

Multiple Disciplines Product Design Knowledge Representation Strategy Based on Ontology and Semantic Network

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Abstract

The complicated products design is a process of conflict resolution and integration decision for collaborative optimization involved in multiple disciplines including mechanical engineering, electrical engineering and control engineering, etc. It's also a multi-disciplinary field of complex knowledge fusion process. The architecture of the product design knowledge is given by the description of the forms of knowledge in complex product design. The representation mechanism for multidisciplinary knowledge based on ontology and formal definition of the design knowledge ontology are put forward by using the theories and methods of ontology and semantic network. Finally, the multiple disciplines design knowledge expression strategy is proposed based on the above analysis and conclusions. This paper provides a new method and means for complicated product design knowledge representation involving the integration of multidisciplinary knowledge.

Keywords: ontology, semantic web, multiple disciplines, collaborative design, knowledge management

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1. Introduction

Complicated product design process is an application process involving a large number of multiple disciplines knowledge. From the perspective of knowledge, the product design process is the process of product design knowledge retrieval, combination and creation of new knowledge. The final product is materialized in the form of design knowledge reuse. The documentation, graphics, data and collaborative records during different departments in the product design process are the carriers, which used to express the design knowledge [1] [2] [3].

Product design process involves two types of knowledge: one is the methodology, that is, management skills knowledge; the other is the knowledge of the target market and technical knowledge. The latter has the characteristics of significant difference with the different companies, markets, product, and company's strategic orientation [4]. In product development, design knowledge mainly in six aspects: design standards and specifications, design principles and theories, products instances, empirical data and computational model, mechanical constraints, such as mechanical properties, machining assembly, etc., and design experience.

Distribution and heterogeneity is the primary manifestation of knowledge in the product design process. And product design knowledge has the characteristics of fuzzy, hierarchy and coupling. This makes the manifestations of product design knowledge is very complex and lack of a quantitative description. In order to express the multiple disciplines knowledge involved in the design of complicated products, we propose the architecture of product design, and describe them based on ontology and semantic network.

2. Architecture of Design Knowledge

According to the description above, we adopt the architecture as shown in Figure 1 to express the design knowledge.

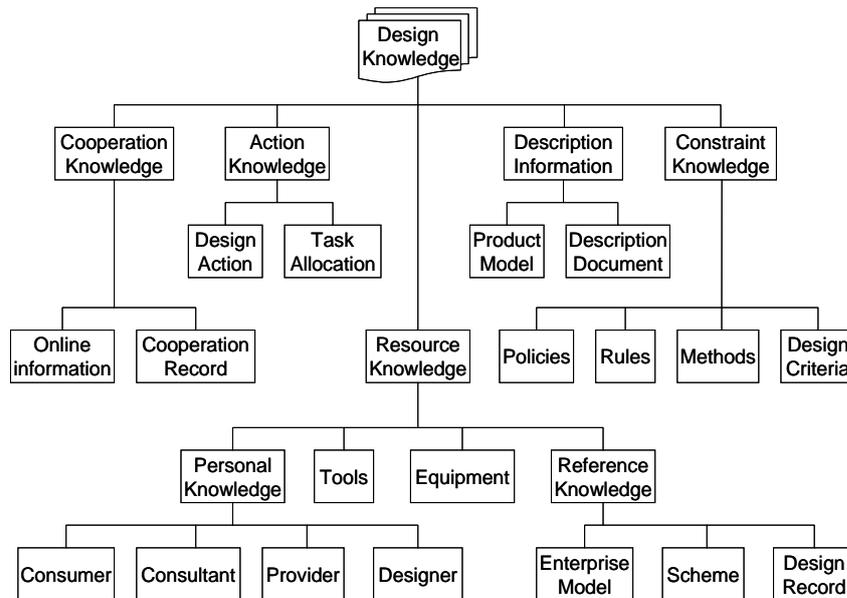


Figure 1. The architecture of design knowledge

The Architecture shows five kinds of knowledge: the first, cooperation knowledge, denotes the knowledge involved in coordinated operation during product development, and includes online information and cooperation records; the second, action knowledge, represents the knowledge related to activities in the design processes, comprises design action and task allocation knowledge; the third, resource knowledge, is the reference knowledge about staff, implements, facilities, enterprises, documentation, designing records, and so on; the fourth, description information, is the information of production itself, as product model, description documents, and etc. the last, constraint knowledge, is a set of constraint information, includes law, statute, policy, technique and criterion for product development.

