A method for determining the key structure of 3D parts based on rough set and concept lattice

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Abstract: - The key of parts model retrieval is how to complete the similarity calculation as quickly and accurately as possible. The similarity calculation is closely related to the model feature extraction. Concept lattice is a powerful tool in knowledge processing and analyzing, its reduction can improve the efficiency. In this paper, by mapping relationships among the parts functional surfaces and the positions to the binary formal context, a concept lattice of 3D parts structure model was built, authors use discernibility matrix of rough set in simplifying the concept lattice of formal context based on parts assemble structure, and then quickly determine the key structure to reflect the characteristics of the parts, which has very strong regularity and lays the basis for the efficient parts query.

Key-Words: - Mechanical parts assembly structure; Concept lattice; Discernibility matrix; 3D parts key structure；Rough set；Simplifying

1 Introduction

The parts 3D model retrieval technology based on structure is started from parts 3D data, and it utilizes the algorithm to automatically extract the characteristics of structure's appearance from the model, and uses a compact data structure (feature descriptor) to express the characteristics. Extracting feature descriptor is the core part of the 3D model retrieval system. General process of 3D model retrieval is: first to extract the characteristics of the model, and then through the comparison of characteristics and matching to complete retrieval. According to the different extracted features, 3D model's retrieval method mainly includes: the method of global characteristics. Using transform function such as Fourier, spherical harmonic and others to extract global geometric feature vector of the model profile; The method of statistical characteristics .Sampling on the surface of the model, extracting probability distribution of distance and angle between random points; The method of topological

characteristics. By Reeb figure or skeleton diagram [1-5], expressing the connected relationship between different parts of model.

These methods mainly focus on the research of model's geometry similarity, and complete the retrieval of similar model by matching shapes. However, 3D models of mechanical parts not only have geometry information but also have function information, and according to different load function, the part surfaces can be divided into the joint surface and function surface and the non-working face. The function surfaces have the dual nature of functional and structural. The function surface directly reflect the basic function of the parts from the perspective of function; the function surfaces are the minimum modelling units to realize the basic function of parts from the perspective of geometry, these function surfaces and their spatial layout determine the physical structure of the parts function. Therefore, in the process of retrieving the similar parts, the non-working faces of parts can be put aside and we can only use function surface and their mutual relation to evaluate the similarity feature of parts. The

model of parts composed of function surface and their mutual relationship does not affect the expression of assembly relations, and it is an abstract description for parts on assembly level, which is called the assembly structure of parts. The method that matching retrieval similar parts by assembling structure considers the similar of shape and function, and it is conducive to innovation design for product. Its shortcoming is in dealing with complicated and a lot of engineering drawings, one by one contrast can cause time-consuming and inefficient.

Concept lattice is also called the formal concept analysis, it is proposed by the German professor Rudolf Wille. It has a wide range of applications such as the analysis of concept data, the processing or classifying on concept knowledge and the determination on object in a given attributes set. Rough set theory is a kind of mathematical methods of dealing with problem such as fuzzy, imprecise or incomplete and etc. It gives the formal definition of knowledge and provides a series of tools to process knowledge by using set algebra. the method of general concept lattice in structure of the data pretreatment will cause large-redundancy extracting rules, and this redundancy in the actual database maybe have dozens or even hundreds dimensional attributes, therefore simplifying attributes in structuring the concept lattice becomes an important work in extracting rules based on concept lattice.

This paper proposes a method to determine the key structure based on rough set and concept lattice. By mapping the relationship among the parts surface function and the position to the binary formal context, a concept lattice of 3D parts structure model is built, The discernibility matrix of rough set is used in simplifying attributes of concept lattice, which can effectively reduce the computational complexity of concept lattice to determine key structure reflecting the core relationship.

2 The structure model of 3D parts assembly

Dong Yan [6] puts forward a retrieval method of similar parts engineering drawing based on 3D part assembly structure. This method will mark the geometry features of parts engineering drawing as the function surface, and determine whether the function surface is topology connected according to common edge, concurrent, or point on the edge, and further determine the positional relationship of the function surface, then generate parts structure model of 2D. Through the constraint definition "and" operation of public vertex and edge for the view structure model, the 3D structure model of parts is built.

