition methodology, much effort has gone into applying well-established optimisation algorithms, such as genetic algorithm, particle swarm optimisation, and ant colony optimisation, to the task of selecting manufacturing resources for a given request. Quality of Service (QoS) is usually used as the optimisation goal in these methods. Parameters such as lead-time and cost make up the key parts of QoS. However, research outcomes from these efforts cannot easily cope with real business cases, as business situations are far more complicated. Most reported research work applied large-data scale numerical algorithms to production planning for real industrial settings where most of the metrics or parameters defined in these algorithms are hard to capture. In addition, many of the reported algorithms tended to simplify complex knowledge-based production activities to quantitative mathematical problems. In the published research outcomes, the common hypothesis is where there is a pool of feasible resources for a given task, the research question is to select the best combination of resources for the task. However, this is often not the case. A service provider has a clear description of a resource's capability boundary. A cloud environment needs to screen the resource pool to find feasible resources for a given job, before generating an effective service scheme. Therefore, the service composition process in general consists of two phases: (1) capability assessment, which is to find feasible resources for a given task, based on the characteristics of the job and the capability of each unique resource, and (2) service recommendation, where economic analysis and sustainability analysis are carried out, after which an optimal set of manufacturing resources is recommended.

The research work reported in this paper proposes a systematic framework for capability assessment and service recommendation in a cloud manufacturing environment. The proposed solution

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utilises distributed knowledge for intelligent capability assessment and service recommendation. This unique approach makes the proposed system applicable to various engineering situations, as the main duty is simply maintaining the back-end knowledge base. As service composition in cloud manufacturing is relatively new, Section 2 discusses the unique features and requirements of capability assessment and service recommendation in a practical cloud environment. Section 3 reviews related technologies and Section 4 presents the overall architecture of the proposed solution. Section 5 presents the industrial implementation of the proposed environment with a case study. Conclusions are given in Section 6.

2. Service composition in cloud manufacturing

As discussed in the preceding section, the fundamental issue in cloud manufacturing is to map personalised manufacturing requirements with distributed manufacturing resources. Sometimes, this process can be simple cross-checks between a service request and a service, while other times it requires an experienced engineer to investigate the technical difficulties in undertaking a job with certain resources. Both scenarios require the use of engineering knowledge to drive the decision-making process, though sometimes this knowledge can be as simple as comparison of numerical numbers. In addition, a service recommendation is not just a simple multi-objective optimisation. In an industry setting, the selection of the final service provider(s) can be derived from multiple unquantifiable factors that are critical to a business, such as IP (Intellectual Property) protection concerns, business partnerships and personal relationships. Even for quantifiable factors such as lead-time and cost, it is not feasible to appoint a default coefficient for each variable that applies to every service consumer because different service consumers have different purchasing preferences. The industrial implementation of cloud manufacturing imposes special requirements on service composition that many proposed solutions fail to address.

2.1. Systematic knowledge utilisation

The process of mapping manufacturing jobs with an optimal set of manufacturing resources is a knowledge-intensive activity. This process often requires a manufacturer to reuse existing knowledge (such as drawings, assembly instructions, manufacturing processes and resource capability) to compose a sequence of activities, subject to specified constraints. Knowledge reuse is especially significant for the design and manufacturing process of highly personalised products. Human input is best minimised in this process when a good knowledge-based system can handle these activities.

The collaborative and distributed nature of cloud manufacturing makes knowledge utilisation more challenging. In cloud manufacturing, the product development process often involves contribution from multiple stakeholders concurrently. It, therefore, requires knowledge inputs from different manufacturers. The best practice of production process in a workshop often stems from years of evolution, subject to its in-house resources, and this knowledge could be very different in different workshops. This means using a standard knowledge base for processing manufacturing requests is not always feasible, as the resultant request-resource pairs can conflict with the best practice of some workshops. Hence, a systematic approach for capturing and utilising disparate knowledge from distributed manufacturers is required.

Subsequently, there is a call to design a feasible mechanism to integrate distributed knowledge from different parties, such as tooling suppliers, manufacturers, and regional governments, and use the right subset of knowledge in the process of mapping a service request with manufacturing resources. There are two main tasks to be undertaken: (1) generating a representation scheme for manufacturing knowledge and (2) creating a mechanism to allow smooth knowledge integration and utilisation in any decision-making activities.

2.2. Dynamic event handling

Cloud manufacturing aggregates loosely-connected enterprises, and forms a dynamic marketplace network. In this network, the commencement of new projects and the closure of existing projects happen concurrently. This means a manufacturing resource is in a constant status of switching between being in use and idle. It is, therefore, necessary to consider the actual capacity and availability of a manufacturing resource during service composition.

In other words, cloud manufacturing needs to consider the actual resource capability instead of nominal resource information. Information such as availability, unique access policy, and unique operation of a manufacturing resource are some essential inputs. Service composition is thus required to be capable of processing this information and generating a feasible service plan, adaptive to the real shop-floor status [6].

2.3. Posteriori articulation of service preference

Selection of a preferred service plan for a request is very similar to online shopping, in the sense that a service consumer selects his/her favourite service plan, based on personal experience rather than a default indicator pre-defined by the cloud system. In a cloud manufacturing environment, factors that contribute to the final decision include but are not limited to cost, lead-time, reputation, and transaction history. For a service consumer at a specific business situation, the dominant reason for final selection may be completely different. For a low-urgency order, a service consumer may be inclined to a service plan with low cost, whereas a high-urgency order may require a short lead-time. It is not very feasible to develop a normalised formula that can be applied to every service consumer for all business cases. Therefore, in an industrial setting, one of the basic requirements for service composition is that it outputs all reasonable service plans for a service consumer to select. A more advanced scenario would also allow a service consumer to input additional selection criteria to filter the returned results.

In summary, industry implementation of cloud manufacturing imposes special requirements on service composition because of the knowledge-intensive, collaborative, and web-based nature of cloud manufacturing. Service composition for cloud manufacturing needs systematic knowledge utilisation, dynamic event handling and posteriori articulation of service preferences. The next section reviews existing efforts on service composition.

3. Existing methods and tools

In cloud manufacturing, there are three mapping relationships between resources and services [1,7,8]: One-to-One mapping, when a manufacturing resource can only provide a single function and can directly be encapsulated as one service, One-to-Many for a resource with multiple functions or capabilities, which each matches different manufacturing requirements independently, and Many-to-One, when multiple resources are combined to create a more powerful resource.

One-to-One and One-to-Many mapping is technically the same as the service an end-user gets is from one resource, and the mapping process is to find a single resource to undertake a given task. Semantic similarity is recognised as a feasible approach for task and resource mapping. In order to create an intelligent matching process between supply and demand in a cloud manufacturing environment, an ontology method to facilitate unified