Module Parameter Programming Method of Complex Product System Based on Customer Demand Distribution

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Abstract

In view of the bad effect of traditional module parameter programming method in the application of module parameter programming of complex product system. This paper puts forward a kind of system module parameter programming model of complex product optimized by the AHP (analytic hierarchy progress) algorithm which is based on improved genetic algorithm. Analyzing from the perspective of customer functional requirements, and putting forward the principle of parameter programming module, and then according to the relevant principles of module partition, assessing the correlation matrix between the structure components, and AHP is adopted to establish the criteria to determine the weight of each correlation, aiming at the existence of low accuracy in AHP, using the improved genetic algorithm in the biological evolution rule and chromosome information exchange mechanism to optimize the AHP. The simulation experiments show that the effect of proposed improved method for module parameters programming of complex product system is more outstanding.

Key words: MODULE PARAMETERS PLANNING, COMPLEX PRODUCT SYSTEM, IMPROVED GENETIC ALGORITHM, ANALYTIC HIERARCHY PROGRESS, CUSTOMER DEMAND DISTRIBUTION, BIOLOGICAL EVOLUTION RULE

1. Introduction

In the backdrop of the division and transferring of lobal value chain, modular network outsourcing manufacturing of complex product has become a powerful weapon to increase the competition ability of enterprise, industry, and is gradually evolved into the powerful tools to achieve for the goal of each life cycle stage of a complex product [1]. Manufacturing of complex product system synergy innovation research, from the product modularization, organization to modular production network, the attentio to complex product innovation and cost efficiency is constantly deep going. Using the complex network theory, contract theory and social network theory to study the generation mechanism of the modular design, the production network, modeling mode, supply chain collaborative optimization becomes the new watchful direction [2].

The vast majority of the product design is improved type product design, new product design is often on the basis of the model modification of original product information, and the parameterized design technology came into being in this background. Parametric design technology at present mainly includes variable geometric method, geometric reasoning method, process construction method and modelling method based on the characteristics of the parametric operation, etc. [3]. Variable geometric method transform the geometric constraint to a series of characteristic points as the argument of nonlinear equations, using numerical method to slove nonlinear equations and determine the geometric details, this method request users to input full and consistent geometric constraints so as to find the solution of constraint equations, the inconsistent constraint model is difficult to effectively distinguish, and processing is also difficult to effectively limit local variations in the local scope of solving [4]. Geometric reasoning method is based on expert system to be established, using predicate to denote geometric constraints, by reasoning machine to export geometric details, this method can check the validity of the constraint model, and has the function of local changes, but there is a reasoning problem such as slow speed, huge system [5]. Process constructing method uses a mechanism called parameterized CV by recording geometry element in a graphical form in the process of order and connection relationship, tracking the designer's intention; not like variable geometric method to solve the nonlinear equations, so the model can be more complex and used for 3D entity or surface parametric modeling [6]. Feature modeling technology is a kind of new modelling technology which not only gears to the needs of the design process and also manufacturing process, which is the development of a new generation of geometric modelling technology [7]. The appearing of feature modelling, on the one hand, provides a high-layer design personnel which complys with the design thinking of human-computer interaction, revolutionizes traditional low layers of interaction design method based on the geometric topology, makes a design personnel concentrate on a higher layer of design problem and a design more convenient, and helps to improve the quality of the design [8]. On the other hand, because the characteristic is a high layer of design concept and contains a large number of design inten of designers, and is much meaningful for the modification and maintenancdesign of desig and subsequent comprehensive analysis, etc [9]. Characteristics is to express the information of complete product and put forward a new concept, it is a set of specific properties of interconnected geometric form, is comprehensive description of the information set including shape of parts, process and function characteristics. It can carry and transmit the information needed to be designed and manufactured. For manufacturing, the geometry information includis the size and tolerance, surface roughness, materials and heat treatment etc. [10]. Among them, the shape feature is the main carrier of carrying some characteristic information.The process of establishing shape feature can be considered as constraint satisfaction, the process of design is essentially by extracting characteristic and effective constraints to establish its constraint model and do constraint solving. Along with the development of artificial intelligence technology, the knowledge driven parametric design emerged, the basic idea in the knowledge driven is the method to seek, record different kinds of knowledge, this knowledge is used to plan, design and finish a product, project or program and integrate the artificial intelligence with CAX system organically as one [11].

From the perspective of customer functional requirements to analyze, this paper puts forward a module parameter programming mode of complex product system with an improved analytic hierarchy process algorithm which is based on improved genetic algorithm, and its experimental simulation verify the validity of the improvement strategy.