In function surface view, uppercase P, C, H and S respectively express plane, cylinder, hole and slot, lowercase w, k, h and r respectively express threaded connection, flat key links, half surface of revolution and ring structure. Fig.1 has a few common parts and their function surface views.
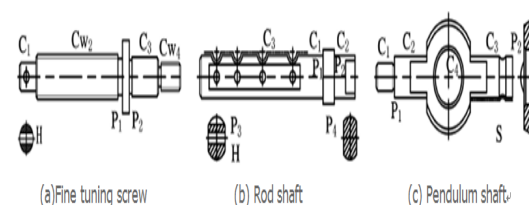

Fig.1. some common parts and their function surface views

Function surface topology relation is represented through the concave and convex feature of connection edge, concave side is marked "0", and convex is marked "1". If both connected function surface are surface of revolution, topology relationship will be defined by whether the surface of revolution is inner surface or outer surface, and will be marked "!". The engineering drawing of parts judges a function surface whether is topology connection by three conditions, which are i common edge, concurrent, or point on the edge.

The positional relationship of function surface includes orientation relationship and domain. Orientation relationship is defined by the space position relation of position vector with parallel (//), coaxial ($\odot$), vertical ($\perp$) and deflection ($\angle$);Domain relationship refers the relationship between the space area occupied by the function surface, the kinds of domain relationship is associated with the type of orientation relationship, some knowledge of binary

relations can be consulted in the literature [6].Because the length of the area occupied by flat function surface is zero, so the meet, overlap, concurrent relation between the rotary surface and the flat surface is merged to meet. Two vertical flats aren't defined binary domain relationship and marked "!". Symbol "! #" indicates that two function surfaces are topology connection, while the symbol "#" indicates no topology connection. Symbol "?" indicates that the positional relationship between the function surface cannot be determined by a single view.

Marking the function surface of the parts engineering drawing, and then according to the geometry conditions of judging the topology connection of function surface, the method to determine the relationship of location between the function surface and the definition of distribution relationship, we can get the engineering drawing of parts structure model [6].Fig.2 is the engineering structure model drawing of Fig.1.
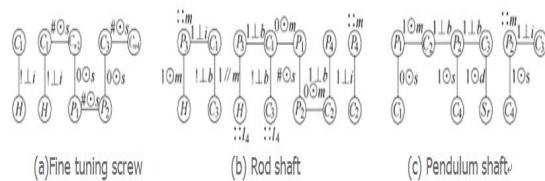

Fig.2. engineering structure model drawing

3 Concept lattice based on the assembly structure model

Definition 1 a formal context, K :=(G, M, I),constitutes set G,M and the relationship I between them ,the elements of G are called objects, the elements of M are called attributes. To express an object g and an attributes m, we write gIm or (g,m)∈ I,that is to say object g has attribute m.

Definition 2 a formal concept(A,B)of a formal context(G,M,I) ,A⊆G,B⊆M,A'=B and B'=A.A is called the epitaxial of concept(A,B),B is the connotation of concept(A,B). And in it:

$$A' = \{m \in M | \text{all } g \text{ in } gIm, g \in A\}、\ B' = \{g \in G | \text{all } m \text{ in } gIm, m \in M\}$$

Definition 3 if (A1, B1) and (A2, B2) are two concepts of one context. If $A_1 \subseteq A_2$(equale to $B_2 \subseteq B_1$), then (A1, B1) is called sub-concept of (A2, B2), (A2, B2) is

called sup-concept of (A1, B1), marked $(A_1, B_1) \leq (A_2, B_2)$.the relationship "≤" is called hierarchical sequence or simple sequence. All formal concept collections of (G, M, I) structured by this method are called concept lattice of (G, M, I).

The mainly parts of parts assembly structure model are function surface and the position relations. According to the features of formal concept analysis, we can build the formal context of parts engineering drawing structure, and then build the concept lattice of parts engineering drawing [7].

The function surface and its relation of the parts engineering drawing structure model can be expressed by their arrived in each other, Set SourceSurface, Relation and TargetSurface are three components in G of PG (Part Graph) , and they are respectively shown with g.source, g.relation and g.target. I is a set (Object, Attribute) structuring the formal context, there is

$$g \in G \Rightarrow (g.\,target, g.\,source \sim g.\,relation) \in I$$

Mapping is a concept transfer that the relationship goals of PG can become a source CG (Concept Graph) of another relationship. The transfer can produce an inference of implicit mapping:

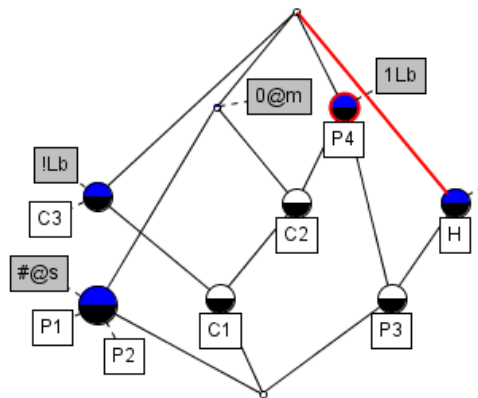$$\forall g_1, g_2 \in G \cdot g_1.\,target = g_2.\,source \Rightarrow (g_2.\,target, g_1.\,source \sim g_1.\,relation) \in I$$

Fig.3 is formal context and concept lattice corresponding to Fig.2.

