Research on Method of Product Configuration Design Based on Product Family Ontology Model

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Abstract

In order to meet the design requirements of quick configuration of products for consumers, facing the problems of the poor share and reuse of product configuration knowledge, and inefficient configuration, propose the product configuration design method of product family model based on the forecast of user demands. Build the ontology modeling of product family using the share and reuse of ontology in the semantic and knowledge level; Achieve the dynamic update of product family model using the method of ontology integration; Based on getting the users ' needs, through the map from ontology of user requirements to ontology model of product family, convert customer needs into knowledge of product configuration effectively, then complete the ontology map of user demands, and achieve the conversion from customer requirements to function of product family .Verify the validity of the method through the example of reducer.

Keywords: *Forecast of demand; Ontology model of product family; Ontology mapping; Product configuration design*

1. Introduction

Mass customization is a production mode, which is driven by customer demands. Mass customization has been got more and more value by enterprises in the case of the fierce market competition all over the world[1]. Product family is an important technology in the realization of mass customization. Product configuration is an effective mean, which connects individual customer demand and customized product[2]. According to the statistics, 90% of the product design is variant design or adaptive design, which means most of the design work can reuse the previous product design knowledge. In order to provide customers demand for personalized products In short time, high quality, and low cost, the share and reuse of knowledge of product design is the key factor. Therefore, we can say that modern product design is based on knowledge, centered for knowledge acquisition .Design is materialized through knowledge, and new design is materialized through the new knowledge. The success of design depends on accumulation of corporate design knowledge, and relies on whether can effectively reuse accumulation of corporate design knowledge.

Through the forecast of user demands under the mode of mass customization production, excavate the customer demand of the potential market, and improve the configuration efficiency of product, shorten the time to market. Reference[3] researches on modeling method of product demand structure in product development process, describes a relatively universal information model of product demand, express the relationship of products, product requirements and design activities. Reference [4] gets structure configuration of product through achieving the transformation of customer demands by establishing the product platform. Reference [5] establishes ontology model of product design examples, and proposes retrieval method of product design ontology to respond to customer needs using the Principles of product design of case-based reasoning. Reference[6] proposes the class of product family requirements and templates of demand matching, establishes the model of product configuration of demands based on instance, and product configuration results of customer demand by the method of second-level similarity match. Reference [7-9] propose the method of Solution for configuration problem including method of constraint satisfaction, method based on instance, the method of resource balance and fuzzy reasoning. Reference [10] study on the expression methods of product extended service semantic knowledge based on ontology. Face with the problems including the less researches of dynamic market and customer demand forecasting, the poor versatility of product family model built, the less Consider of the needs of configuration design, and not conducive to the expansion and reuse of knowledge.

This paper research on modeling method of product family based on ontology, transform the customer needs into product configuration knowledge effectively, and establish a product family model of information of product structure, configuration constraint rules, and customer demand. Propose the improvement of the method of ontology mapping, improve the sharing and reuse of level of knowledge and semantic level. Accelerate the process of product configuration, provide products meeting the individual needs quickly.

2. Constructing and Updating Product Family

2.1. Obtaining Forecasting Customer Demand

Obtaining forecasting customer demand which is potential customer demand is a complex process. It is commonly used market survey method to complete. Market survey method is the most direct and effective mean to obtain the information of forecasting customer demand.

Market survey method includes two aspect, they are confirmation of investigation item and implementation way of investigation method. Confirmation of investigation item: market survey item includes demand type, demand weight and the satisfaction of the demand, *et al.*; implementation way of survey method: market survey method includes observational method, inquiry method and experimental method.

The merit of market survey method is that it can obtain potential customer demand information directly and effectively; the shortcoming is that it needs lots of people and high cost.

Market is ever-changing, and customer demands for products are changing constantly too. For this reason, firstly, companies need to keep abreast of the dynamic demands of the market for products, and then obtain forecasting customer demand timely, at last make the new effective demands add to the product family and update product family.

