COLOR DESIGN BASED ON KANSEI ENGINEERING AND INTERACTIVE GENETIC ALGORITHM

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ABSTRACT: To reduce the dependency on designers' experience or other professional knowledge in product color design and obtain the color scheme meeting user's Kansei requirements, a method based on Kansei engineering (KE) and interactive genetic algorithm (IGA) is proposed in this paper. Firstly, color scheme was obtained from plane image by using color merging and fuzzy processing techniques, and based on this, color scheme database was constructed. Then, the mapping model of image words and individual color was constructed by using KE to obtain the color image contribution values. The fitness function was given based on the color image contribution values, color harmony and user's evaluation. The color scheme could be generated and optimized with the IGA until acquiring satisfactory scheme. Application process and procedure of the proposed method were described by a case of numerical control machine tools color design. The case study results reveal that the approach can effectively obtain satisfactory color scheme.

KEY WORDS: Kansei engineering; interactive genetic algorithm; color design; color image

1 INTRODUCTION

Product color, as an important part of the product design, has the vital role in product style and image positioning. At present, relevant experts and scholars pay more attention to product method research of modeling design, while the product color design mainly depends on professional knowledge of professional designers, little considering user requirements, especially the Kansei demand, therefore, intelligent and accuracy design need to be improved.

At present, the research of product color design focuses on two aspects, on the one hand, the research makes the products get a variety of different color scheme method (Wang et al., 2004; Luo 2006), and build color matching scheme base used for three dimensional products through getting a lot of color matching schemes from two dimensional images. On the other hand, it studies the user evaluation and optimization method of the color scheme and intelligent computer method mainly including the genetic algorithm, neural network, fuzzy hierarchy analysis, ant algorithm, grey correlation analysis method are used to evaluate and optimize images of color matching scheme (Sun et al., 2007; Man et al., 2010; Li and Zhu, 2012; Liu et al., 2012, Zhang et al., 2013). Kansei technology is mainly used for product modeling research, and building the Kansei engineering model, so as to guide product design by obtaining product modeling elements of the image (Luo 2007, Press 2010). Interactive genetic algorithm considering the advantage of traditional evolutionary algorithm, combines with the evaluating value of user interaction to make the evolution results more in line with the user requirements, and it has the characteristics of simple operation, fast convergence. Sun et al., (2012) uses interactive genetic algorithm to optimize product design scheme to meet image requirements of users. Geng et al., (2011) uses interactive genetic algorithm for 3D garment design, reducing the specialty of fashion design, and improving the efficiency of the clothing design.

This article first extract the color scheme from the source two-dimensional image, and build the color scheme base. Based on this, image value of matching scheme is obtained by using Kansei engineering method and the contribution factor of each individual color is obtained through constructing engineering model. Interactive genetic algorithm is used to build fitness function based on contribution factor, harmony evaluation and interactive evaluation, and make interactive heredity, realizing the automation of product color.

2 ACCESS TO COLOR SCHEME

Product color scheme is mainly composed of three parameters: color variety, color RGB value (the basic mode of color have RGB mode, CMYK mode, Lab, etc. this paper takes RGB model as example to demonstrate), and color area proportion. Because the source two-dimensional image contains a variety of colors, and the color number of the product is less than or equal to 4 commonly, so analyze and induce the color contained by source of two-dimensional image to determine the product

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color scheme is operation first needed. The processing of source two-dimensional image can be divided into two steps, one is fusion, which uses the fuzzy processing algorithm, fusing similar color by setting the threshold. Another is choosing, namely according to the proportion of each color area, remain color that has big proportion and significant influences on the whole, and delete the ignorable color with small proportion. The process is shown in figure 1.

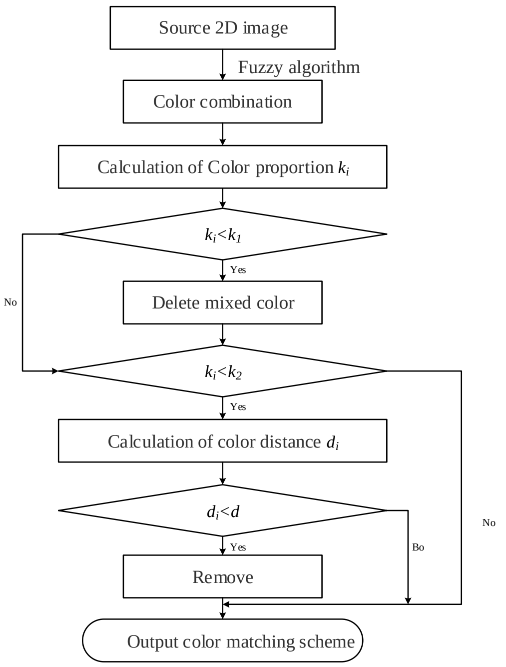

Figure 1. Extracting Process of Color Matching Scheme

Color combining with related research theory and system has become improved, so color is combined by using common image processing software. After combination of image, according to the formula (1), the proportion of each color image is calculated.

