Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 15 (2011) 5313 – 5317

Procedia Engineering

www.elsevier.com/locate/procedia

Advanced in Control Engineering and Information Science

Product Module Identification Based on Assured Customer Requirements

Quan Shan[*a] , Yan Chen[b]

[a]*Automation Engineering Department, Northeastern University at Qinhuangdao, Qinhuangdao 066004, China*
[b]*Automation Engineering Department, Northeastern University at Qinhuangdao, Qinhuangdao 066004, China*

Abstract

Modular design includes module identification and module assembly. To obtain the optimization project of module identification, the assured customer requirements must be gained. So, the gain technology of assured customer requirements, which using gray system theory, is proposed in this paper. Then, the assured customer requirements should be change to the factors of product function, performance, physics and so on. After to gain above factors' relation matrix, a synthesis design structure matrix can be obtain. An optimization function which based on the axiomatic design theory is established. Then, a new numerical optimization approach about product module identification, which used improved harmony search algorithm, is presented in this paper. This approach is tested several times. The optimization project can be attaining at each time. The result demonstrates the feasibility of the proposed approaches.

*Keywords:*Product Module Identification, Customer Requirements, Gray System Theory, Improved Harmony Search Algorithm;

1. Introduction

As one of key technology of mass customization, modular design is meet with much recognition recently. Module design has been used in many areas, such as product design, software development and so on. One essential technology in modular design is module identification. To date, lots of researches are concentrated on module identification ways, such as heuristic [1], fuzzy clustering analysis [2], maximal dendrogram [3] and so on. Some researches have been done on numerical module identification method, such as simulation annealing algorithm [4, 5], genetic algorithm [6], particle swarm optimization [7] and so on. In fact, the optimization project of module identification should be support by assured customer

* Corresponding author. Tel.:+8613731796686
E-mail address: shanquan@mail.neuq.edu.cn

1877-7058
doi:10.1016/j.proeng.2011.08.985

requirements. But, because of the abstract, complexity and mobility characteristic of the customer requirements, it is difficult to identify and master the idiographic modality of customer requirements. So, it straight affects the design quality of product and succeed rate of new product development. In order to obtain assure customer requirements, lots of enterprises and research institutes pay attention to the capture, analysis and comprehension of customer requirements [8].

Gray system theory was advanced by Deng in 1982, where this theory works on unascertained systems with partially known and partially unknown information by drawing out valuable information and also by generating and developing the partially known information. [9]. It can describe correctly and monitor effectively the systemic operational behaviors. In this theory, the color "gray" indicates that the information within a system is partially unknown. Conversely, the color "white" in a gray system denotes that all of the information is definite and complete (i.e., fully known), and "black" indicates that the information within the system is completely unknown. The objective of gray system theory is to transform the "black" (unknown) information of the system into "white" (definite) information from the available information. Gray methods have the powerful advantage of being capable of dealing with complex problems concerning uncertain or fragmented systems by means of a simple process and a reliable analysis technique. Customer requirements are, by their nature, complex and usually fragmentary, and it is the small swatch "poor information" for manufacture enterprises. Accordingly, the customer requirements that manufacture enterprises are investigating is ideal for the application of gray system theory.

In order to obtain optimization project of module identification, assured customer requirements must to be acquired. The method of customer requirements gained is discussed firstly in this paper. The assured customer requirements can be obtained by gray system theory. Then, the assure customer requirements can be mapped to some issues of product design, such as function, performance, structure and so on. The product parts' synthesis design structure matrix (DSM) can be gained by above issues. An optimization function for module identification based on the principle of axiomatic design [10] is established. Lastly, the optimization project of module identification can be obtained using improved harmony search (HS) algorithm. The effectiveness of the proposed method is validated for the module identification of an air conditioning system.