	!Li	#@s	0@s
P1		X	X
P2		X	X
C1	X	X	
C3		X	X
Cw2		X	X
Cw4		X	
H	X		
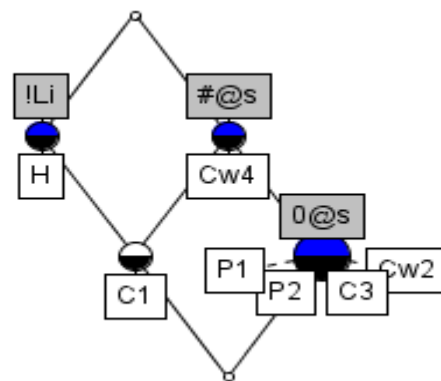
(a) trimmer screw

	!Lb	1Lb	0@m	#@s	l//m
C1	X	X	X		
C2		X	X		
C3	X				
H					
P1				X	X
P2				X	X
P3		X			
P4		X			

(b) pull rod shaft

	1Lb	0@s	1@s	l@m	1@d
C1		X			
C2	X				X
C3	X				X
C4			X		
P1		X			X
P2	X		X		
Sr					X
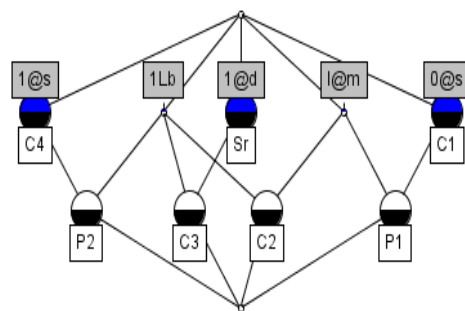
(c) pendulum shaft

*Fig.3. the formal context and concept lattice
corresponding to Fig.2.*

4 The determination arithmetic for discernibility matrix and key structure of assembly structure model background

Discernibility matrix (distinct matrix) is put forward by professor Skowron. It is mainly applied to knowledge acquisition in information table, a knowledge representation system S of an information table, can be expressed as S=<U、R、V、f>.U is a collection of objects, r=C∪D is a collection of attributives. C, D are respectively called condition attributes set and result attributes set, $V = \bigcup_{r \in R} V_r$ is a collection of attribute values, V_r is the attribute value range of attribute r∈ R, just the range value of attributes r. f: U× R → V *i*s an information function, it specifies the attribute value of every object x in U.

Definition 4 to formal context K:=(G,M,I),G={X_1,X_2,…, x_n}，$a_i(x_j)$ is the value(0 or 1) of object x_j in attribute a_i. $C_n(i,j)$ is the element of row i and column j in discernibility matrix ,then discernibility matrix C_n is defined: $Cn(i,j) = \{a_k | a_k \in M \wedge a_k(x_i) \neq a_k(x_j)\}$,in it i,j=1,…， n.

The determination arithmetic for key structure based on discernibility matrix and logical operation

(1) Calculate the discernibility matrix C_n of context ;

(2) Set up a corresponding disjunction logic expressions L_n for all elements $C_n(C_n \neq 0, C_n \neq \emptyset)$ withthe values not empty collection in the discernibility matrix,
$$L_n = \bigvee_{a_i \in C_n} a_i;$$

(3) Put all the disjunction logic expressions into conjunction operation, get a conjunctive normal formula ,just
$$L = \bigwedge_{C_n \neq 0, C_n \neq \emptyset} L_n;$$

(4) Convert conjunctive normal form to disjunctive normal form ,get L'=$\bigvee_i L_i$;

(5) Output the result of attribute reduction.

According to the conclusion of while, in fact the conjunction of the conjunctive normal form should be unique.

5 Examples

Using pull rod shaft as an example to calculate the key structure based on discernibility matrix algorithm. Set a=!⊥b, b=1⊥b, c=0@m,d=#@s,e=1//m.