2.2. Constructing Ontology Model of Product Family

Product family ontology can be defined as a 5-tuple:

$$Pont = (Pdom, Pcon, Patt, Pass, Pcas)$$

Where $Pdom$ is product family field, and it consists of conceptual entity, physical property of concept, conceptual relevance and instance set; $Pcon$ expresses conceptual entity; $Patt$ expresses physical property of concept; $Pass$ expresses conceptual relevance, including $sub\text{-}function\ of$, $connection\ of$, *et al.*; $Pcas$ expresses instance set of $Pont$, it can be constructed by product record of enterprise.

Product family includes the functions, which realizes all customer demands, is a collection of similar products; however, each function is composed of different structures, different structures will lead to different function; parts are composed of the smallest unit of product structure, it is important part of function and structure; port is important, which connects different parts, port determines the combination of rule between parts and affects the function and structure ultimately.

As the above, product family can be constructed according to functional layer, structural layer and part layer. Ontology model of product family is shown in Figure 1.

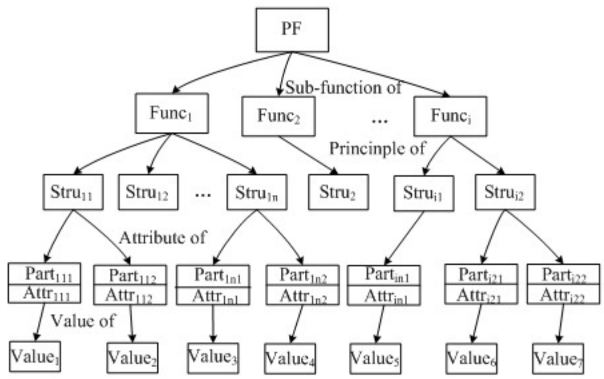

Figure 1. Ontology Model of Product Family

Product family ontology model can be regarded as a concept tree, the node of concept tree represents a concept and arrows represent the relationship between them. So, the product family ontology model can be seen as the product family ontology tree, nodes stand for the knowledge of product configuration.

2.3. Updating Product Family

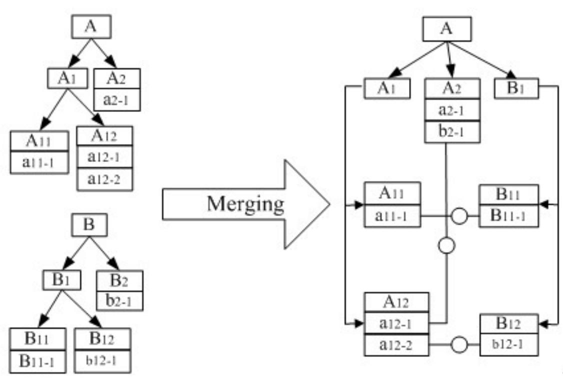

Figure 2. Merger Operation

This paper uses dynamic merger method to update product family. Dynamic merger method is process of adding the new module to the existing product family. This paper makes the new module add to the existing product family structure by ontology merger method, which ensures semantic association of model elements and the integrity constraint. Ontology merger is the basic function of ontology's operating. Firstly, it merges the same concepts, and then constructs the relevance among ontology, finally constructs new ontology model. The specific operation process is shown in Figure 2, which A is original module, B is dynamic demand module.

3. Constructing Ontology Model of Customer Demand

3.1. Identifying Customer Demands

In order to acquire customer demand for enterprises, we can build matter-element model of customer demand, so as to achieve the transformation customer demand into constraints of product configuration efficiently and quickly. So-called matter-element refers to things, characteristic of things and value of characteristic [5]. Given the name of things N , it's value is V about the characteristics of C , so we can use a triple $R=[N,C,V]$ to express a matter-element. If the characteristics of a thing that contains n items, so characteristic of C can be expressed as $C=[C_1,C_2\cdots C_n]$, value of characteristic V can be expressed as $V=[V_1,V_2\cdots V_n]$, thus this matter-element can be expressed as:

$$R=[N,C,V]=\begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \cdots & \cdots \\ & C_{\mathrm{n}} & V_{\mathrm{n}} \end{bmatrix}$$

Using demand matter-element model to divide every demand's category, therefore, it needs to increase demand category-element in customer demand triple, so it can be expressed as: customer demand [Need Name, Need Type, Need Value Type, Need Value].

