Unitized Association Design Based on Structural Feature Analysis

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Abstract. Structural association design is an very important aspect in modern design. In order to realize change propagation effectively, the product association features and geometric features are analyzed, and the association rules are formulated according to the association strength. The associated directed network model as well as its simplifying rules is given. The termination rules are designed for the optimally selecting of the change propagation path. Finally, the feature segmentation change technology and the associated driving change design method are used to complete the product structural change propagation design.

1. Introduction

Structural association design is an efficient design method. When a structure changes or replaces, the structure associated with it changes correspondingly. many scholars have done a lot of research on it. Kima [1] used structural analysis techniques and a unified modeling language to complete the construction of structural association models in the product design process. Huang Boyuan [2] used the shape description and structural layout as the top-down design basic model, and established the product structure correlation model. Qian Qiankun [3] proposed the product form and structure correlation design, and the structure design aims to show the product form. VANBEET [4] establishes a method for calculating the correlation strength of matrix elements by modeling the functional behavior state of products. Ding Liping [5] based on product characteristics subdivide the related factors and attached weights, using the method of calculating the weighted average method to develop the product association design matrix. Yang Fan [6] analyzed the relationship between engineering changes and product characteristics, and developed a change propagation path search method based on the associated network model.

Since the structural variation design only involves changes in local structural parameters, it has great limitations [7]. In practical design, the change of topological relationship between structures is also required which has great influence on design result, so it needs to be studied in depth.

2. Associated directed graph basic information

2.1. Basic information of associate directed graph

Structural features consist of multiple geometric features with topological relationships. Due to factors such as the different of the functional unit or part model and the different process, the geometry of each part inside the unit is different, but the geometric features are similar. As shown in tab.1.
Table 1. Common geometric features.

| Geometric Features | Subdivision geometry | Figure |
|--------------------|----------------------|--------|
| plane              |                      |        |
| curved surface     |                      |        |
| cylinder           |                      |        |
| cone               |                      |        |
| sphere             |                      |        |
| gear face          |                      |        |
| composite face     |                      |        |
| thread surface     |                      |        |

To analyze an assembly model in a three-dimensional environment, it is first necessary to extract the constraint relationships in the model and the attribute information contained in the constraint relationship, based on which the associated geometry and feature information model can be built. Its relational expression is:

\[ G=(H_k,Q_{(i,j)},W_{(i,j)},L_{(i,j)}) \]  

(1)

Here, \( H \) is the assembly information matrix, and \( k \) is the functional unit number. Where \( T_{(i,j)}=(Q_{(i,j)},W_{(i,j)},L_{(i,j)}) \), \( T \) is the associated attribute, \( i,j \) are part numbers, \( Q_{(i,j)} \) is a mating feature matrix between two part. \( W \) is a structural feature of participation constraints. \( L \) is the main geometric feature corresponding to the structural features.

2.2. Formulation of correlation strength

The correlation strength is the degree of interaction between features, which is affected by many factors. For the purpose of calculating the correlation strength, the correlation index and its application criterion are formulated. And fuzzy value of associated strength are given including associated strength based on number of mateches, and associated strength based on formula constraints as shown in tab.2. Here, \( x_1 \) means number of fits, the more the number of matches, the higher correlation strength is. \( x_2 \) means formula constraint, it is determined by whether relationship between dimensions is calculated by formulas. When there is a formula constraint, it can be represented by "have" or by the number "1"; if not, it is represented by "no" or "0". \( y \) means the associated strength level.

Table 2. Basic associated strength.

| Number of matches \( x_1 \) | Strength level \( y_{1i} \) | Formula constraints \( x_2 \) | Strength level \( y_{2j} \) |
|-----------------------------|-----------------------------|-------------------------------|-----------------------------|
| 1                           | 0.5                         | have (1)                      | 1                           |
| 2                           | 0.7                         | no (0)                        | 0                           |
| 3                           | 1                           |                               |                             |

3. Construction of association model based on directed graph

3.1. Construction of association directed graph

The associated directed network model expresses the association between parts based on which the associated path can be built, as shown figure.1. The specific construction steps are as follows:
(1) Unit modeling of assembly model. The assembly is divided into functional units according to functions, and the directed graph of each unit is constructed.

(2) Construction of intra-unit associations according to the mating feature matrix Q. When there are matching features between two parts, there is a line connecting them. The direction of the directed line is determined according to the order of assembly. As shown in figure. 1, the line between \( P_1 \) and \( P_2 \), means \( P_1 \) is assemble before \( P_2 \) during assembling process.

(3) According to the matching feature matrix Q, the parts with the matching features between the functional units are retrieved, the association between the functional units is constructed, and the directed line representation is used; Then the associated attribute \( T_{(i,j)} \) and intensity level \( y_{(i,j)} \) are added to the corresponding directed line. In this way, all functional units are traversed to complete the construction of the relationship between the units.