$$k_i = \frac{p_i}{AB} \tag{1}$$

K_i is the ratio of each color, p_i is a certain color pixels. A and B represent the length, and the width sizes of 2 dimensional images. k_1 in figure 1 is the critical value of mixed color, used to remove motley. If it is less than k_1, then motley is regarded to be removed. k_2 is critical value of eyeball color, "Dot eyeball" refers to that main colors are highlighted with small proportion and strong comparing color in some excellent matching color to reach the good visual effects of whole matching color. For example, large proportion red usually uses small proportion and strong comparing black color as dot eyeball color. Therefore, when choosing small proportion color, it needs t judge whether it is dot eyeball color. Through calculation and analysis of small proportion color and Euclidean distance between small and large extracted proportion color, recognition is made to maintain dot eyeball color and delete motley. color that k_1 is less than k_2 is judged when those color proportion meets condition.

Euclidean distance among colors

$$D_{ij} = \sqrt{(X_{rj} - X_{ri})^2 + (X_{gj} - X_{gi})^2 + (X_{bj} - X_{bi})^2} \tag{2}$$

D_{ij} in formula (2)is the Euclidean distance of j color. X_{ri}, X_{gi}, X_{bi} are respectively RGB value of i in small proportion color. X_{rj}, X_{gj}, X_{bj} are respectively RGB value of j in color matching scheme. When small proportion color meet $\min(D_{ij})>D$ (in particular, D is Euclidean distance threshold), then color is not eyeball color, and remained. On the contrary, if it meets $\min(D_{ij})<D$, then the color is motley and deleted.

The processing method not only reduces color number of the source two-dimensional image, making it meet the need of product color, and also remain dot eyeball color of source two-dimensional image and its source color style is preserved to the greatest extent, providing effective configuration scheme for product color design.

3 CONTRIBUTION CALCULATION OF COLOR IMAGE BASED ON KANSEI ENGINEERING

3.1 Confirmation of Image Vocabulary

Collect image adjectives describing object color scheme from different aspects as experimental variables, to build the multidimensional cognitive space of color scheme. First, lots of initial image vocabularies are obtained through the literature research and the consultation of related design expert. Divide the collected image vocabulary into groups and use the card analysis (card system) to choose a representative image vocabulary for each group (Eklund et al., 2004); then use the principal component analysis (PCA), according to contribution of each indicator, choose the main image vocabulary. Finally get 6~8 groups Kansei word.

3.2 Building of the Emotional Image Cognitive Space

Space image of emotional cognitive building is completed based on the user survey. First, select multiple configuration schemes with big difference, and design space in view of perpetual sense of constituted by captured image vocabulary and build the 7 subscales of semantic differences. Each single color is corresponding to each semantic difference scale in matching scheme and build image cognitive experiment questionnaire.

For a certain image vocabulary, through the emotional image cognitive experiment of configuration scheme by users, emotional value of each configuration scheme by users is obtained, forming the emotional image cognitive space. Set n image vocabulary of m evaluator to evaluate the emotional cognitive vector and the vector is $\{A_1^{m,n}, A_2^{m,n}, \ldots A_i^{m,n}\}$. Particular, $A_i^{m,n}$ means i evaluating scheme's emotional evaluation value on n image vocabulary of m evaluator, then all schemes' cognitive space formula (3) on n image vocabulary of m evaluator is shown below.

$$\begin{bmatrix} A_1^{m,n} & A_1^{m,n} & A_1^{m,n} & \cdots & A_1^{m,n} \\ A_2^{m,n} & A_2^{m,n} & A_2^{m,n} & \cdots & A_2^{m,n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_i^{m,n} & A_i^{m,n} & A_i^{m,n} & \cdots & A_i^{m,n} \end{bmatrix} \tag{3}$$

Then all evaluators' cognition on n image vocabulary constitutes the high-dimensional space image cognition. In the high-dimensional image cognitive space, set average emotional evaluation value of i of n image vocabulary to be $\sum_{m=1}^{q} A_i^{m,n} \Big/ q$.

It is key value to realize the conversion and the expression between user needs and configuration scheme and build mapping model between the color image and single color, in particular, q is the user number participated in the test.

3.3 Color Semantic Contribution Calculation Based on Linear Regression

In KE, multiple Regression Analysis is usually used to establish linear relationship between image vocabulary and a single color.

