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Abstract

This paper explores an ontology-based multi-perspective task decomposition strategy to support composite service discovery of manufacturing resources across ubiquitous virtual enterprises in distributed manufacturing environments. A new ontology-based decomposition-supported service modeling approach is proposed for distributed management of heterogeneous manufacturing resources, enabling to add decomposition-aware semantics to manufacturing services to endow them with semantic capabilities needed for their flexible decomposition and reuse in distributed manufacturing. The multi-perspective task decomposition strategy based on description logic, production rule and workflow is used to support the decomposition and discovery of the heterogeneous manufacturing services in a meaningful manner. The proposed work can be combined with existing manufacturing service modeling and discovery works to handle much complicated service-oriented manufacturing tasks.

Keywords: Distributed Manufacturing, Manufacturing Service, Ontology, Semantic Web, Service Discovery, Task Decomposition

1. Introduction

The usage of SOA (Service-oriented architecture) in today’s complex, distributed and dynamic manufacturing environments has seen an exponential growth in the past decade since it facilitates the development of ubiquitous computing infrastructures for collaborative enterprises to establish and maintain global and agile supply chains through efficient and effective discovery of shared manufacturing resources among each other. Firms or individuals may advertise or access manufacturing services in the ubiquitous internet through PCs, PDAs, smart phones or other fixed and mobile devices without limitation. However, the required manufacturing services are often not discovered easily when a manufacturing task is too complex to be matched with lower-level atomic services directly. For example, if a user requires a Lathe turning service, an advertised Lathe rough service or Lathe finish service would not match with the service request automatically, though the service request can be satisfied by composing these two advertised services in a certain context.


The prelude to the composite manufacturing service discovery is a formal representation of heterogeneous manufacturing services with decomposition-supported modeling. Therefore, an ontology-based decomposition-supported service modeling approach is proposed for distributed management of heterogeneous manufacturing resources, through which, various manufacturing services are annotated with decomposition-aware OWL-based manufacturing resource ontology. The multi-perspective knowledge of description logic, production rule and workflow has been
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encapsulated in the manufacturing service ontology to support task decomposition in composite service discovery. OWL is a widely recognized semantic markup language on the Semantic Web [2].

The multi-perspective task decomposition strategy based on description logic, production rule and workflow can be used to decompose a complex manufacturing task into a set of atomic manufacturing service requests so that these atomic service requests can be semantically matched with the advertised atomic manufacturing services in the composite service discovery process.

The proposed work can be combined with existing manufacturing service modeling and discovery works to handle a rich set of much complicated service-oriented manufacturing scenarios across ubiquitous virtual enterprises.

2. Related work

With SOA rapidly proliferated all over the world, the diverse service discovery technologies have been explored widely in the past decade to support resource cooperation and application integration in distributed environments. This section reviews the related works and identify what can be improved in the future works.

Esfahani et al. [3] presented a model of reputation improved Web services discovery considering the quality of services that include a reputation administrator to allocate reputation marks to the services based on customer feedback of their efficiency. Dharamyadevi et al. [4] elaborated on the matchmaking architecture, its information flow and types of matchmaking techniques (functional based matchmaking, non-functional based matchmaking and hybrid matchmaking). Ameri and Dutta [5] proposed a graph-based MSDL (Manufacturing Service Description Language), which is an upper ontology for the structural representation of manufacturing services. MSDL is dynamic in nature and includes a collection of manufacturing domain-specific taxonomies, subclasses, and instances that support semantic manufacturing service discovery through a manufacturing-compatible service repository. In our previous work [6], A SOA is laid out in the peer-to-peer network of a distributed, scalable semantic registry to address, in an open, decentralized and loosely coupled manner, the life cycle of multidisciplinary collaborative design activities involved in publishing, discovering and reusing various design services efficiently. Our previous work [7] represents the complex manufacturing services from both aspects of structural knowledge and constraint knowledge using an ontology-based service modeling approach, to deal with the more complex matches in manufacturing service discovery.

Although the diverse service discovery technologies have been widely explored in the past decades, most of them like the above reviewed ones only deal with atomic service discovery but don’t support composite service discovery via task decomposition, which, however, is often encountered in the practical, complex manufacturing environments.