3.2. Clustering of Customer Demands

Supposing A is collection of customer orders, there are m samples of customer orders, so $A=\{A_1,\ A_2,\cdots A_m\}$, each customer demand haves n demands, therefore $A=\{A_{i1},A_{i2}\cdots A_{in}\}$, A_{ij} expresses customer i 's demands of demand j.

Demand clustering of customer order should realize clustering of demand A_{ij} of every customer orders firstly. For the convenience of clustering, each column demand is similar demand. For example, A_{11} is transmission rate, then the corresponding $A_{21},A_{31}\ldots A_{m1}$ Am1 are needs of transmission rate and each column need can be expressed as: $A_{ijk}=\lfloor x_{ij1} \quad x_{ij2} \quad x_{ijk}\rfloor$, where $k=4$.

Because of the dimension and magnitude of each customer's n demand indexes are different, in order to eliminate influence of different dimension or magnitude for clustering results, before the similarity calculation of demands we can make demand value normalized, which can be make each demand value to unify some numerical value scope. Literature 6 lists five kinds of methods of data normalization, this paper uses logarithmic normalization method: $x_{ijk}{}'=\log(x_{ijk})$。

Establishing fuzzy similar matrix $R=\lfloor r_{ij}\rfloor_{m\times n}$, ri_j expresses similar degree between customer order Ai and A_j ,which is called the similarity coefficient between orders. Because of an order is composed of n items different customer needs, so we can transform the similarity between orders into the similarity between the demands.

Similarity of order A_i and order A_j :

$$r_{ij} = \sum w_j sim(A_{ij}, A_{jj}) / \sum w_j \tag{1}$$

Where w_j is importance of demand j, $\sum w_j = 1$. $sim(A_{ij}, A_{jj})$ is the similarity of demand attribute. According to the expression of demand we can know that the similarity of $sim(A_{ij}, A_{jj})$'s calculation of any two demands is composed of four parts ,they are similarity of need type s_1, similarity of need name s_2, similarity of need value type s_3 and similarity of need value s_4,namely $sim(A_{ij}, A_{jj}) = \sum_{k=1}^{4} w_k s_k / \sum_{k=1}^{4} w_k$,among which we can suppose $w_1 = w_2 = w_3 = w_4 = 0.25$;where need type is the same with need value , coefficient of similarity is 1,when they are different ,coefficient of similarity is 0.

3.3. Constructing Customer Demand Ontology Model

Customer demand ontology can be defined as a 5-tuple: $Cont = (Cdom, Ccon, Catt, Cass, Cin)$.

Where, $Cdom$ is customer demand field, and it consists of conceptual entity, physical property of concept and conceptual relevance; $Ccon$ expresses conceptual entity; $Catt$ expresses physical property of concept; $Cass$ expresses conceptual relevance, including *is a* , *component of* , instance of and *attribute of* , *et al.*; Cin expresses instance set of $Cont$.

Customer demand type includes functional demand, performance demand, structural demand, economical demand, reliability demand and repair demand, so $Cdo = (F, S, P, E, \mathrm{Re}, R)$, each customer demand field is described as follows:

Functional demand field F: functional demand is that customer requests the demand of functional aspect, for example, transmission capacity, adaptation capacity and carrying capacity, *et al.*; structural demand field S: structural demand includes product appearance size and tightness, *et al.*; performance demand field P: performance demand is physical properties and usability of the product, for example, quality, weight and material of product; economical demand field E: economical demand includes the price of product; reliability demand field Re: reliability demand is trouble-free, safety, durability and useful life of product; repair demand field R: repair demand is that the product is convenient to be repaired.

Therefore, ontology model of customer demand is constructed as shown in Figure 3. In this figure, the concept composition and relationship of customer demand ontology is described, a semantic network model of customer demand is constructed.