According to the theory of quantification class 1 (Yang et al., 1999), assume dependent variable y_n and independent variable x have linear correlation. in each image vocabulary, y_n is average Kansei evaluation of each configuration scheme, namely $\frac{\sum_{m=1}^{q} A_i^{m,n}}{q}$ x is single color. It constitutes function like formula (4)

$$y_i = \sum_{j=1}^{r} \sum_{k=1}^{C_j} a_{jk} \delta_i(j,k) + \varepsilon_i \tag{4}$$

a_{jk} in formula (4) is coefficient value of k item of j item. ε_i is a residual and C_j is class number of each category. $\delta(j, k)$ is determined in accordance with formula (5).

$$\delta(j,k) = \begin{cases} 1 & \text{when qualitative data of} \\ & j \text{ item in sample is } i \\ 0 & \text{None} \end{cases} \tag{5}$$

In formula (5), j is item, k is category, $\delta(j, k)$ is the response of k category of j item in i sample. the color of the configuration scheme constitutes qualitative data that is transformed into quantitative data expressed by 1 and 0.

SPSS statistical software is used for multiple linear regression. The solved value of a_{jk} is the color semantic contribution.

4 COLOR HARMONY DEGREE EVALUATION UNDER REGIONAL DIFFERENCES

Differences of Color effect area (area and relative position) will affect the evaluation results of the color combination's harmony degree. The traditional aesthetic formula is $M=O/C$ (o means color sequence measurement; C means measurement of color complexity) (Tsai and Chou 2007). Three basic attributes of color in Munsell color space including hue h, brightness v and chroma c are used to make mediate calculation, without considering the influence of the shaded area. this paper gives full consideration to the effects of shading area of color harmony, if areas waiting to be shaded is adjacent to each other, sequence them depending on contribution factor size of the assigned color image size. The high contribution factor is regarded as main color effect area, whereas it is inferior color effect area. Harmonic degree evaluation method influenced by shading area differences is $M=O/C$, $C=C_m+C_h+C_v+C_c$, $O=\Sigma(G+O_k+O_v+O_c)$. In particular, C_m is the total color number of color scheme, C_h, C_v, C_c are color logarithm with differential values of h, v, c. O_h, O_v, O_c are order coefficients determined by h, v, c.

Harmony assessment results of scheme composed of n kinds of colors is within $-n$~n. According to Moon and Spencer theory, when assessed value M>0.5, it means harmony stat of color scheme is good, therefore, harmony of color scheme shown in definition formula (6) fixes assessment values.

$$\begin{cases} H=0, & \text{if } M<0 \\ H=M, & \text{if } 0\le M<0.5 \\ H=0.5+\frac{1}{2n-1}(M-0.5), & \text{if } M\ge 0.5 \end{cases} \tag{6}$$

5 COLOR INTERACTIVE GENETIC OPERATION

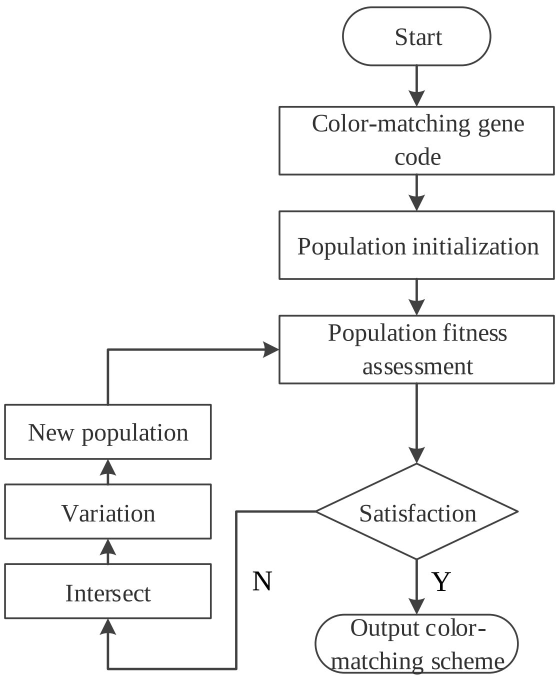

Figure 2. Interactive Genetic Operation Process

Interactive genetic algorithm uses global optimization characteristic of genetic algorithm and make users evaluate evolution results. The designer's design knowledge can be incorporated into computer technology, to ensure that solutions to achieve optimization for the purpose of users demands. This paper use the algorithm to evaluate population fitness with image values, the user evaluation value and harmony degree evaluation, and finally satisfied results of users are obtained, and the optimization process is shown in figure 2.

First, according to designated needs of users, objective products and color image vocabulary of color-matching design produce population initialization. Then individual fitness value can be obtained by combining image assessment, harmony evaluation and user interactive assessment results and judged according to conditions: if it meets requirements, then input color-matching scheme; otherwise, optimum maintaining simple genetic algorithm is used to enable best population fitness individual of each generation directly conserve to next generation and other individuals implement genetic operation including selection, intersection and variation. In actual operation, with the increase of genetic algebra, when fitness of color-matching scheme sets higher than the set threshold or user in the process of operation have found satisfactory results, genetic process ends, and inputs color-matching scheme.

