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Modularization of product service system based on functional requirement

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Abstract

The customers need no longer just a physical product, but rather the required function provided by the offering of product and service, namely product service system (PSS). Modularization plays a key role in the PSS development in order to address and support individual conceptual design. Functional requirements of PSS can be identified and then classified into different clusters by using a fuzzy clustering algorithm. Considering the relationships between the products and services in a PSS with functional requirement clusters, PSS can be clustered into several modules. Through the modularization, PSS can be easily to customized design for meeting individual requirements. A numeral control machine case is used to show the validity and feasibility of the proposed method.

Keywords: Product service system(PSS); Modularization; Functional requirements; Fuzzy clustering

1. Introduction

Product Service System (PSS), as one of main development direction in the manufacturing markets, aims to provide from just a physical product to a result or a function offered by leveraged product combining with corresponding services jointly to meet customer requirements [1, 2]. Aurich et al. [3] used a process library to select, combine, and adapt the appropriate modules. Mannweiler et al. [4] used a standardized method framework to describe the interface of the product and service modules. Yicong et al. [5] proposed the considerations of not only the traditional function related attributes, but also the maintenance related ones. The structure of PSS is composed of a series of different types of physical modules and service modules, where is necessary to identify proper module partition for facilitating PSS customized design. The relationships among PSS modules are more complex and mixed [6]. According to these complex relationships, PSS can be modularized and then configured based on personalized physical structure and service model to better meet customer requirements [7]. Modularization can reduce the number of modules by diversifying PSS internal module combination, which helps to reduce production cost and environmental impact and realize sustainable development [8, 9].

Modular design can not only improves the response speed of PSS and consequently meet individual requirements, but also greatly improve stakeholders profits, including customer, manufacturer, servicer, environment, and so on. Modular design method has its own unique performance in the analysis of product composition mode, mechanism optimization and system decomposition, reorganization and coordination. There are a large number of relevant literatures on product and service modularization. Piran et al. [10] analyzed the causal effects of product engineering efficiency and production processes to modularize the product and demonstrated that product modularization can significantly improve efficiency and productivity. Taking into account the complex modular products, Fan et al. [11] proposed a modular product platform model, which was based on the breadth first search, and constructed the modular structure of product family. Li et al. [12] made use of the weight of the complex network to modularize the product system. Li et al. [13] described the

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modular structure modeling of complex integrated service-type mechanical products. By discussing the fuzzy relationship between product service and functional requirements, the modularization of product service can be integrated on the basis of functional requirements modularization [14].

From function aspects, functional requirements of PSS are easily identified by customers and design engineers. The products and services in PSS are connected with the functional requirements separately. Deng et al. [15] used ant colony clustering algorithm for module partition. Asok et al. [16] put forward the module partition method based on graph theory and fuzzy logic, which is defined as the process of selecting the best module to divide the seam position. Cheng et al. [17] used the design of the structure of the matrix module division method, through the module of the product matrix calculation to obtain module partition program. Li et al. [18] proposed a method of product module clustering based on Rough Set. All of these elaborated separately the product modularization or the service modularization, and lacked the discussion of the integration for the product service. The functional requirements are clustered by using a fuzzy clustering algorithm. Through these established relationships, all the constituent components of PSS can be classified into proper modules. Section 2 describes the module division principle of PSS. Section 3 proposes PSS modularization method using functional requirements. Section 4, a numerical control machine case is used to illustrate the proposed method.

2. PSS module division principle

Based on functional requirements, PSS modularization is generally performed according to the following division principles. All these principles are effective in the process of preliminary establishment of product and service components, functional requirements identification and cluster, and final PSS module division.

(1) The independent principle of product and service characteristics: the characteristics of products and services are strived to typical and independent. All the main product and service component/modules are as far as possible independent according to functional requirements. So it is easy to assemble to form a variety of PSS concepts.

(2) The function correlation principle of products and services: all the products and service for achieving the same function are as far as possible to cluster together. Its aim is to keep the independence and integrity of one function, where the connections between products and services modules are least, and the internal connections among the modules are closer.

