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Function Analysis of Mature Products based on Function Unit Table

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Abstract: Product functional analysis is the foundation of product modularization. Before product module division, function-related analysis of every component or function unit is necessary. As for completely innovative products, the traditional methods are consistent with the habits of designers mind and can help product innovation, while it is difficult to determine the function decomposition granularity. The issue of function decomposition granularity determination challenges the same for mature products. To achieve the function decomposition of made-products, bottom-up function decomposition are proposed and researched. Firstly, determine the possible function unit (bottom function) list for mature products. Secondly, cluster the function units to get their parent functions, and then execute iterated clustering of parent functions until the parent function is product overall function. Finally, products function tree is obtained to achieve function decomposition. In the proposed methodology, the function hierarchy matrix and function incidence matrix are defined to describe the function and the function unit table is built based on which the function units of products are achieved. The relationship between function units achieved above is expressed by using the function hierarchy matrix and function incidence matrix. The function incidence matrix is operated to get the function tree and function decomposition based on bottom-up method by using -intercept. The example shows this method is feasible and easier for programming in computer. Since function units are identified at the beginning, the issue of function decomposition granularity determination is solved.

Keywords: Function decomposing, Function hierarchy matrix, Function incidence matrix, Function unit table, Fuzzy clustering

1 Introduction

Product functional analysis is the foundation of product modularization. Before product module division, function-related analysis of every component or function unit is necessary first [1]. In 2000, Stone proposed a methodology of quantitative function model for product family design based on function analysis of existing products, which included the following steps: 1)determine sub-functions according to user requirements and build function structure; 2) determine the corresponding module to function structure according to the principles of mainstream, tributaries and converting / transferring; 3) evaluate the satisfaction of product family functions to user function requirements; 4) determine the share module and establish product platforms [2].At present, axiomatic design is a popular method of function decomposition for function analysis [3,4].The general process of function decomposition is to start from production total function and achieve the means this function with astern method until the last function. According to axiomatic design principle, a ”functional domains - physical domain - Principles domain” functional decomposition method was proposed, which can convert functions into behavior descriptions [5].As for completely innovative products, the above methods are consistent with the habits of designers mind and can help product innovation, while it is difficult to determine the function decomposition granularity [6].The issue of function decomposition granularity determination challenges the same for mature products.

The present work was carried out in order to solve the product decomposition with the issue of function decomposition granularity determination by discussion and research on bottom-up function decomposition. Firstly, determine the possible function unit (bottom

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function) list for mature products. Secondly, cluster the function units to get their parent functions, and then execute iterated clustering of parent functions until the parent function is product overall function. Finally, products function tree is obtained to achieve function decomposition. Since function units are identified at the beginning, the issue of function decomposition granularity determination is solved.

2 Product function analysis preparation

2.1 Product function description

The essence of product features behaviors as a combination of sub-functions and function units with constraint relations, which generally can be represented by tree structure. In order to analyze product functions, it is necessary to express and quantitatively describe the relationship between sub-functions and function units firstly.

Definition 1: Function tree is denoted as a two-tuple array,*FT=(F,FE)*.

Here, *FT* denotes a function tree, *F* denotes function node sets of product function tree and *FE* denotes edge combinations to describe the subsidiary relationships and constraints among functions. Root node of the function tree represents product function and leaf node represents functions of components. If there aren't leaf nodes or forks somewhere, it means that the leaf node is a function unit, which cannot be decomposed anymore. On the function tree, the leaf nodes are ordered by their importance *I* and the left leaf is of greater importance than the right at the same layer.

Definition 2: Function hierarchy matrix is an $n \times n$ upper triangular matrix, where *n* denotes the total number of nodes of function tree, and $n = |F|$.

In function hierarchy matrix, diagonal elements are the function code (may be character) and non-diagonal elements are 0 or 1.

Set *i,j* as node of function tree,(i,j) as the edge connecting node *i* and *j*,and

$$(i,j) \in FE = \begin{cases} 0, i \neq j \\ 1, i = j \end{cases} \quad (1)$$

In order to make function tree in accordance with function hierarchy matrix, the importance *I* is arranged in function hierarchy matrix according to BFS-breadth first search. Here, *I* denotes the importance of the sub-function at the same layer to the same parent function. Function hierarchy matrix has the following properties:

1) Function hierarchy matrix and function tree are uniquely determined by each other.

2) Diagonal elements of function hierarchy matrix describe the function information of nodes.

3) The order of columns in function hierarchy matrix reflects the importance of nodes at the same layer.