2. Module parameter programming model based on customer demand distribution

Analysis of module parameter programming model based on customer demand distribution is mainly from the perspective of customer functional requirements, and to put forward the principle of parameter planning module. we can say that function analysis is the basis of module partition, function refers to the function of complex product system, subsystem, subsystem, components, spare parts and its role, from the functional analysis, it can make the thought not subject to the limitations of the existing structure, it also can be better to seek some same and different purposes of the performance function of the unit. According to the function analysis method, therefore, it can divide the complex product system into several small system or unit, these small system are known as the class system module, unit called function module, the module are combined to realize the total function of system .

This paper adopt average distribution form $[0,1]$ to define the relevant numerical , fuzzy correlation value is shown in Table 1.

Table 1. Fuzzy correlation value table

Related Layer	Relevance	Correlation value
1	Strong	1.0
2	Close	0.8
3	Moderate	0.6
4	ordinary	0.4
5	Weak	0.2
6	No	0

Then evaluatiing the function sub-correleated matrix RM_F, principle sub-correleated matrix $RM_{P(T)}$, behavior sub-correleated matrix RM_X, DFX sub-correleated matrix RM_X between structural components according to the relevant principles of module partition. For example, the construction of founction sub-correleated matrix RM_F among n components and parts is shown below:

$$RM_F = \begin{bmatrix} r_{F11} & r_{F11} & \cdots & r_{F11} \\ r_{F21} & r_{F22} & \cdots & r_{F2n} \\ \cdots & \cdots & r_{Fij} & \cdots \\ r_{Fn1} & r_{Fn2} & \cdots & r_{Fnn} \end{bmatrix} \quad (1)$$

In abve, RM_F denotes the function of the correlation matrix between components and parts i and j according to the definition of correlation function description, r_{Fij} is the founction sub-correleated value between components and parts i and j. Similarly, principle sub-correleated matrix $RM_{P(T)}$, behavior sub-correleated matrix RM_B, DFX sub-correleated matrix RM_X are constructed according to correlation description, the method and constructing founction is same with construction sub-correleated matrix RM_F.

For complex product system, its function structure is very complex, from a different point of view, the degree of coupling between components is also different, so this article is from the angle of the whole life cycle of product system, comprehensively considering every link factor in the process of product system development, AHP analytic hierarchy process (AHP) is adopted to establish the criteria to determine the weight of each correlation.

Supposed that it needs to compare the influence of n factors $X=\{x_1,...,x_n\}$ on a certain element Z, to provide more reliable data, we can take the factors to be compared two paired to establish comparison matrix method. Namely selecting two factors x_i and x_j, a_{ij} denotes the ration of the influence of x_i and x_j on Z, all the comparison results are expressed with matrix, which is as follows:

$$A=(a_{ij})_{n\times n} \quad (2)$$

In the formula, named A as judgement matrix among $Z-X$. It is easy to find that if the ration of the influence of x_i and x_j on Z is a_{ij}, then the ration of the influence of x_i and x_j on Z:

$$a_{ji}=\frac{1}{a_{ij}} \quad (3)$$

Judgment matrix A corresponding to eigenvector W of the maximum eigenvalue $\lambda_{\max}$, after normalization, is a sort of weights of the same layer factors corresponding to the relative importance of factors, this process is known as hierarchical single order.

The way to construct judgment matrix can reduce the interference of other factors, more objectively to reflect the difference of influence between a pair of factor. But comparing comprehensive results, it inevitably contains a certain degree of inconsistency. If the compared result is completely consistent, the matrix elements shall also meet:

$$a_{ij}a_{jk}=a_{ik}, \forall i,j,k=1,2,...,n \quad (4)$$

n order reciprocal matrix A is consistent matrix, If and only if its biggest characteristic root $\lambda_{\max}=n$; $\lambda_{\max}>n$ when there is an error on the consistency of A, the larger the error, the value of $\lambda_{\max}-n$ will be larger.

We can examine if the judgement matrix A is the consistent matrix by checking if $\lambda_{\max}$ is equal to n. Because the characteristic root continuously rely on a_{ij}, $\lambda_{\max}$ is much larger that n, the degree of inconsistence of A is more serious, the standardized eigenvector $\lambda_{\max}$ corresponded also can not reflect actually the ration of $X=\{x_1,...,x_n\}$ on the influence of factor Z. Therefore, it necessary for decision maker to do consistency check on judgement matrix, so as to decide whether to accept it.