(3) The category correlation principle of products and services: the products and services have the same or similar characteristics. The related products and services with same/similar characteristics/attributes are divided into the same cluster to form a product service module. This can facilitate for product structure and service activity management. As the same time, the mechanism can provide the customers with more diverse products and services of low costs and high quality.

(4) The process correlation principle of products and services: the product components and service activities have continuity in time or service process. As is, products and services during a continuous process are to achieve the same functional goals within a continuous period of time. All these products and services should be as far as possible to divide into on module.

(5) The structural similarity principle of products: the product should try to make the independent components or the large base pieces as a modular unit considering their independence and assembly ability. Modularization of complex components can enhance the efficiency and flexibility product maintenance and replacement, which reduces the cost and time of product maintenance and replacement.

3. PSS modularization using functional requirement

3.1. PSS and functional requirements analysis

The customers and design engineers can easily identify functional requirements, and preliminary PSS components/modules can be divided by the above principles. The PSS modularization framework is given in Fig. 1 based on identifying the relationships between products and services with functional requirements.

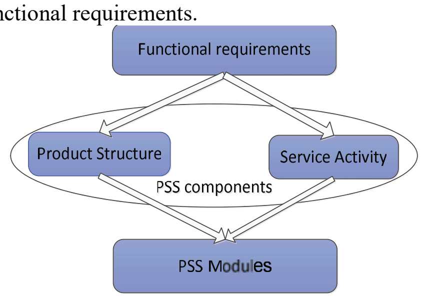

Fig. 1. PSS modularization using Functional requirements

The correlation with its intensity between each two functional requirements can be expressed as shown in Table 1. All the correlation intensity can be used to characterize the relationships among functional requirements.

Table 1. Correlation intensity

Description	Correlation intensity
No or negligible correlation	0
Weak correlation	1
Existing correlation	5
Strong correlation	9

Correlation intensity matrix of functional requirements can be established based on their correlation identification.

Element d_{ij} expresses the correlation intensity between the ith and jth functional requirements, which can form the correlation intensity matrix M in Formula (1), the formula of d_{ij} is shown in Formula (2). When i = j, d_{ij}=1, and d_{ij} = d_{ji}, where the matrix is symmetric.

$$M = \begin{bmatrix} 1 & d_{12} & \cdots & d_{1j} \\ d_{21} & 1 & \cdots & d_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ d_{i1} & d_{i2} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$d_{ij} = \frac{1}{9}\left(\omega_p A + \omega_s B\right) \quad (2)$$

ω_p and ω_s are the weight of demand constrain, $\omega_p + \omega_s = 1$, Here $\omega_p = \omega_s$ =0.5. Setting $F1, F2, \cdots, Fn$ for the decomposition of the *N* functional requirements, *A* and *B* function influence weight.

For example: the influence weight of product functional requirements Fi and functional requirements Fj was 1 and 5, respectively, then the $d_{ij} = 1/9 \times (1\times 0.5 + 5\times 0.5) \approx 0.33$, other data and so on can be obtained matrix M.

In order to ensure the calculation accuracy, the correlation intensity matrix can be identified by using group decision making method. Several design engineers, from different market, product or development departments, can give their individual judgments. All these individual judgments can be formed into group consensus judgments through general group decision making methods.

3.2. Clustering calculation

A clustering method can classify a set of physical or abstract objects into several classes composed of similar objects. Several calculating methods, such as quality of house [19], structure matrix, heuristic algorithms, Genetic Algorithm, Simulated Annealing Algorithm, Extenics and Fuzzy Tree, can be used to fulfill product/service modularization. Fuzzy clustering algorithm is to use mathematical methods to quantitatively determine the relationship of objects, and thus objectively classified. Fuzzy cluster algorithm has the advantages of calculation simplicity and result objectivity [20-21]. The boundaries among objects, some are exact, but others are vague. Fuzzy clustering is needed when clustering involves fuzzy boundary among objects.

