Design and Implementation for Ontology Modeling of Design Knowledge Based on UML Class Diagram

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Abstract
With the research and development of knowledge management in product design, OWL models and other semantic languages have some problems such as the fuzziness hierarchy, lack of the representation of visualization model, so the modeling of semantic web maybe become the main bottleneck. Now it has become important research direction that applying UML which is the concept modeling language into the modeling of semantic web. This paper proposes the knowledge management model in product design through the UML class diagram. By using the UML modeling method and object-oriented technology the knowledge-oriented task structure model of product design was established through the task structure of product design. And the knowledge-oriented component structure model of product design was established though the component structure of product design and object-oriented design knowledge of design feature. At last, through the simulation of design knowledge ontology that was established and tested for the bicycle product, it shows that using this method can build ontology modeling directly and clearly which also can reduce the complexity of establishment and maintenance of large-scale ontology model, and lay a good foundation for the future research about developing more mature semantic soft.

Keywords: design knowledge, ontology modeling, UML, class diagram

1. Introduction
With the continuous development of manufacture information engineering, it is an inevitable trend that realizes the design data management and the design process management in the domain of product design based on the semantic model. At the same time, implementation of effective knowledge management mechanism in the manufacturing supply chain network is the important ways that could train the competitive advantage of the whole manufacturing supply chain. Therefore, it has the important theoretical and practical value that establishes the semantic model of knowledge application for supporting the collaborative product design (CPD) [1]. Product design, especially variant design, is capable of making rapid response to the variations of market demand by reusing the design experiences and knowledge accumulated in years of design practice [2]. Since product design is a kind of knowledge intensive activities involving multiple knowledge fields, complicated product design tasks are generally divided into a series of relatively simple subtasks or subcomponents through decomposition and integration. This kind of characteristics of product design has laid a good foundation for building the ontology model for CPD based on structural relationship between task and component.

2. Knowledge-Oriented Structure Model of Product Design Task
Being different with common information, design knowledge presents more complex expression ways. This attributes to that the complex correlations in the structure, behavior, and function of design knowledge also are also in a dynamic evolution. Such correlations would be damaged when the static and concentrated methods were used for organization and storage. Moreover, the knowledge in the database is hard to be queried, transformed, and updated due to the information deficiency concerning the background and usage process of the knowledge. Therefore, the product design task-oriented knowledge organization, as well as the
characteristics and attribute information of knowledge unit recorded would facilitate the query and utilization on the knowledge in perspective of design task [3].

The structural model of the knowledge-oriented product design task defines the basic functional structure of the acquisition, description, management, and usage on the information and knowledge of the tasks in design knowledge management. Such task structure model further provides standard description framework for the information and knowledge of task. Figure (1) shows the UML static structure of this model [4].

![Knowledge-oriented structure model of product design task](image)

**Figure 1. Knowledge-oriented structure model of product design task**

### 3. Object-Oriented Design Feature Knowledge

Features are the information set that constitute the expressions concerning the shape, parameters, attributes, and properties of product. It mainly includes shape, accuracy, assembly, material, and performance analysis etc. in content. In accordance with the requirements in different design phases, features are categorized into demand features, design features, manufacturing features, and evaluation features etc. In conceptual phase, as the early embryos of the parts and components composing the product, design features can be used to describe the basic composition of the design product. In conceptual design phase, the structures that are designed for function purpose are mainly analyzed in regard of principle rather than manufacture. Moreover, the design features are extracted to establish corresponding design features database in actual application domain. Design features can be used to describe the basic composition of the design product. In conceptual design phase, the structures that are designed for function purpose are mainly analyzed in regard of principle rather than manufacture. Moreover, the design features are extracted to establish corresponding design features database in actual application domain. Design features show the following features: (1) they are associated with the geometric description of parts; (2) they are designed based on the principle of design; (3) they can be identified and conversed; (4) they show disparate forms and connotation in different engineering activities; (5) they are capable of covering all the requirements in their application domains [7].

Brunetti proposed a feature-based integrated product model, which involved the function model, working principle model, assembly model, component model, feature model,
generalization model [8]. However, this model failed to solve the connection and mapping relationship between models effectively; Jiang et al. redefined the connotation of demand features, design features, manufacturing features etc. [9]. Moreover, he put forward the concept of neutral features and the component structure modeling method based on features and multiple plans; Xia et al. constructed the generalized feature information model by packaging the design knowledge and generalized features [10]. Using this model, the design process was expressed through constructive solid geometry. Wu et al. stated that the relationship between user demand and original understanding could be established by employing design features as functional units [11]. Moreover, the design information could be brought to downstream for application. On these bases, she proposed the design feature-based conceptual design process.