3. Knowledge Representation and Ontology

The expression of the product design knowledge is a knowledge protocol, and is the key foundation technology to form design knowledge management. Expression of knowledge is different from the information processing. Information processing is generally not concerned about the content of the information only to determine the format and the amount of information, and knowledge representation must be able to understand the content of the knowledge.

3.1. Knowledge Representation Method

The knowledge representation method is the continuum structure for data and control, its essence is the symbol of knowledge and formal process. Knowledge representation method has the requirements of complete, concise and hierarchy. The common knowledge representation includes: model-based knowledge representation, object-oriented knowledge representation, ontology-based Knowledge Representation, fuzzy knowledge presentation, production rule knowledge presentation, semantic network knowledge representation, and etc. [5] [6].

The rules for choice of method of formal representation are as follows: firstly, adequately represent the domain knowledge, secondly, conducive to the use of knowledge, thirdly, to facilitate the organization, maintenance and processing of knowledge, lastly, easy to understand and implement.

3.2. Ontology

Ontology is a shared conceptual model of the formal specification [7] [8]. Ontology can express the various concepts in the field and its relationship explicitly and formally. The ontology

definition includes four meanings: firstly, conceptual model, is the model through the concept of abstract objective world phenomenon, secondly, clear and explicit, the definitions and descriptions for the concepts and the constraints of these concepts are clear and explicit, thirdly, formal, the content contained in ontology can be understood by computer, and lastly, sharing, knowledge reflected in the ontology is common recognition, and it is not an individual private, but can be accepted by a group. It reflects a recognized set of concepts related filed, enabling knowledge sharing between systems and knowledge reuse in new systems. Sharing and reuse is an important advantage of using ontology.

A large number of researchers work in the field, and so many kinds of ontology description language have been brought into being, such as RDF and RDF-S, OIL, DAML, OWL, of KIF, SHOE, the XOL, OCML, Ontolingua, CycL, Loom, etc.

4. Ontology-Based Product Design Knowledge Representation

The task and goal of ontology-based design knowledge representation is to capture the design knowledge of related fields, to provide a common understanding of domain knowledge, to determine the common recognition vocabulary in the field, and to give an exact definition of these terms and the relationship between them.

4.1. Knowledge Representation Mechanisms

The ontology is a formal description of the shared model. Perez and others believe ontology can be organized by taxonomy. They summarized ontology contains five basic modeling primitives [9] [10] [11] [12].

Firstly, concepts or classes, means anything, Such as job description, function, behavior, strategies and reasoning process. Semantically it is a collection of objects, including the name of the concept, the collection of relation of concepts, as well as a description of the concept. Secondly, relations, are the interactions between concepts. They are formally defined as a subset of the n-dimensional Cartesian product, as $R: C_1 \times C_2 \times \dots \times C_n$. They correspond to a collection of object tuples semantically. Thirdly, function, is a special kind of relations. The element n can be determined uniquely by the first n-1 elements. It is defined formally as $F: C_1 \times C_2 \times \dots \times C_{n-1} \rightarrow C_n$. Fourthly, axioms, represents eternal really assertion. Lastly, instance, represents the element. Instance represents object semantically.

Relation is very important in ontology. Semantically, there are four kinds of basic relations: part-of, kind-of, instance-of and attribute-of. During actual modeling process, the relations between the concepts are not limited to be listed four basic relations above, and the relations can be defined according to the specific circumstances. Ontology organizes the knowledge of the real world by using these modeling primitives.

4.2. The Formal Definition of the Design Ontology

According to the knowledge of ontology above, a formal definition of the design ontology is given as follows:

Definition 1, the concept of design knowledge is objective abstract knowledge involved in the product design process, is the nodes of the tree structure, and is the unique attributes of the design knowledge concept.

Definition 2, design knowledge ontology is the conceptualization in the field of product design, and it can be formalized with the dualistic structure as $O = (D, W)$. Where D is the design domain, W is the largest state set on D, called the domain space.