Consistency check of judgement matrix, the steps are as follows:

(1) Consistency indicator CI calculating

$$CI=\frac{\lambda_{\max}-n}{n-1} \quad (5)$$

(2) Seeking corresponding average random consistency index RI. Randomly constructing 500 sample matrix: randomly extracting number to construct reciprocal matrix from 1-9 or their reciprocal, and calculating the biggest characteristic root of the average $\lambda'_{\max}$, defining

$$RI=\frac{\lambda'_{\max}-n}{n-1} \quad (6)$$

(3) Consistency ratio CI calculating

$$CR=\frac{CI}{RI} \quad (7)$$

When $CR<0.10$, considering that the consistency of judgement matrix can be accepted, or the judgement matrix appropriate correction.

(4) Total ordering layer and consistency check

Supposed last layer (A layer) contains m factors including $A_1,...,A_m$, their total order weight are $a_1,...,a_m$. And supposed the subsequent layer (B layer) contains n factors including $B_1,...,B_n$, their single order weight as regard to A_j are $b_{1j},...,b_{nj}$ (when A_j and A_j have no relationship, $b_{ij}=0$).The weight of each factor about the overall goal are calculated in B layer, namely the total ranking weight $b_1,...,b_n$ of B layer, calculating according to the following formula:

$$b_i=\sum_{j=1}^{m} b_{ij}a_j, i=1,...,n \quad (8)$$

Supposed factors are correlated to A_j in B layer compare by pairs to check the consistence of judgement matrix in single ranking, acquiring the consistence index of single ranking $CI(j),(j=1,...,m)$, the corresponding average random consistency index are

$CI(j),(j=1,...,m)$, the corresponding mean random consistency index are $RI(j)$, $CI(j)$, $RI(j)$ which have been calculated in single hierarchical arrangement, and hierarchical random consistency ratio of B layer is:

$$CR = \frac{\sum_{j=1}^{m} CI(j)a_j}{\sum_{j=1}^{m} RI(j)a_j} \tag{9}$$

When $CR < 0.10$, considering that the hierarchy total sorting result is satisfactory consistency and subject to the analysis of the results.

Then according to the different correlation matrix in the form of root to construct comprehensive correlation matrix with n components, its building method is as follows:

$$RM = \sqrt{\sum_{k=1}^{m} (\omega_k RM_k)^2} = (r_{Rij})_{n\times n} \tag{10}$$

In the formula, RM is comprehensive correlation matrix, its order is n; RM_k is the k sub-correlated matrix, $k=1,2,...,m$, respectively representing function sub-correleated matrix RM_F, principle sub-correleated matrix $RM_{P(T)}$, behavior sub-correleated matrix RM_B, DFX sub-correleated matrix RM_X; ω_k is the k correlated weight, and satisfies $\sum_{k=1}^{m}\omega_k = 1$, r_{Rij} is the comprehensive correlation coefficient between i and j. Compared with the traditional direct sum, taking this form of root to build a comprehensive correlation matrix can be more effectively to reflect the contact tightness between the components.

3. AHP algorithm optimization based on the genetic mechanism

3.1. genetic algorithm based on the improved fitness function

Before optimization of the AHP layer evaluation model based on the genetic algorithm, first to improve the fitness function of genetic algorithm. Direct purpose of fitness sharing function is to geographically separate the search space of different peak, each peak number accept a certain percentage of the individual, the size and peak height ratio. In order to realize such distribution, the goal of individual fitness sharing method is reduced, namely the fitness value f_i is divided by niche count m_i to acquire sharing founction, niche count m_i acts as estimation of individual adjacent set intensity

$$m_i = \sum_{j\in Pop} sh[d[i,j]] \tag{11}$$

In above formula, $d[i,j]$ is the distance between i and j, $sh[d]$ is the sharing founction which is a decreasing founction, $sh[0]=1$ and $sh[d \geq \ _{share}]=0$.

The following is a typical triangle shared functions:

$$sh(d) = \begin{cases} 1-\dfrac{d}{\sigma_{share}}, d \leq \sigma_{share} \\ 0, d > \sigma_{share} \end{cases} \tag{12}$$

Here σ_{share} is the niche radius r which is given by user and the minimum distance between individual with better peak value. Individual cut each other fitness in the range of distance σ_{share}. Because niche of these individuals are same, and they are converged in one niche in order to avoid convergence of the whole population. When one niche is filled, its niche court increased to make shared founction lower than other niche.