（1） Calculate the discernibility matrix C_D=

$$\begin{pmatrix} 0 & a & bc & abce & cde & abd & ace & ac \\ & 0 & abc & ae & acd & acd & abe & ae \\ & & 0 & ae & acd & acd & abe & ab \\ & & & 0 & cde & cde & b & be \\ & & & & 0 & 0 & bcde & bcd \\ & & & & & 0 & bcde & bcd \\ & & & & & & 0 & e \\ & & & & & & & 0 \end{pmatrix}$$

（2） Establish a disjunction logic expressions:

$L_{1,2}=a$, $L_{1,3}=b\vee c$, $L_{1,4}=a\vee b\vee c\vee e$, $L_{1,5}=c\vee d\vee e$, $L_{1,6}=a\vee b\vee d$, $L_{1,7}=a\vee c\vee e$, $L_{1,8}=a\vee c$,

$L_{2,3}=a\vee b\vee c$, $L_{2,4}=a\vee e$, $L_{2,5}=a\vee c\vee d$, $L_{2,6}=a\vee c\vee d$, $L_{2,7}=a\vee b\vee e$, $L_{2,8}=a\vee e$,

$L_{3,4}=a\vee e$, $L_{3,5}=a\vee c\vee d$, $L_{3,6}=a\vee c\vee d$, $L_{3,7}=a\vee b\vee e$, $L_{3,8}=a\vee b$,

$L_{4,5}=c\vee d\vee e$, $L_{4,6}=c\vee d\vee e$, $L_{4,7}=b$, $L_{4,8}=b\vee e$,

$L_{5,7}=b\vee c\vee d\vee e$, $L_{5,8}=b\vee c\vee d$,

$L_{6,7}=b\vee c\vee d\vee e$, $L_{6,8}=b\vee c\vee d$,

$L_{7,8}=e$,

（3） Get the conjunctive normal form and merge reduction

$L=L_{1,2}\wedge L_{1,3}\wedge L_{1,4}\wedge L_{1,5}\wedge L_{1,6}\wedge L_{1,7}$ $\wedge L_{1,8}\wedge L_{2,3}\wedge L_{2,4}\wedge L_{2,5}\wedge L_{2,6}\wedge L_{2,7}\wedge$ $L_{2,8}\wedge L_{3,4}\wedge L_{3,5}\wedge L_{3,6}\wedge L_{3,7}\wedge L_{3,8}\wedge L_{4,}\wedge L_{4,6}\wedge L_{4,7}\wedge L_{4,8}\wedge L_{5,7}\wedge L_{5,8}\wedge L_{6,7}$ $\wedge L_{6,8}\wedge L_{7,8}\wedge L_{1,2}$

$=a\wedge b\wedge e$

The context and concept lattice after been reduced are shown in Fig.4.

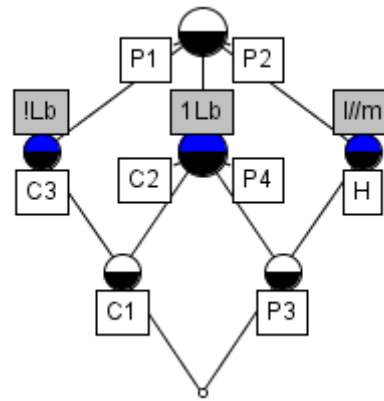|	!Lb	1Lb	l//m
C1		X	X
C2		X	
C3		X	
H C2			X
P1			
P2			
P3		X	X
P4		X	

Fig.4. the context and concept lattice after been reduced

It's easy to see the structure nodes by 10 reduced to 6, removal the top and down nodes with no practical significance, structure nodes also by 8 reduced to 5, these five nodes can be thought as the key structure of original model.

6 Conclusions

Modeling method based on the key structure can solve the problem of repeatability machining of typical parts and improve the production efficiency. At present, most of the parts 3D model retrieval is oriented the overall features of model, so only in the overall level to a relatively rough comparison, which could not find the similarity of local details characteristic, but this need is especially important in some professional field model retrieval. For parts model in the field of CAD, designers not only require the similar of overall appearance, more demand the match of local characteristics, only arrived to local features retrieval can achieve the purpose of reference and design model.

This paper puts forward a modeling technology and a determination method of key structure. We select the existing functional structure of parts, and use the form context of assembly structure model to establish the form concept, through the method of rough set to simplify attribute to determine the key structure reflecting the local characteristics, this method can accelerate to retrieve out parts with chosen typical structure. But some parts shape are very complicated, which makes the decomposition is difficult, and after the

decomposition the complete of the shape may be destroyed, therefore to make this method has a wider range of adaptability, we still need further more in-depth research.

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