Definition 3, the relationship between the concepts of design knowledge is the edge of the tree.

Definition 4, the attribute of the design knowledge relationship refers to the nature of the relationship.

Definition 5, triples $O = (D, W, \zeta)$. ζ is the concept associated set of design knowledge in the domain (D, W) . κ^n , the concept association of n-dimensional design knowledge, is a full function, can be expressed as $W \rightarrow 2^{D^n}$. It represents the set of all n-dimensional relationship mapping from W to D, called the concept system of design knowledge.

Definition 6, product design domain ontology may be expressed by triples as (D, C, R) . Where D is product design domain concept set. C is the abstraction layer structure for the concept of product design domain, and it can represent the hierarchical relationships between the different domains. R is a full function of parent-child domain. It maps each concept from sub-domain to parent domain. Equivalence relations of the domain can be defined according to the full-function.

In order to clearly express the design knowledge ontology, we give fourteen relations and attributes of the relations, such as directionality of the relations, kind-of, part-of, instance-of, attribute-of, transitivity, inherit, opposite inherit, inverse, symmetry, reflexivity, equivalence, inverse relationship inheritance, and synonymy.

4.3. Design Knowledge Expression Strategy

In order to express the product design knowledge, we should analysis the design knowledge source at first and express them by using a suitable method. Design knowledge representation strategy based on ontology can be divided into top-down and bottom-up methods. The top-down is first constructing ontology concepts, then identifying the ontology under the constraints of the ontology concepts, and building ontology attributes and ontology instance. Expression of bottom-up is extending semantic abstraction, gathering, mapping and joint of design knowledge to product design ontology. The bottom-up expression has the advantage of flexibility, scalability, good compatibility. But the design ontology formed by using this method lacks detail levels and consistency. In this paper, design knowledge representation shown in Figure 2 is proposed referring to unstructured knowledge, semi-structured knowledge and structured knowledge involved in product design according to the characteristics of heterogeneity, fuzzy, hierarchical, coupled, and etc.

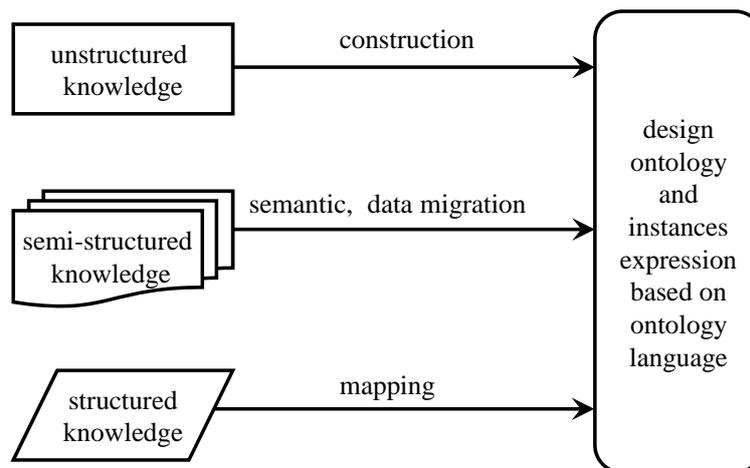


Figure 2. Knowledge expression strategy

Structured and semi-structured knowledge are expressed by using the representation strategy of bottom-up, and unstructured knowledge of a large number of text documents and other experience knowledge in product development is expressed by using top-down representation strategy. This knowledge would be expressed by using semantic web.

4.4. Semantic Web

The goal of the Semantic Web is to make information on the web having the definition can be understood by computer, achieve semantic interoperability between information systems with ontology's support, access and retrieval of web resources intelligently [13-17]. The purpose of this paper is to build a Semantic Web based on product design knowledge in the design enterprise, in order to achieve internal design knowledge access and retrieval intelligently.

Semantic Web is a vision of the future network. In such a network, the information is given a clear meaning, and the computer can automatically process and integrate the information available on the internet. Semantic Web uses XML to define a custom label formats, and express data with the flexibility of the RDF. Next, need an ontology web language to describe the clear meaning of the term network documentation and the relationship between them.