2. Customer Requirements Collecting

Customer requirements are defined as the customer using themselves language to express the demand to product. Customer requirements are the foundation of the enterprise set down the right product design schema, also are the origin and gist of product design. In order to design the welcome product for customer, the collect requirements must reflect the most of customer demands. At the time of collecting the customer demands, we should added more origin items of customer demands, such as the final users, proprietors, manufactures, designers, managements, other users and so on. So, the generalized customer requirements, which facing to the product life-cycle, can be gained. At the same time, the customer requirements should be offered the extend mechanism. The special requirements can be decompose in this mechanism. Then, the deep customer requirements can be obtained. The ways of gaining the customer requirements are as follow.

1) investigate questionnaire.
2) ask face to face.
3) enterprise continue survey the shortage of product and development direction of technology.

Customer requirements should face to the product life-cycle, include the requests of product capability, time, economy, use, recycle and so on. Usually, the requirements of market or customer are a tanglesome concourse. The exhibition form of the requirements is not fixation. So, the customer requirements must be refined onto assured customer requirements. Additional, customer requirements can not disengage the stratagem demand of enterprises. In other words, the requirements of new product must combine the market requirements with enterprise requirements.

3. Assured Customer Requirements Obtaining Based on Grey System Theory

At the early phase of product design, there have ambiguous influence between the factors of customer requirements. It is difficult to describe the incompleteness or uncertainty information system. Using generic means to analyze this system is more difficult. Gray system theory has the powerful advantage of being capable of dealing with complex problems concerning uncertain or fragmented systems by means of a simple process and a reliable analysis technique.

In current gray theory applications, the primary areas of academic research activity are gray relational analysis. Gray relational analysis is applied to determine the relationship between two sequences of serial data in gray system. A high degree of correlation between the two data sequences is referred to as high relation; otherwise, the correlation is referred to as low relation. Generally, the degree of correlation is denoted by a gray relational grade. Therefore, gray relational analysis is a method used to evaluate the degree of gray relation according to the extent of similarity or difference of the developing trend. A gray relational generating operation refers to the derivation of an unknown element in the compared sequence by applying gray relational analysis to the reference sequence and that compared sequence.

There are some functions about assured customer requirements based on gray system theory in this paper. Firstly, information of customer requirements can be deal with using gray cluster analysis, so the redundant customer requirements can be delete. Secondly, the relative weightiness of customer requirements can be gained by gray correlation analysis. Thirdly, it can guide to add some new customer requirements into requirements concourse after using gray system analysis.

4. Synthesis DSM and Optimization Function

After obtaining the assure customer requirements, it can be mapped to some issues of product design, such as function, performance, structure and so on. Thus, some sub-DSM (function sub-DSM, structure sub-DSM, physics sub-DSM et. al.) can be obtained through analysis of the correlation between product elements. The correlation degree is described by a real number between 0 and 1.then, the product parts' synthesis design structure matrix can be gained by above sub-DSM.

According to the principle of axiomatic design, the module design should keep the high-bandwidth communication within a module and the low-bandwidth links between modules. Assume product P is a set of product elements $\{C_1, C_2, \dots, C_n\}$. Product P is identified into V modules, where P also is a set of product modules $\{M_1, M_2, \dots, M_v\}$. Assume module M_i contains k_i elements, then $\sum_{i=1}^{v} k_i = n$. Based on synthesis DSM, the optimization function for module identification can be written as:

$$F = \frac{f_1}{f_{1\max}} * \frac{\overline{f_{1\max}}}{\overline{f_1}} + \frac{f_2}{f_{2\max}} * \frac{\overline{f_{2\max}}}{\overline{f_2}} + \dots\dots + \frac{f_v}{f_{v\max}} * \frac{\overline{f_{v\max}}}{\overline{f_v}} = \sum_{i=1}^{v} \left(\frac{f_i}{f_{i\max}} * \frac{\overline{f_{i\max}}}{\overline{f_i}} \right) \tag{1}$$

where f_i is the summation of element relationships within module M_i.

$f_{i\max}$ is the maximum of f_i when all relationships are equal to 1. If k_i is the number of elements in module Mi, then $f_{i\max} = k_i * (k_i - 1)/2$.