### Figure 1. Extended associated directed network model.

#### 3.2. Structure simplification of associated directed graph

The above mentioned association directed graph is complex and hard to tackle. So, structure is association network model is simplified step by step. The unit base component is used as the search starting point, and the one-way search is performed along the associated directed line until all levels of the unit are simplified. The unit 3 in the associated network model illustrated in figure. 1 is used as an example, the simplified result is shown in figure. 2.

### Figure 2. Simplification of the associated directed network model.

### 4. Structural association propagation analysis

#### 4.1. Structure-related propagation rules

In order to analysis of the transmission more efficiently, the propagation termination rules and the transmission direction rules are given, based on which the direction of transmission and the propagation path have been established.
1. Termination rules. Termination rules are given based on association strength, association constraints and external cause. The rules are as follows:

(1) Correlation strength rule association constraints rule. If the association strength is less than 0.5 the association delivery is terminated.

(2) Association constraints rule. If the association strength is more than 0.5, the association strength transmission is satisfied. Then the associated attribute is verified. If the change of the structure does not cause a contradiction or conflict between the associated parts, the association is terminated.

(3) External cause rules. The external cause mentioned here are standard restrictions, space limitations, and user requirements. If those external cause are not conflict with each other. Then the delivery is not interrupted.

2. Determination of propagation direction. According to the location of the changed part in the simplified associated model, two types of propagation can be occurred.

(1) When the changed part or unit is at the start on end point of the directed graph model, the direction of the transfer is one-way.

(2) When the changed part or unit is in the middle of the simplified model, the direction of transmission is two-way.

3. Choose path. To reduce the complexity of the change propagation, the shortest principle is used to the selecting of the association path. When the associated attribute requirement can’t be met, the other path is selected and transferred according to the delivery rule.

According to the above method, the change is made in the association model to complete the associated variant design of the product.

4.2. Association propagation analysis

Based on the simplified associated directed network model, association propagation can be performed as follows:

(1) Search for the in-cell associated path containing the changed part and sort it from small to large according to the number of included parts.

(2) The transmission is started from the shortest path, then the direction can be determined.

(3) Execute the transmission according to the direction of transmission and judge whether the transmission is terminated according to the termination rule.

(4) The transmission does not satisfy the termination condition and enters the structural association drive variant design.

According to the above structure association transfer method, the intra-unit association transfer process is established. As shown in figure 3.

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**Figure 3.** Structural association changes are passed in the simplified model within the unit.
5. Equations and mathematics
Additions or changes in performance, metrics and functionality sometimes cause structural changes, and due to the association between the parts, the structural changes cause a chain change in the associated structure in the associated part. When structural changes are propagated, it should be ensured that structural interferences are avoided while completing predetermined functions, performance and specifications.

The steps for structural association design based on change propagation are as follows:
1. Identify and delete the changed source structure feature. Determine the changed source feature, split and remove it from the source structure feature on the changed part. Then, build a new structure feature according to design requirement and save it.
2. Associate the transfer and determine the associated structural features. Find the associated part along the associated directed line; then search for the associated structural feature that matches the source geometry and the normal vector. Finally, the segmentation operation is performed on the associated structural features, and the conflicting features are deleted in the part model.
3. Build associated structural features. According to the geometric features of the new structural features and their normal vectors, the main shape of the new structure is judged, and based on the mapping relationship between the geometric features and the matching features, the geometric shape of the new structure on the associated parts is determined, thereby the structural features of the part are determined which associated with the new structure. Construct structural features and compose new part models with structural features of the part associated with the new structure.

6. Example
Taking the reducer shown in figure 3a as an example, the meshing mode of the gears the design requirement is that change from the ordinary key connection to the spline connection, figure 3b is the output shaft unit of the reducer.

![Figure 4. Reducer function unit (1.Key 2.Shaf 3.Sleeve 4.Bearing 5.Cast oil retaining plate 6.Large cylindrical gear 7.Key 8.Cast oil retaining plate).](image)

Firstly, construct the associated directed network model as shown in figure 4. Then simplify the association model according to the simplified rule, and get 7 associated paths as shown in figure 5.

![Figure 5. Simplification of the associated directed network model.](image)
According to the above-mentioned association propagation rule, the path of 1, 4, 7, 3, 2 can be terminated; Path 5 is excluded because of the attribute constraints conflict between part 13 and 18, so the 5 path is excluded; Finally path 6 is selected, part 17 is changed until part 19 meets the termination principle and complete the modification. As shown in figure 6.

According to the structural association change design step, the drive shaft and other related parts can be changed as well. Finally, the input shaft system unit is changed to new structure to fit the design requirement of spline connection.

Figure 6. Structure Association Change Design.

7. Conclusions
In this paper, the basic correlation features are analyzed, the extended structure association model is established, and it is simplified, and the association rules including termination rule and determination of propagation direction are formulated. The method proposed in this paper can improve the accuracy and efficiency of change propagation design, which will be helpful in structural association design.

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