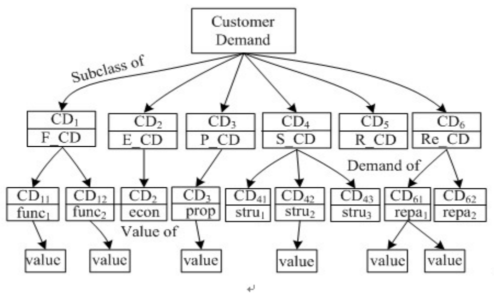

Figure 3. Ontology Model of Customer Demand

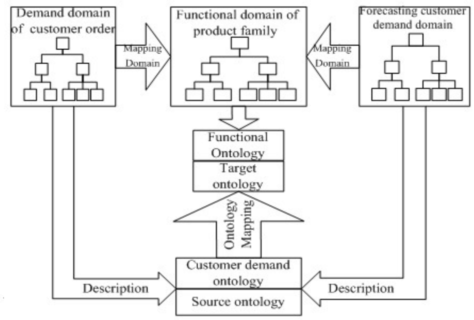

Figure 4. Mapping Framework

4. Product Configuration Process

4.1. Ontology Mapping Framework of Customer Demand

In mass customization, the character of enterprise is rapid acquisition of product configuration model and meets the personalized customer demand. Constructing product family which orient to forecasting demand can make enterprise see the dynamic change of customer and market, and as well as timely extend and update the product configuration model and product family cases. Customer demand mapping based on ontology should complete the two aspects of functional mapping. Mapping framework is shown in Figure 4.

The mapping process is from forecasting demand ontology model to product family ontology model. This process is to construct configuration model of product family which expresses a configuration product family. The purpose of constructing product family is to provide product configuration model of for customer.

The mapping process is from order customer demand model to product family ontology model. Customer demand is proposed on the form of order in MC. Because of the difference and personalized of customer demand, there is an effective method that meets customer demand by product family configuration. In order to increase the configuration speed, sharing product platform is obtained quickly after customer orders cluster. This paper constructs the mapping from customer demand model to product family ontology model by applying the generalization and modularization of product family.

4.2. Similarity calculation

The mapping representation form of customer demand ontology $Cont$ and product family ontology Pont is as following: $Map : Cont \rightarrow Pont$.

If $Sim(Con_i, Pon_j) > S$, then $Map(Con_i) \rightarrow Pon_j$. The calculation formula of Sim is:

$$Sim(Con_i, Pon_j) = \frac{P(Con_i \cap Pon_j)}{P(Con_i \cup Pon_j)} = \frac{P(Con_i, Pon_j)}{P(Con_i, Pon_j) + P(Con_i, \overline{Pon_j}) + P(\overline{Con_i}, Pon_j)} \quad (2)$$

$Sim(Con_i, Pon_j) \in [0,1]$. 0 represents two concepts are independent completely and 1 represents two concepts are similar perfectly.

Three probabilities about similarity computation of concept based on example are as follow: $P(Con_i, Pon_j)$、$P(Con_i, \overline{Pon_j})$、$P(\overline{Con}, Pon_j)$. S represents similarity threshold and carries out setting by the needed strength of enterprise, $S \in [0,1]$. It means that the value of S is high when customer requirement reaches high satisfaction.

4.3. Mapping Rules

Mapping rules of Con and Pon are as follows:

Rule one: direct mapping. Concept entity is the core of ontology, one-to-one relation (1:1) exits between Con and Pon, namely one function can meet one kind of customer demand.

Rule two: conjugate mapping. Many-to-many relation (m: n) exits between Con and Pon, namely many functions can meet many kinds of customer demand.

Rule three: indirect mapping. Con and Pon may not exist the direct mapping relationship;

Rule four: empty mapping. Con and Pon may not exist the mapping relationship, which is that function can not meet customer demand.

5. Analyzing Example

This paper takes reducer product family as an example. Forecasting customer demand is carried out according to market, the possible customer demands are as shown in Figure 5. Product family structure tree of reducer are as shown in Figure 6. Customer demand and product family functional requirement of reducer are as shown in Table 1 and Table 2.

Customer demand ontology and functional requirement ontology are established respectively. Two kinds of ontology mapping processes are as follows:

Extracting the characteristic of similarity; we take the concept and example as the computation object. The characteristic of customer demand ontology domain is shown in Table 3. The characteristic of product family functional domain is shown in Table 4.