$\overline{f_i}$ is the summation of element relationships between module M_i and other modules in product P.

$\overline{f_{i\max}}$ is the maximum of $\overline{f_i}$ when all relationships are equal to 1. If k_i is the number of elements in module Mi, then $\overline{f_{i\max}} = k_i * (n - k_i)$.

The $\frac{f_i}{f_{i\max}}$ represents the high-bandwidth communication in one module. The $\frac{\overline{f_{i\max}}}{\overline{f_i}}$ represents the low-bandwidth links between the modules.

5. Improved Harmony Search Algorithm

The HS algorithm was recently developed in an analogy with music improvisation process where music players improvise the pitches of their instruments to obtain better harmony. Musical performance seeks a best state determined by aesthetic estimation, as the optimization process seeks a best state determined by objective function evaluation. Aesthetic estimation is done by the set of the pitches sounded by joined instruments, as objective function evaluation is done by the set of the values product by composed variables; the aesthetic sounds can be improved practice after practice, as the objective function values can be improved iteration by iteration [11]. In this paper, the improved HS algorithm is combined some conceit of particle swarm optimization (PSO). When rand1 is bigger or equal to HR, a new harmony memory (56000 harmonies), not a harmony, will be build in this improved HS algorithm. So, the search area will be wider, and the optimization harmony can be getting more quickly.

6. Example

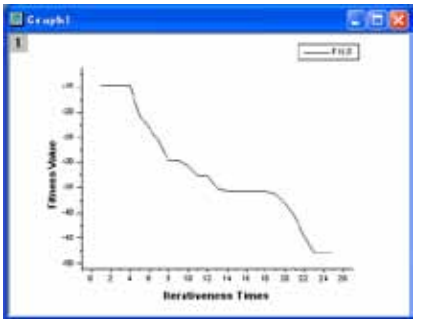
To demonstrate and validate our approach, we chose to modularize the household hanging air-conditioning system (indoor part). The collected customer requirements are expressed as follows: long-distance control by WWW, air decontamination, power 2.5 kw., ratio of energy to effect is rank 3 or more, silver or white panel, satisfy the circumstance's need, price under 2500 yuan and cash on delivery. After using gray system theory, the assured customer requirement are expressed as follows: wireless network function, negative function, power 2.5 kw., ratio of energy to effect is rank 3 or more, silver or white panel, received safety authentication, price under 2500 yuan and cash on delivery. Before analyzing the correlation between product elements, we should group the similar elements of the product. So, the product components can be predigested into 28 elements. After we gained the function sub-DSM, structure sub-DSM and so on, the synthesis DSM is shown in Table 1.

Table1 The synthesis DSM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1		0.27	0.27	0.27	0.27	0.27	0.27	0.06	0.6	0.6	0.06	0.06	0.69	0.6	0.6	0.18	0.06	0.06	0.06	0.06	0.06	0.06	0.6	0.06	0.06	0.06	0.06	0.06
2			0.72	0.72	0.72	0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.24	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
3				0.72	0.72	0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
4					0.72	0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
5						0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
6							0.72	0.06	0.06	0.06	0.06	0.06	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
7								0.06	0.06	0.06	0.06	0.06	0.24	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
8									0.12	0.12	0.06	0.06	0.12	0.12	0.12	0.72	0.12	0.06	0.06	0.06	0.06	0.06	0.06	0.72	0.72	0.06	0.06	0.06
9										0.6	0.6	0.06	0.54	0.72	0.66	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.6	0.06	0.06	0.06	0.06	0.06
10											0.12	0.12	0.78	0.6	0.6	0.18	0.06	0.06	0.06	0.06	0.06	0.06	0.6	0.18	0.06	0.06	0.06	0.06
11												0.89	0.06	0.06	0.06	0.06	0.06	0.9	0.78	0.78	0.78	0.06	0.06	0.06	0.06	0.06	0.06	0.72
12													0.06	0.06	0.06	0.06	0.06	0.72	0.72	0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.06	0.66
13														0.72	0.4	0.2	0.06	0.06	0.06	0.06	0.06	0.12	0.72	0.06	0.06	0.12	0.12	0.06
14															0.66	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.72	0.06	0.06	0.06	0.06	0.06
15																0.06	0.06	0.06	0.06	0.06	0.06	0.66	0.36	0.27	0.06	0.06	0.06	0.06
16																	0.06	0.06	0.06	0.06	0.06	0.12	0.54	0.54	0.06	0.12	0.06	
17																		0.06	0.06	0.06	0.9	0.06	0.06	0.36	0.9	0.78	0.06	
18																			0.78	0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.72	
19																				0.72	0.72	0.06	0.06	0.06	0.06	0.06	0.78	
20																					0.72	0.06	0.06	0.06	0.06	0.06	0.72	
21																						0.06	0.06	0.06	0.06	0.06	0.72	
22																							0.06	0.06	0.36	0.9	0.78	0.06
23																								0.06	0.06	0.06	0.06	0.06
24																									0.6	0.06	0.06	0.06
25																										0.36	0.36	0.06
26																											0.78	0.06
27																												0.06
28																												