Having realized the importance of task decomposition in complex service discovery, some researchers have integrated task decomposition function in the service discovery framework. Chen et al. [8] proposed a service level agreement (SLA) decomposition approach that combines performance modeling with performance profiling to solve composite computing service discovery problem by translating high level tasks to more manageable low-level sub-tasks. These sub-tasks feature several low level system and application level attributes and metrics that are used for creating an efficient design to meet high level SLAs. Huang et al. [9] presented the service discovery architecture in pervasive environments by analyzing the hierarchy of task-computing and decomposition scheme of complicated tasks. The architecture relies on semantic representation of service and context and the semantic representation is based on the shared ontology. Tao et al. [10, 11] described distributed manufacturing resource services based on OWL-S in the manufacturing grid environment, enabling these services to be semantically discovered and optimally composed to realize the multi-objective decision-making industrial task. A complex manufacturing grid task can be decomposed into several sub-tasks that can be executed by invoking corresponding atomic
manufacturing resource services. Ukor and Carpenter [12] presented a goal-oriented and task-decomposition approach to service selection which abstracts from the individual business process activities used to access service capabilities based on non-functional properties such as Quality-of-Service (QoS) metrics.

However the above decomposition-aware composite service discovery approaches have not addressed how the complex task decomposition can be realized automatically in the distributed environments, due to the lack of a much hierarchical and elaborate ontology that encapsulates heterogeneous, service-oriented task decomposition knowledge.

3. Ontology-based decomposition-supported service modeling to the distributed manufacturing resources on the Semantic Web

To address the service decomposition issues in composite service discovery, our previous work on ontology-based manufacturing service modeling approach [7] is extended in this work by adding decomposition-aware semantics to manufacturing services to endow them with semantic capabilities needed for their flexible decomposition and reuse in distributed manufacturing (figure 1).

The Manufacturing service concept provides the key top-level ontology that supports the rigorous and unambiguous description of manufacturing resource capabilities across ubiquitous virtual enterprises by wrapping up them as Web services based on ontology, for making usage of them as transparent and meaningful as possible from the users’ point of view.

A top-level ontology concept can be further specialized into optimal number of lower-level sub-concepts through class inheritance to represent the domain as accurately as possible. For example, the Manufacturing service class can be specialized into Composite manufacturing service, Manufacturing workflow service and Atomic manufacturing service classes through ontological inheritance. The Lathe turning service class can be specialized into Lathe rough service, Lathe finish service and Lathe polishing service classes. The Manufacturing object class can be specialized into Feature, Part and Assembly classes. The Feature class can be specialized into Hole, Cylindrical surface, End surface classes, etc. The inheritance relationship can be expressed using owl:subClassOf property.

The multi-perspective knowledge of description logic, production rule and workflow has been encapsulated in the manufacturing service ontology to support task decomposition in composite service discovery. The Has part association defines a Description Logic (DL)-based whole-part relationship between a complex task and a sub-task. For example, the Composite manufacturing service class associates with the Atomic manufacturing service class through Has part association. The Lathe turning service class associates with the Lathe rough service, Lathe finish service and Lathe polishing service classes through Has part associations. The Shaft class associates with the Cylindrical surface and End surface classes through Has part associations. The Has part association can be expressed using owl:unionOf property.

The Has rule association defines the context-aware task decomposition strategy, i.e., a complex task may be decomposed into different sub-tasks in different contexts. For example, if a Lathe turning service is enabled by a Polishing lathe, then it should be decomposed into Lathe finish service and Lathe polishing service; if a Lathe turning service is enabled by a High precision turning lathe, then it should be decomposed into Lathe rough service and Lathe finish service; if a Lathe turning service is enabled by a Low precision turning lathe, then it is not decomposed. The production rule can be formalized using SWRL (Semantic Web Rule Language) [13], which is a very expressive semantic markup rule language on the basis of OWL. SWRL allows users to formulate horn-like production rules in the form of IF-THEN formats expressed in terms of OWL concepts.

The Has workflow association defines that a workflow service is completed by invoking several atomic services through their concurrent, alternative, sequential or iterative compositions. For example, a Production workflow service of crank shaft is completed by invoking several sequential atomic manufacturing services including Stock forging service, Lathe turning service, Heat treatment service and Grinding service. The workflow service is
usually formed through long term of successful practical application. Reuse of mature workflow service knowledge helps to avoid the usage of some unreliable or unavailable atomic services, which may cause service invocation failure. The Has workflow association can be expressed using OWL-S process model that supports service composition.