In this PSS development, the products and services are divided into modules based on functional requirements. The functional requirements are determined according to individual customer requirements, which have uncertain boundaries. Fuzzy clustering can accommodate data and classes that are not very good for separation, which allows the ambiguity of the nature of the data, providing detailed information for the description of the data structure. The correlation between product service and functional requirements is ambiguous, that is to say, the uncertainty of the correlation strength, FCM is used to analyze, so as to achieve the organic unity of product and service quality, variety and benefit. Therefore, in this paper, fuzzy clustering algorithm is used to divide functional requirements into modules by using correlation matrix in Formula (1).

In the fuzzy clustering analysis, fuzzy similarity matrix must be first calculated. That is, the fuzzy relationships among products, services and functional requirement. The sample r_i, $i = 1, 2, \cdots, n$ of the classified object X in the fuzzy clustering, belongs to a certain class with certain membership degree. That is, all the samples belong to a certain class with different membership degrees. Thus, each class is a fuzzy subset of the set of functional requirements X, so that the classification matrix corresponding to each such classification result is a fuzzy matrix.

The classification matrix satisfies the following three conditions:

(1) $r_{ij} \in [0,1]$, that is, the element values of the classification matrix between 0 and 1.

(2) $\sum_{i=1}^{c} r_{ij} = 1$, that is, the sum of the membership degrees belonging to each class is 1 in each column. For a sample, its sum of the membership of the various classes is 1.

(3) $\sum_{j=1}^{n} r_{ij} > 0$, that is, the sum of the elements in each row is greater than 0, which guarantees that each class must have a sample. There are some samples with different memberships belong to various categories.

In this paper, the dividing process of functional requirements using fuzzy clustering algorithm is given in Fig. 2. Functional requirement modules can be identified based on the clustering calculation of functional requirements. PSS modularization can be implemented according to the relationships between functional requirement modules and products and services. And then, the final PSS modules can be obtained based on classification modules of PSS.

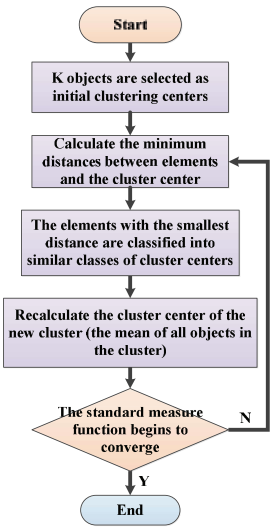

Fig. 2. Fuzzy clustering process

4. **Case study**

A numeral control machine case is used to illustrate the proposed method. In the case, there are ten functional requirements, including execution function F1, support function F2, ..., quick maintenance F10. The product structure includes 14 types of product components, base part P1, spindle part P2, ..., and other tool accessories P14. While the service include 19 kinds of service categories, cutting part maintenance S1, programming service S2, ..., machine tool recycling service S19. The relationship mapping framework of functional requirements and PSS is given in Fig. 3.

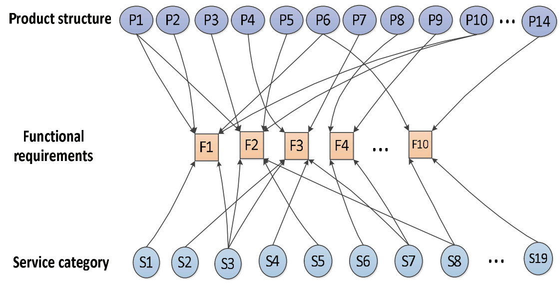

Fig. 3. Relationship mapping.

As shown in Fig. 3, product component P1 partially provides functional requirements F1 and F2, while service category S3 influences functional requirements F1, F2, and F3. Thus, product component P1 is associated with service category S3. In addition, product component P1 is associated with service category S1, S5 and S8. The product component P1 and P2 affect the functional requirements F1 at the same time, and then there exists a connection between P1 and P2. Similarly, the service category S1 and S3 affect the functional requirements F1 at the same time, then there is a connection between S1 and S3. The mapping intensity between function requirements with products and services can be identified by the decision making team. Nine engineers, form markets, development, and production departments, are selected to form the decision making team.