According to the synthesis DSM, we construct a 28-dimensional harmony, and then initialize a harmony memory (HM), which has 56000 harmonies. The number of modules is six. In this paper, the probability HR, PR and iterative times is 0.8, 0.2 and 25, respectively. The optimization program is run several times. The optimization process takes about 30 seconds. Optimization curve is shown in Figures1.

The best project is achieved firstly at the 23th iterative. Its fitness value is -47.973043. The result meets the module design needs.



Figures1 Optimization curve of using IHS algorithm

7. Summary

In this paper, the method of customer requirements collecting is discussed firstly. Then the assured customer requirements can be obtained by gray system theory. The assure customer requirements should be mapped to some issues of product design phase, such as function, performance, physics, structure and so on. The synthesis DSM of product parts can be gained by above issues' sub-DSM. An optimization function for module identification based on the principle of axiomatic design is established in this paper. Lastly, the optimization project of module identification can be obtained based on IHS algorithm. The effectiveness of the proposed method is validated for the module identification of an air conditioning system.

References

[1] R. B. Stone, K. L. Wood, and R. H. Crawford, A heuristic method for identifying modules for product architectures. *Design Studies* 2000;**21**:5–31.

[2] Y. T. Tsai and K. S. Wang, The development of modular-based design in considering technology complexity. *European Journal of Operational Research* 1999;**119**:692–703.

[3] K. Holtta, Modular product platform design. Espoo: Helsinki University of Technology, 2005.

[4] H. J. Wang, J. J. Wang, B. Y. Sun, Z. F. Liu, and X. P. Wei, Optimization design of modularized product family based on kernel platform. *Computer Integrated Manufacturing Systems* 2005;**11**:162–167.

[5] P. Gu and S. Sosale, Product modularization for life cycle engineering. *Robotics and Computer Integrated Manufacturing* 1999;**15**:387–401.

[6] T. L. Yu, A. Y.Ali, and E. G. David, A genetic algorithm for developing modular product architectures. *ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (DETC 03)*, ASME Press, 2003, p. 515–524.

[7] Q. Shan, Y. Chen. Research on Numerical Module Identification Approaches，*8th IEEE/ACIS International Conference on Computer and Information Science* 2009, p.672–676

[8] Charles A Diaz. Product Re-Configurability and Product Introduction. *Concurrent Engineering: Research and Application* 1998;**6**:172–177

[9] J. L. Deng. Essential topics on grey system: theory and applications. Wuhan: Huazhong University of Science and Technology Press, 1987

[10] N. Suh, Axiomatic design theory for systems. *Research in Engineering Design* 1998;**10**:189–209.

[11] Geem Z.W., Tseng C.-L., and Park Y., Harmony Search for Generalized Orienteering Problem: Best Touring in China. ICNC 2005, LNCS 3612, p. 741 –750.