Definition 3: Function incidence matrix reflects the connection relationship and strength between function units, as shown in Figure 1.

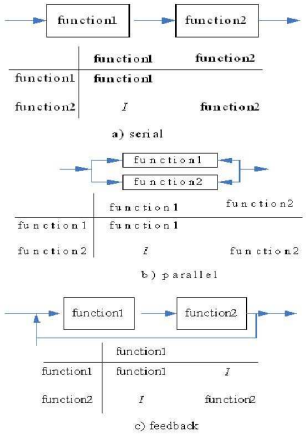

Fig. 1: Function incidence and its expression by function incidence matrix

The functions of one product (indicated by A) can be decomposed as shown in Figure 2(a) as well as the incidence among functions and function units in Figure 2 (b) and 2(c). The function tree of A product can be transformed to function hierarchy matrix and function incidence matrix as shown in Figure 3.

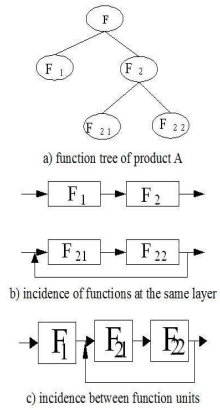

Fig. 2: Product tree and its indication of function incidence

Function incidence matrix reflects the function incidence and incidence strength. In Figure 3, function hierarchy matrix and incidence matrix of product A are illustrated, where I_{F_{21},F_1} denotes the incidence strength between function F_1 and function unit F_{21}.

2.2 Construction of function incidence matrix

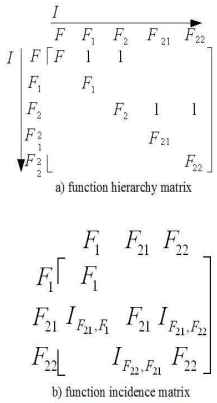

Fig. 3: Function hierarchy matrix and incidence matrix of product A

Since the non-diagonal elements are 0 or 1 and diagonal elements are corresponding function code in function hierarchy matrix, it is easier to get solutions with respect to mathematical computations. While the elements of incidence matrix include incidence strength I_{ij}, 0 and corresponding function code, so it is the most important to calculate the incidence strength I_{ij} to construct function incidence matrix.

In literature [7] and [8], the correlations between functions are divided into four types from the view of modular: function-related, assembly-related, space-related and information-related, and the correlation indexes between functions are calculated based on the four types of correlations. In this presented research, the incidence among sun-functions and function units are calculated based the methodology reported in literature [7] and [8].

Four types of correlations between functions [7][8]

(1) function-related: If f_i and f_j are sub-functions belonging to the same parent function, then f_i and f_j are function-related;

(2) assembly-related: If there exist assembly correlations between f_i and f_j, then f_i and f_j are assembly-related;

(3) space-related: If vectors of f_i and f_j occupy the same space in products, then f_i and f_j are space-related;

(4) informationCrelated: If there exist the exchange correlations of energy flow, information flow, force flow and so on, then f_i and f_j are information Crelated.

Suppose the number of correlation types is n and the weight of kth correlation is W_k, then the incidence between f_i and f_j can be calculated as:

$$I_{ij} = \sum_{k=1}^{n} W_k r_{ij}^k \tag{2}$$

Here,

$$r_{ij}^k = \begin{cases} 1, f_i \ \ and \ \ f_j \ \ meet \ \ kth \ \ correlation \\ 0, otherwize \end{cases} \tag{3}$$

2.3 Function unit table and meta-module table

Definition 4: Function unit refers to the function with no need to decompose anymore in product design.

Definition 5Meta-module refers to the vector of function unit, which can be obtained from 1: n mapping.

Function unit table can be variable due to different product characters and requirements, and function units are coded as well as corresponding meta-modules. A mapping of function unit and meta-modules is constructed as shown in Figure 4. As for mature products, function unit extraction is based on the designers experiences of product structure, and can obtain different extraction results from different views (i.e. design, manufacturing, marketing, transportation, repair and so on). In Figure 4, the meta-modules corresponding to function units are case schemes in essence. The series of meta-module can be obtained by variant design of case schemes [9].

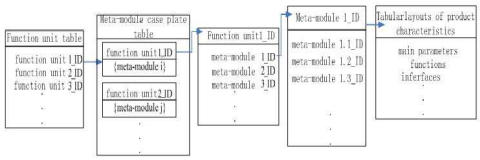

Fig. 4: Mapping of function unit and meta-modules

Function unit extraction is built on mature product structure and the extraction criteria can be summarized as follows from the perspective of function unit vectors [10]:

(1) Function unit should be independent and can be integrated and encapsulated structurally.