Customer demand item	Demand value
Input demand	Input speed: n≥1000r/min
	Input power: 20KW
Transmission demand	Transmission ratio: i=20
	Max torque: T≤320KNm
Output demand	Transmission efficiency：η=0.9
Aided demand	Working place：elevator
	Working time: 16h/d

Figure 5. Forecasting Customer Demand

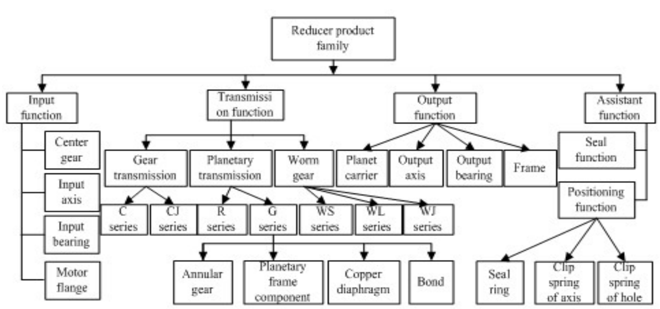

Figure 6. Product Family Structure Tree of Reducer

Table 1. List of Customer Demands

Customer demand C	Parameter C values	Value of description
OutputSpeed $Con_1(C_1)$	C_{11} C_{12} C_{13}	2-8r/min 8-80r/min 80-350r/min
Output torque $Con_2(C_2)$	C_{21} C_{22} C_{23} C_{24}	8-120N.M 120-900N.M 900-4500N.M 4500-8000N.M
Reduction ratio $Con_3(C_3)$	C_{31} C_{32} C_{33}	2.4-8 8-110 110-300
Working load type $Con_4(C_4)$	C_{41} C_{42} C_{43} C_{44}	Generators Pumps Plastics Machinery
Price $Con_5(C_5)$	C_{51} C_{52} C_{53}	<3500yuan 3500-8200yuan 8200-12000 yuan

Table 2. List of Functional Requirement

Functional requirements F	Values of parameter F	Description of values
Power of motor $Pon_1(F_1)$	F_{11} F_{12} F_{13}	Less than 1KW 1-8KW 8-120KW
Output shaft size Pon_2 (F_2)	F_{21} F_{22} F_{23}	620-880mm 880-3500mm 3500-12000mm
Carrying capacity $Pon_3(F_3)$	F_{31} F_{32} F_{33} F_{34}	4-90N.M 90-860N.M 860-4500N.M 4500-9200N.M
Size of input shaft $Pon_4(F_4)$	F_{41} F_{42} F_{43}	180-480mm 480-600mm 600-750mm
Transmission type $Pon_5(F_5)$	F_{51} F_{52} F_{53} F_{54}	Cycloid pinwheel Turbine/Worm Planet Gear speed reducer

We seek for the concept couple, and calculate the similarity of concept Con_x and Pon_y, and obtain the semantic similar concept couple.

We obtained Table 5 calculation results according to the similarity calculation equation.

According to the above concept similarity, we determine corresponding relationship between the concept of customer demand domain ontology and product family functional domain ontology, that is the mapping relation R from matrix C to P. We may set the higher similarity Sim threshold value according to customer demand, we set threshold value $Sim = 0.66$. If similarity is greater than 0.66, there is corresponding relationships, $r_{xy} = T$ or $r_{xy} = 0$, the mapping relations matrix is as follows:

$$R = \begin{array}{c} \\ \\ \\ \\ \end{array}\begin{array}{ccccc} Con_1 & Con_2 & Con_3 & Con_4 & Con_5 \end{array}$$

$$R = \begin{bmatrix} T & T & 0 & 0 & T \\ 0 & 0 & T & 0 & 0 \\ T & T & 0 & 0 & 0 \\ T & 0 & 0 & T & T \end{bmatrix} \begin{matrix} Pon_1 \\ Pon_2 \\ Pon_3 \\ Pon_4 \end{matrix}$$

From the above mapping result we can see that output torque Con_1 is mapped to motor power Pon_1, carrying capacity Pon_3 and transmission type Pon_5, output speed Con_2 is mapped to motor power Pon_1 ,carrying capacity Pon_3 and the size of input axis Pon_4, reduction ratio Con_3 is mapped to the size of output axis Pon_2, working load Con_4 is mapped to the size of intput axis Pon_4 and transmission type Pon_5 ,price Con_5 is mapped to the size of intput axis Pon_4 and transmission type Pon_5.