According to the correlations among functional requirements, the relationship intensity matrix of the ten functional requirements F1 ~ F10 is established by using the method as given in Section 3.1. Based on the individual judgment of each engineer, the final group consensus results can be calculated through weighted calculation. The correlation matrix B is given as follows:

$$B = \begin{bmatrix} 1 & 0.33 & 0.06 & 0.56 & 0.06 & 0.33 & 0.06 & 0.1 & 0.56 & 0.1 \\ 0.33 & 1 & 0.28 & 0.78 & 0.1 & 0.33 & 0.28 & 0.56 & 0.06 & 0.56 \\ 0.06 & 0.28 & 1 & 0.5 & 0.06 & 0.28 & 0.78 & 0.06 & 0.1 & 0.78 \\ 0.56 & 0.78 & 0.5 & 1 & 0.56 & 0.78 & 0.28 & 0.1 & 0.28 & 0.56 \\ 0.06 & 0.1 & 0.06 & 0.56 & 1 & 0.33 & 0.33 & 0.78 & 0.33 & 0.06 \\ 0.33 & 0.33 & 0.28 & 0.78 & 0.33 & 1 & 0.5 & 0.56 & 0.56 & 0.33 \\ 0.06 & 0.28 & 0.78 & 0.28 & 0.33 & 0.5 & 1 & 0.1 & 0.78 & 0.5 \\ 0.1 & 0.56 & 0.06 & 0.1 & 0.78 & 0.56 & 0.1 & 1 & 0.28 & 0.06 \\ 0.56 & 0.06 & 0.1 & 0.28 & 0.33 & 0.56 & 0.78 & 0.28 & 1 & 0.5 \\ 0.1 & 0.56 & 0.78 & 0.56 & 0.06 & 0.33 & 0.5 & 0.06 & 0.5 & 1 \end{bmatrix}$$

The fuzzy clustering algorithm is used to divide the above matrix B into several modules. According to the criteria of modular division, the value of the number of modules is n: $1 \le n \le m$, for the modularization of m elements. In the case, the number of modules is $1 \le n \le 10$. The fuzzy clustering algorithm is used to calculate the formula (2), and the results are compared. The clustering coefficients are identified as 0.56, 0.78, and 1. When the clustering coefficient is 1, each element is self-contained which cannot reflect the relationships among them. When the clustering coefficient is less than 0.56, all the elements are in the same module, so it is not convenient to analyze the differences among them. Therefore, the clustering coefficient 0.78 is selected, and then the module number is calculated as n = 4. The clustering results are four modules {F1}, {F2, F4, F6}, {F3, F7, F9, F10} and {F5, F8}.

The products and services that are mapped to functional requirements in each module can be identified according to Fig. 3. F1 is associated with P1, P2, P6 and P10. The corresponding services are S1 and S3. F2 is associated with P1, P3, P5, and P10. The corresponding services are S3 and S5. The products and services associated with the rest of the functional requirements can be easily obtained by using the same manner.

The correlation intensity between each product or service and functional requirement modules can be calculated through the sum of individual mapping relationships. The affiliated relationships of each product or service with the four function requirement modules can be identified based on the comparison of correlation intensity. Finally, all the products and services are divided into four clusters. Through adjusting the clustering coefficients, the different clustering results can be obtained according to the actual applying situation.

5. Conclusions

In order to achieve the integration of products and services, to achieve the organic unity of quality, variety and efficiency, a modularization method is proposed for PSS based on functional requirements. The proposed method can give a clustering result for classifying PSS into several modules from a new aspect of functional requirements. Five division principles are given for function requirements and PSS modularization. All the functional requirements can be divided into servile categories using a fuzzy clustering algorithm. The products and services in a PSS can be clustered by using the correlation intensity values between each item with the function requirement modules.

Future work will consider the inter-relationship between products and services during the clustering process. And the comparison analysis of different methods in the PSS modularization will be performed.