(2) Selection, configuration and at most variant design of function unit vectors can be carried out during the procedure of design. Adaptive or innovative designs are not involved.

(3) A function unit can correspond to multiple function unit vectors, while a function unit vector can only to one function unit.

Function unit table collects all the function unit classifications of enterprise and also meta-modules of function unit vectors have the same collection table. A mapping exists between function unit table and meta-module table.

3 Function analysis process of made-products

As for mature products whose parts are determined, function decomposition can be carried out from the structural analysis so as to construct products function tree [11, 12]. Therefore, product function analysis is actually to construct corresponding product structure tree. In order to facilitate the expression with computers, function hierarchy and incidence matrix discussed above are adopted.

In this presented research, function decomposition for mature products is to construct product function tree based on bottom-up approach and to express using function hierarchy matrix and function incidence matrix defined above.

The basic idea of constructing function tree shown in Figure 5 is as follows:

Step1: Based on analysis of existing products' structure with combinations of function unit table, extracted all the product function units;

Step 2: After analysis of the correlations between function units, calculate the incidence strength between function units and construct function incidence matrix;

Step 3: Obtain the parent functions based on based on fuzzy clustering tree with multi-λ for function units clustering;

Step 4: Repeat step 3 until the superior function become product overall functionality.

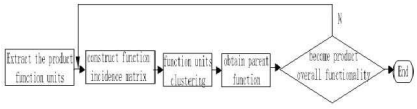

Fig. 5: Construction procedure of function tree

4 Case study

After structure analysis of one product, function units F_1-F_9 are obtained, whose incidences are illustrated in Figure 6(a). The incidence strength can be calculated using the above method to construct function incidence matrix. Fuzzy clustering tree with multi-λ is adapted to convert the function incidence matrix [7,8] (Here, λ=0.7) . Then the superior functions F'1-F'3 of function units are obtained, whose incidence are illustrated in Figure 6(b) , and the function incidence matrix can be stripped out of the matrix in Figure 6(a). The stripped procedures are as follows:

(1) Determine the function unit pair sets, incidence strength of which is less than λ in Figure 6(a), and the incidence strength of each function unit pair. Express them as f_i and f_j, where $f_i f_j$ and I'_{ij} respectively function unit i, function unit j and their function incidence strength.

(2) Search the parent function (F'1-F'3) corresponding to each function unit pair.

(3) The incidence strength of function unit pairI'_{mn},and

$$I'_{mn} = \sum^{N} I_{ij} \tag{4}$$

where I'_{mn} denotes the incidence between F_n and F_m

$$(F_n, F_m \in \{F'_1, F'_2, F'_3\}, f_i \in F_n, f_j \in F_m),$$

and N denotes the number of function unit pairs.

(4) Calculate and construct the new function incidence matrix. If the incidence matrix in Figure 6(b) is converted further with λ=0.5, then F'1 and F'2 can be clustered to F"1 with high superior. The final function tree can be obtained as shown in Figure 6(c) after ordering the functions according to their importance, which can be calculated based on the sensitivity analysis and calculation of corresponding structures.

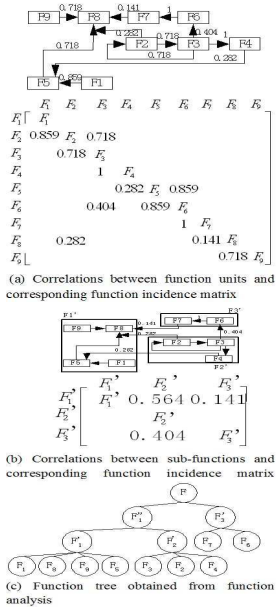

Fig. 6: Case study procedure of function analysis

5 Conclusions

Functional analysis is essential regardless of product innovative design or variant design. The main results of this research can be concluded as follows:

1) Functional analysis of mature products is discussed in detail. It is favourable for computer programming and solution to express functions and their incidence with function hierarchy matrices and function incidence matrix.

2) Function unit tables are established, based on which too coarse or too small granularity of function decomposition can be avoided.

3) The corresponding of function unit table to meta-module table is also discussed. With combinations of function decomposition and the function-structure mapping, the research can lay good foundations for mature product modularization.

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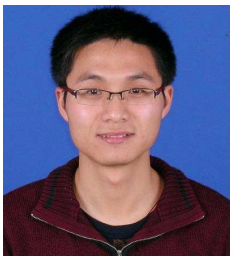

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