In order to define a niche, this paper uses a combined hamming distance measure and fitness distance method. If $d_1(x_i,x_j)$ is the hamming distance between two random individuals x_i and x_j, $d_2(x_i,x_j)$ is fitness distance, at this time sharing function can be defined as:

$$Sh(x_i,x_j) = \begin{cases} 1-\dfrac{d_1(x_i,x_j)}{\sigma_1}, d_1(x_i,x_j)<\sigma_1, d_2(x_i,x_j)\geq\sigma_2 \\ 1-\dfrac{d_2(x_i,x_j)}{\sigma_2}, d_1(x_i,x_j)\geq\sigma_1, d_2(x_i,x_j)<\sigma_2 \\ 1-\dfrac{d_1(x_i,x_j)d_2(x_i,x_j)}{\sigma_1\sigma_2}, d_1(x_i,x_j)<\sigma_1, d_2(x_i,x_j)<\sigma_2 \\ 0, else \end{cases} \tag{13}$$

σ_1 and σ_2 are the niche radius, namely the respective genotype and phenotype as the largest distance of individual in niche.

At last, after sharing, transforming individual fitness function into the form of the following:

$$f'(x_i) = \frac{f(x_i)}{\sum_{j=1}^{M} sh(x_i,x_j)} \tag{14}$$

$f(x_i)$ and $f'(x_i)$ are formulas for individual fitness function before and after sharing.

3.2. The analytic hierarchy process (AHP) model based on improved genetic algorithm

Firstly separating evaluation system into target layer A, criterion layer B and index layer C. Then suppose the single ordering weight value of each factor in layer B as $w_k, k=1,2,...,n$, and satisfy $w_k > 0$ and $\sum_{k=1}^{n} w_k = 1$, then

$$b_{ij} = w_i / w_j, i,i=1,2,...,n \tag{15}$$

If judgement matrix B satisfies formula (15), and $b_{ij} = w_i / w_j$, it is sure that can be called completely consistent, then we can get the type:

$$\sum_{k=1}^{n}(b_{ik}w_k) = \sum_{k=1}^{n}(w_i/w_k)w_k = nw_i \tag{16}$$

Thus:

$$\sum_{i=1}^{n}|\sum_{k=1}^{n}(b_{ik}w_k)-nw_i|=0 \qquad (17)$$

On the contary, it needs to be modified. Supposed he optimized formula of B is $X=\{x_{ij}|i,j=1,2,...n\}_{n\times n}$, and single ranking weight of each factor in X is $\{w_k|k=1,2,...,n\}$, then if the matrix X is smallest, the consistence of B is best.

$$\min CIC(n)=\sum_{i=1}^{n}\sum_{j=1}^{n}|x_{ij}-b_{ij}|/n^2 + \sum_{i=1}^{n}|\sum_{j=1}^{n}(x_{ij}w_j)-nw_i|/n \qquad (18)$$

$$s.t.\begin{cases} x_{ii}=1 \\ 1/x_{ji}=x_{ij}\in[b_{ij}-db_{ij},b_{ij}+db_{ij}]\cap[1/9,9] \\ w_k>0 \\ \sum_{k=1}^{n}w_k=1 \end{cases} \qquad (19)$$

In the formula, objective function $CIC(n)$ is called consistency index system and will be selected among $[0,0.5]$. In addition, single ranking weight value w_k and element facor of optimized formula $X=\{x_{ij}|i,j=1,2,...n\}_{n\times n}$ are modified variables, and there are total $n(n+1)/2$ independent modified variables for judgement matrix B with n orders. It can be concluded that the smaller the objective funcation $CIC(n)$ in formula (18), the higher the degree of consistence.

If $CIC(n)=0$ and $X=B$, formula (18) and (17) are both true, and judgement matrix B can be called totally consistent, then getting the unique value according to the formula

$$\sum_{k=1}^{n}w_k=1.$$

This paper uses the improved genetic algorithm in the biological evolution rule and chromosome information exchange mechanism to optimize the fuzzy evaluation method. When $CIC(n)$ is smaller than a certain value, then naming the consistence of judgement matrix B meets condition, and then calculating the single ranking weight value w_k, or the parameter d must be modified, until the consistence of judgement matrix B meets condition.

In a similar way, suppose the judgement matrix in layer C as $\{c_{ij}^k\}_{m\times m}$, then the single ranking weight val of each factor i of layer C to factor k of layer B is $w_i^k, i=1,2,...,m$, we can get the corresponding consistent objective function $CIC^k(m)$. When $CIC^k(m)$ value is smaller than a certain value, naming the consistence of judgement matrix $\{c_{ij}^k\}_{m\times m}$ meets condition and then calculating the single ranking weight value w_i^k; or the judgement matrix $\{c_{ij}^k\}_{m\times m}$ must be modified repetitively, until the consistence of judgement matrix $\{c_{ij}^k\}_{m\times m}$ meets condition.