Table 3. Characteristic of Customer Demand

Property	Notion				
	Con_2	Con_3	Con_1	…	Con_4
Trading codes	1	5	5	…	50
Product codes	P_6	P_8	P_{19}	…	P_{30}
Parameter C	C_{22}	C_{32}	C_{12}	…	C_{42}

Table 4. Characteristic of Product Family

Property	Notion				
	Pon_1	Pon_2	Pon_4	..	Pon_5
Trading codes	2	7	8	…	15
Product codes	P_2	P_5	P_{20}	…	P_9
Parameter F	F_{21}	F_{22}	F_{42}	…	F_{51}

Table 5. Result of Similarity Calculation

Similarity		Functional requirement				
		Pon_1	Pon_2	Pon_3	Pon_4	Pon_5
CD	Con_1	0.69	0.89	0.50	0.61	0.82
	Con_2	0.40	0.45	0.79	0.60	0.62
	Con_3	0.75	0.88	0.59	0.62	0.41
	Con_4	0.55	0.68	0.58	0.72	0.65
	Con_5	0.68	0.38	0.63	0.76	0.72

6. Conclusion

From the perspective of knowledge sharing and reuse, establish model of product family and mapping framework of product family ontology , which face forecast of user demands and can be dynamically updated. On the basis of mapping rules established, set a threshold of satisfaction of user needs, and achieve the mapping process of ontology entities taking similarity computation of concept ontology. By the example of products of reducer, through the analysis of the individual needs of users, achieve the mapping of the domain of customer demand and the domain of product family function, low diversification of user needs and improve the efficiency of product configuration

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References

[1] M. Comstock, K. Johansen and M. Winroth, “From mass production to mass customization: enabling perspectives from the Swedish mobile telephone industry”, J. Production Planning & Control, vol. 15, no. 4, **(2004)**, pp. 362-372.

[2] B. J. Pine, “Mass customization: the new imperative”, J. Strategic Direction, vol. 20, no. 1, **(2004)**, pp. 2-3.

[3] H. Zhao, L. Y. Zhu and D. M. Qian, "Research on Customer Requirements Processing of Mass Customization", J. Journal of Engineering Graphics, vol. 5, **(2008)**, pp. 44-48.
[4] F. Zhang, Z. N. Chen and X. G. Yan, "Study of product configuration design in mass customization", J. Huazhong Univ. of Sci. & Tech. (Nature Science Edition), vol. 33, no. 2, **(2005)**, pp. 99-102.
[5] Y. Jiang and B. Dan, "Mapping of customer need based on ontology in mass customization", J. Industrial Engineering, vol. 12, no. 4, **(2009)**, pp. 19-23.
[6] B. Dan, L. Yao, Y. G. Jing and J. P. Wang, "Methods of product configuration based on ontology model of product family case", J. Computer Integrated Manufacturing Systems, vol. 15, no. 4, **(2009)**, pp. 645-651.
[7] H. J. Lee and J. K. Lee, "An Effective Customization Procedure with Configurable Standard Models", J. Decision Support Systems, vol. 1, no. 4, **(2005)**.
[8] D. Yang, M. Dong and R. Miao, "Development of A Product Configuration System with an Ontology-Based Approach", J. Computer-Aided Design, vol. 8, no. 40, **(2008)**.
[9] H. Tsai and S. Hsiao, "Evaluation of Alternatives for Product Customization Using Fuzzy Logic", J. Information Sciences, vol. 15, no. 8, **(2004)**.
[10] J. Shen, L. Y. Wang and Y. W. Sun, "An ontology-based approach to product extension services modeling in servitisation", J. International Journal of Services Operations and Informatics, vol. 4, no. 5, **(2010)**.