Figure 1. Ontology-based decomposition-supported service modeling to the distributed manufacturing resources on the Semantic Web
4. A multi-perspective task decomposition strategy to support composite manufacturing service discovery

Traditional manufacturing service matchmaking may fail if a required manufacturing service description (e.g., a composite service request) is too complicated to be matched with published atomic manufacturing services directly, or a published manufacturing service is too coarse to provide fine-grained atomic manufacturing services. Referring to figure 2 as a simple illustrative example, the service $S_A$ and $S_B$ are published by service providers and advertised in the semantic manufacturing service registry. A service consumer is looking for a required service $S_C$. Supposed that either $S_A$ or $S_B$ doesn’t match $S_C$ directly.

However, consider that the composite service $S_A$ can be decomposed into two atomic services $S_{A1}$ and $S_{A2}$; the composite service $S_B$ can be decomposed into two atomic services $S_{B1}$ and $S_{B2}$; and the composite service request $S_C$ can be decomposed into two sub-service requests $S_{C1}$ and $S_{C2}$. Let’s suppose the decomposition process of $S_A$ into $S_{A1}$ and $S_{A2}$ through Has part association, that is, $S_A$ associates with $S_{A1}$ and $S_{A2}$ through Has part associations. So do $S_B$ and $S_C$, whose decomposition process may be realized by either of Has part association, production rule and workflow. In general DL, it can be expressed as below:

$$S_A = S_{A1} \cup S_{A2}$$
$$S_B = S_{B1} \cup S_{B2}$$
$$S_C = S_{C1} \cup S_{C2}$$

In the above case, though $S_C$ can not be matched by $S_A$ or $S_B$ directly, $S_C$ can be decomposed into $S_{C1}$ and $S_{C2}$, which are then matched by combined atomic services of $S_A$ and $S_B$ indirectly. In other words, a task decomposition strategy can be used to decompose a composite manufacturing task into less complex sub-tasks to facilitate composite service discovery.

Therefore, in the present work, referring to figure 3, a multi-perspective task decomposition strategy is adopted to support composite manufacturing service discovery, which applies either approach of 1) DL-based decomposition, 2) production rule-based decomposition, and 3) workflow-based decomposition. The corresponding multi-perspective knowledge of DL, production rule and workflow is encapsulated in the manufacturing service ontology that has been elaborated in Section 3.
1) **DL-based decomposition**

Any practical DL reasoner such as Racer [14] can be applied to perform DL-based decomposition to a composite manufacturing service expressed in `owl:unionOf` property.

2) **Rule-based decomposition**

The knowledge for decomposing a composite manufacturing task can also be captured and stored in a production rule base. All rules are formulated in the form of IF-THEN formats in SWRL. The Java Expert System Shell (JESS) [15] used as the inference engine will reason about SWRL rules, with IF sentence matching the composite service and THEN sentences matching the resulting atomic services.

3) **Flow-based decomposition**

The mature workflow service knowledge can also be developed in the manufacturing service ontology. Therefore, a set of active and robust workflow service instances with its comprising atomic services through their concurrent, alternative, sequential or iterative compositions can be stored in a workflow base through OWL-S process model. In our previous work [6], a service-oriented workflow planner in the manufacturing domain has been developed to manage workflow instances, but won’t be repeated here for conciseness. A composite manufacturing service corresponding to a workflow service can be decomposed into interoperated atomic services by means of the workflow repository when necessary.

### 5. Conclusions

In this paper, an ontology-based multi-perspective task decomposition strategy is presented to support composite service discovery of manufacturing resources across ubiquitous virtual enterprises in distributed manufacturing environments. The meaningful service discovery needs to operate over a formal representation of heterogeneous manufacturing services. Therefore, a new computational model that includes an ontological basis, semantic service representation and multi-perspective task decomposition knowledge is proposed to manage heterogeneous manufacturing resources effectively while handling complex queries in distributed manufacturing environments. The multi-perspective task decomposition strategy based on description logic, production rule and workflow is used to support the decomposition and discovery of the heterogeneous manufacturing services in a meaningful manner. Although the authors’ work is developed in the e-manufacturing domain, the approach can be extended for
more general e-science, e-business and e-government applications. The future work will look into the application of the current work in the wide domains and further validate the current work.

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7. References