In this study, the design feature model was described using object-oriented technology. In this mode, related knowledge, such as the attributes, dynamic behavior, domain knowledge, and process method of the object, were sealed in a unified object structure to more conveniently abstract the features of design feature and the design knowledge used to comprehensively describing a feature. Figure 2 shows the UML static structure of this model.

In this model:

1. Correlations are classified as the static relationship between objects. It is used to represent the information among objects, such as the position relationship, assembly relationship, and tolerance matching relationship.

2. Attributes refer to various attributes of the design features. It includes two aspects, namely, designing attributes and geometrical attributes.

3. Rules are design rules of the features. They are expressible using traditional {if... then...} production rule set and are represented specifically using a series of design process and design regulations. Design rule is a kind knowledge itself.

4. Methods are the methods operated to the feature object.

![Object-oriented UML view of design feature knowledge](image)

**Figure 2. Object-oriented UML view of design feature knowledge**

### 4. Knowledge-Oriented Structural Model of Product Design Component

The collaborative product development is based on the unified structure model of product design established. The support system of the CPD under distributed environment also calls for the support of complete product design knowledge. On the basis of the object-oriented design feature knowledge and the decomposition structure of product design component, the knowledge-oriented structural model of the component of product design was built. A complete component structure model of product design is a set of the product design structure and also a
reflection of the organization approaches, expression approaches, and correlations of the knowledge related to design feature.

4.1. Top-Level Package: Product

Product is composed of components and parts, components are assembled from parts, while parts are provided with various design features. Therefore, the top-level package of product is defined using an object-oriented method which are constituted by product, component, and part. Component is a subclass of the product, while part is a sub-class of component.

4.2. Top-Level Package: Design Feature

This package is a detailed definition of a series of sub-feature model and corresponding relationships in. It is composed of three subclasses, namely, design feature, feature definition, and feature version. Design features provide a definition on the only global identification feature ID of features; Feature definition is used as supplementary information to define the feature code. Moreover, the hierarchical structural relationship between features is defined by the ID of parent features; Feature version is used to define the different design data with the same feature formed in different phases obtained from different designers.

4.3. Top-Level Package: Design Feature Knowledge

It is formed by the entity objects of design features, such as the dimension, structure, surface roughness, and tolerance of form and position of features. Since this top-level package inherits the object-oriented static structure of the knowledge of design features, the design knowledge correlated with the object in this class are expressed by the knowledge structure of the design features in Figure 3.

Using components and features as basic objects, this model supports the collaborative development support system of products under distributed environments obtaining the product structure information required. Meanwhile, it provides high level knowledge expressions that are in agreement with the human thoughts and reflects the design demand and design features. Thus it lays an important basis for building the ontology model of CPD.

Figure 3. Knowledge-oriented structure model of product design component
5. Results and Analysis

This paper selects the bicycle which is relatively simple manufacturing product for modeling object. Because of the intensifying competition in bicycle industry, the product differentiation and innovation of parts is a very urgent task. It is considered that in the bicycle industry combined with consumers, the development for the consumer demand and interact with the consumers in the process of design can improve the product level and enhance the core competitiveness. The bicycle ontology model of CPD established in this paper is based on the national standard of People’s Republic of China "Classification, Name and Main Terms of Bicycle Parts" (GB/T 3564-93) and "General Technical Conditions of Electric Bicycle" (GB 17761-1999), and the industry standard "Method of Bicycle Naming and Model Compilation" (QB 17714-93).

5.1. Logical Structure of Design Knowledge Ontology of Bicycle

According to the above three standards, the ontology structure of design knowledge for bicycle based on the structure of task and component is shown in Figure 4.

![Logical structure of design knowledge ontology of bicycle](image)

Figure 4. Logical structure of design knowledge ontology of bicycle (Part)

5.2. Query Test of Design Knowledge Ontology of Bicycle

On the basis of design knowledge ontology of bicycle, we define the following query rules (see, Figure 5).
The search result is shown in Figure 6. There is one record matched the query rules exactly. It is an instance of class "electric bicycle". To view the detailed information and knowledge entries contained by this instance is easy by clicking on the instance name. The search result shows that the knowledge ontology model for CPD based on task and component is reasonable and perfect on semantic rules, and is able to provide the full support for the knowledge retrieval, also could lay a good foundation for knowledge reasoning [12-14].

6. Conclusions

The knowledge-oriented task structure model of product design was established though the task structure of product design; the knowledge-oriented components structure model of product design was established though the components structure of product design and object-oriented design knowledge of design feature. According to the above analysis, this paper defines the hierarchical structure of knowledge ontology of CPD and the main relationships among the classes of CPD. At last, this paper selects the bicycle for modeling object and has carried on the simulation test for knowledge ontology model for CPD by using Protégé. The results shows that the ontology model for CPD based on structural relationships between tasks and components is accurate and effective on the syntax rules, also is reasonable and perfect on semantic rules.
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