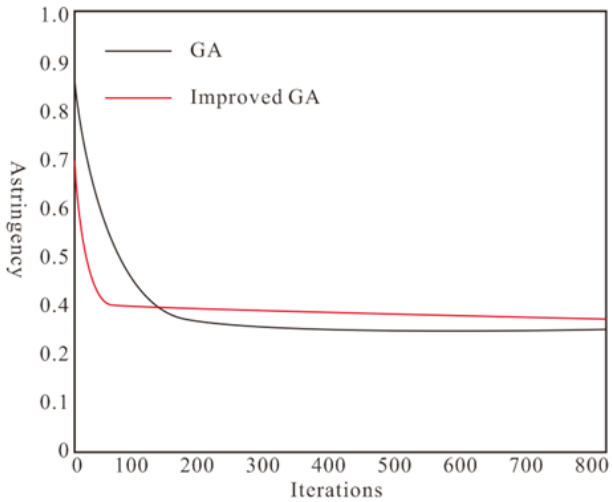

Figure 1. Convergence verification of improved genetic

4. Algorithm performance simulation

In order to verify the effectiveness of the improved algorithm proposed in this paper, simulation experiments is conducted. Firstly validating convergence analysis of the improved genetic algorithm, and compared with the original algorithm, the result is shown in the following figure.

Then the accuracy of AHP analytic hierarchy process (AHP) based on improved genetic algorithm is analyzed, with the improved algorithm and the original algorithm to analyze an evaluation example, its accuracy results are as shown in the figure below.

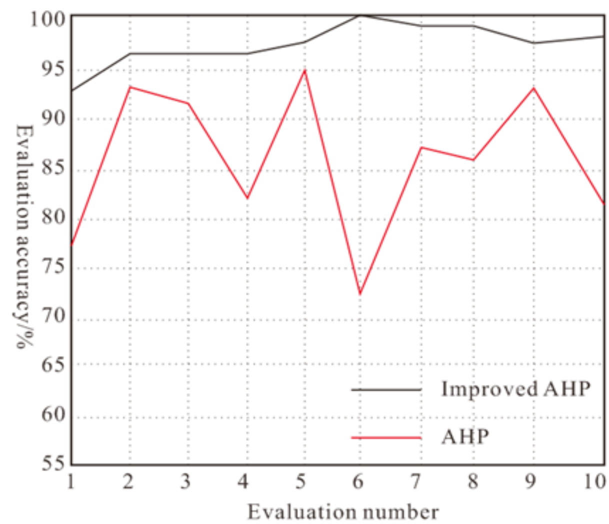

Figure 2. Accuracy analysis of improved AHP analysis

Finally using improved method proposed in this paper to plan a certain complex product and module parameters, the product of the finished products is as shown in the figure below.

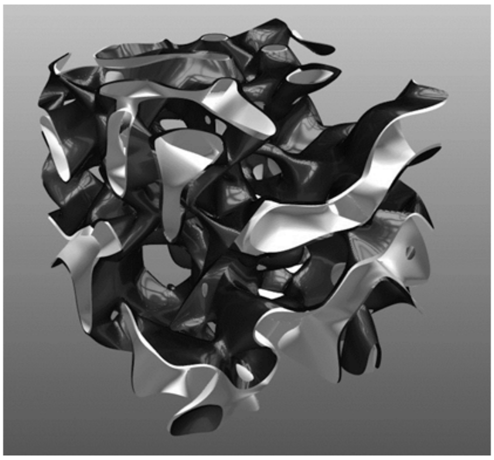

Figure 3. Final product of complex product

5. Conclusion

With the global economic integration and the development of social informatization, enterprises are facing great changes in the market environment, competitive product technology increasing, research and development costs rising, customer demand for personalized, customized products continue to increase, and the modular approach is an effective way to reduce product development costs, resolve customer customization needs, which become the focus in the engineering profession and management scholars. From perspective of customer functional requirements analysis, this paper puts forward a kind of system module parameter programming model of complex product optimized by the AHP (analytic hierarchy progress) algorithm which is based on improved genetic algorithm, the experimental simulation results show that the effect is more outstanding to use the improved algorithm of complex product system to plan module parameters.

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