5. Case Study

According to the above theories of design knowledge ontology, the modeling of impeller design knowledge ontology is given. And the model is expressed using the semantic web. In this paper, the model of impeller design ontology is proposed by Protégé, and the relations between the concepts are defined based on the expression of the concept for impeller design knowledge. The ontology model and formal description of OWL Web ontology language for impeller design knowledge is shown in Figure 3. It solves the semantic representation of the impeller design knowledge.

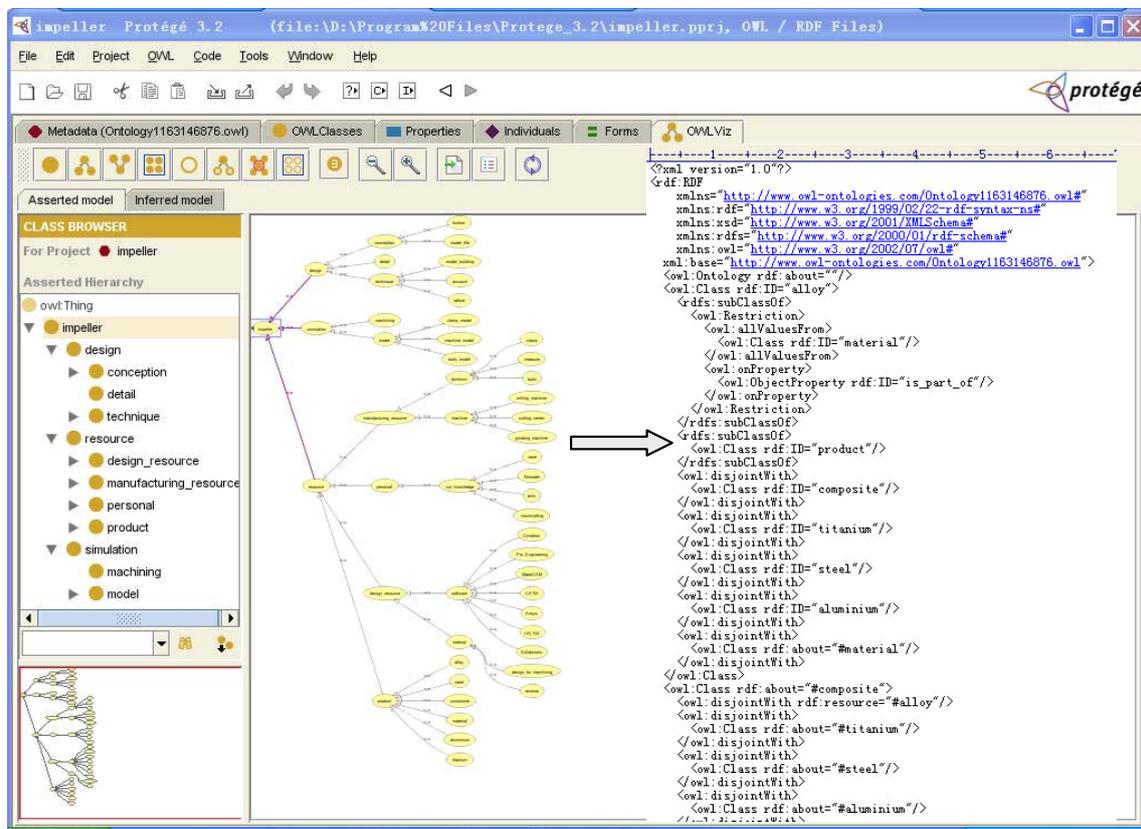


Figure 3. Ontology modeling and OWL description

6. Conclusion

On the basis of analyzing the forms and characteristics of knowledge involved in product development, the architecture of design knowledge is proposed. The design knowledge ontology is defined formally according to the analysis on the knowledge representation methods and Ontology theories. The formal definition of ontology design knowledge is given based on the ontology's basic knowledge, which includes relations and their characteristics. A design knowledge expression strategy is put forward for unstructured, semi-structured and structured knowledge in product design process by using the methods of top-down and bottom-up. The design knowledge ontology model and OWL description of impeller are given by using the

theory of ontology and semantic network. This paper can provide an effective way for realization of access and retrieval design knowledge intelligently during the internal design companies.

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