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References

[1] Baines TS, Lightfoot HW, Evans S, et al. State-of-the-art in product-service systems. Proc. IMechE, Part B: J. Engineering Manufacture 2007; 221(10): 1543-1552.

[2] Sakao T, Shimomura Y, Sundin E, Comstock M. Modeling design objects in CAD system for Service/Product Engineering. Computer-Aided Design 2009; 41(3): 197-213.
[3] Aurich JC, Fuchs C, Wagenknecht C. Modular design of technical product-service systems. Innovation in Life Cycle Engineering and Sustainable Development. Springer Netherlands; 2006.
[4] Mannweiler C, Aurich JC. Modularization of Products and Services for Configuring Product-Service Systems. CIRP IPS2 Conference; 2012.
[5] GAO Y, FENG Y, TAN J. Product Modular Design Incorporating Preventive Maintenance Issues. Chinese Mechanical Engineering Society and Springer-Verlag Berlin Heidelberg; 2016.
[6] Zhang ZF, CHU XN. A new integrated decision-making approach for design alternative selection for supporting complex product development. International Journal of Computer Integrated Manufacturing 2009; 22(3): 179-198.
[7] Li H, Ma J, Xiao Y, Luo G. Research on generalized product and its modularization process. International Conference on System Science, Engineering Design and Manufacturing Informatization 2011; 1(1): 290-293.
[8] Wang PP, Ming XG, Li D, Kong FB, Wang, L & Wu, ZY. Modular development of product service systems. Concurrent Engineering 2011; 19(1): 85-96.
[9] Doualle B, Medini K, Boucher X, Laforest V. Investigating sustainability assessment methods of product-service systems. Procedia Cirp 2011; 30: 161-166.
[10] Piran FAS, Lacerda DP, Camargo LFR, Viero CF, Dresch A, Cauchick-Miguel PA. Product modularization and effects on efficiency: an analysis of a bus manufacturer using data envelopment analysis (dea). International Journal of Production Economics 2016; 182: 1-13.
[11] Fan B, Qi G, Hu X, Yu T. A network methodology for structure-oriented modular product platform planning. Journal of Intelligent Manufacturing 2015; 26(3): 553-570.
[12] Li Y, Chu X, Chu D, Liu Q. An integrated module partition approach for complex products and systems based on weighted complex networks. International Journal of Production Research 2014; 52(15): 4608-4622.
[13] Li H, Qiao D. Review on modular structure modeling method for complex integrated service mechanical product. Journal of Hebei University of Science & Technology 2013; 34(2):102-107.
[14] Yao H, Jin Y, Yan JQ. Qualitative and quantitative analysis of product functional requirements. Chinese Journal of Mechanical Engineering 2010; 46(5):191-198.
[15] Deng K, Liu J. Research on module partition method for mass customization based on ant colony clustering algorithm. Computer Engineering and Applications 2008; 44(2): 130-132.
[16] Asok KA, Aoyama K. Module division planning considering uncertainties. Journal of Ship Production 2009; 25(3): 153-160.
[17] Cheng XF, Chen C. Applying independence axiomand design structure matrix to product module divisions. Proceedings of International Conference on Mechanic Automation and Control Engineering， Wuhan，China，2010: 581-584.
[18] Li YP, Chu XN, Ging XL, et al. Modular Clustering Method Based on Rough Set and Application. Machine Design and Research 2011; 27(4): 1-12.
[19] Chu Y, Ren H. Product requirement analysis based on the improved house of quality. IEEE International Conference on Grey Systems and Intelligent Services 2016. p.547-550.
[20] Giordani P, Ramos-Guajardo AB. A fuzzy clustering procedure for random fuzzy sets. Fuzzy Sets & Systems 2016; 305: 54-69.
[21] Botía JF, Isaza C, Kempowsky T, Lann MVL, Aguilar-Martín J. Automaton based on fuzzy clustering methods for monitoring industrial processes. Engineering Applications of Artificial Intelligence 2013; 26(4): 1211–1220.