5.1 Population Fitness Solution

Fitness function is the basis of evaluating individual in the process of the genetic operations (color scheme), and the standard of individual survival of fittest in genetic operation process. the bigger the function value is, the higher the quality of the solution is, which means that can better meet the user's expectations. The fitness function includes image values, user evaluation score and harmony degree evaluation. Set fitness function is

$$F_W=\begin{cases}(1-\alpha)F_S+\alpha H, & H\in(0.2,\ 1],\ \alpha\in[0,1] \\ 0 & H\in[0,\ 0.2]\end{cases} \tag{7}$$

$$F_S=\beta G_A+(1-\beta)F,\ \beta\in[0,1] \tag{8}$$

F_s is the linear weighted sum of color image score G_A and user interactive evaluation score F, H is the harmony score, α and β are weights. To ensure harmony of color-matching scheme, when system sets $0\le H\le 2$, F_w=0. The calculation method of F and G_A is as followed:

First, the users designate expected color image vocabulary reflected in color-matching scheme, and set corresponding weight coefficient f_i, $\sum_{i=1}^{n} f_i=1$ of each image vocabulary according to users' preferences. Set A_{xy} to be the score of corresponding image vocabulary y of x color in color-matching scheme, then $G_A=\sum_{i=1}^{n} f_i \sum_{t=1}^{m} A_{xy}$. The m means color number of color-matching scheme. Set evaluation scores of color-matching scheme under each image vocabulary to be P_i, i=1, 2,…, n, then $F=\sum_{i=1}^{n} f_i P_i$. In n means image vocabulary number of describing color scheme.

5.2 Color-matching Gene Encodes

Before color genetic operation, the products are divided into different color-matching components, in the process of genetic operations, it remain the same, which is called static property. As a result, the chromosome is divided into static gene and dynamic gene, making the color matching results can be shown directly. Define {(G_1, C_1), (G_2, C_2),…, (G_n, C_n)}, C_i is the i component needed to be dyed of product and C_i is the i color data, C_i={(id), (RGB), (CF_1, CF_2,…, CF_i, CF_n)}, CF_i means corresponded color semantic contribution factor of color, namely a_{jk} described in passages above. Therefore, chromosome structure is shown in the figure below.

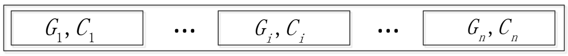

Figure 3. Chromosome structural diagram

6 CASE STUDY

This paper, taking the color design of numerical control machine tool as an example, design product color with the method proposed in this paper. Two-dimensional images of product color design are widely collected. Color is extracted according to methods mentioned above to build scheme database constituted by color-matching schemes extracted.

First 60 image vocabularies are obtained through investigation, interviews of users, interviews of designers, and analysis of literature. After a preliminary screening, only 48 image vocabularies remain left. and then use the card analysis method to divide the image vocabularies into 7 groups, and then use the principal component analysis (PCA) to get the most representative images vocabularies of each group, and the result is shown in table 1. Finally, 7 image vocabularies (bold part in table 1) are obtained, including elegant (E), happy (H), modern (M), simple (S) coordinate (C), deep (D) and passionate (P)

Table 1. Selecting Results of Image Vocabulary

	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7
Image vocabularies	elegant	cute	tide	Keep low	soft	solemn	strong
	reserve	happy	**modern**	ordinary	Warm	dark	bold
	grandiose	bright	fashion	**simple**	kind	Low-spirit	striking
	elegant	personalized	vivacious	austerity	**coordinate**	sad	**vehement**
	classical	**happy**	fashion	natural	comfortable	depressed	passionate
	noble	young	happy	light		**deep**	rigid
	elegant	positive		light		dignified	
		vigorous					
		relaxed					

120 sets of configuration schemes are selected from color-matching scheme database, and teachers and students participated in selecting image vocabulary are invited to evaluate 120 set of color-matching scheme with selected image vocabulary. Make statistical evaluation results, and calculate the average. According to the method mentioned above, build the Kansei engineering model based on linear regression, getting image contribution degree of each color. In particular, each separate color results of two matching schemes are shown in table 2. The bigger contribution means it is more consistent with the image, conversely, it is not.

Table 2. The contribution of each separate color in the image for the two of configuration scheme

Scheme	Color Configuration	Color RGB R	G	B	Image vocabulary contribution value E	H	M	S	C	D	V
Scheme 1		161	161	161	-0.42	-0.64	0.56	0.18	0.27	0.51	0.12
		150	136	131	-0.39	-0.7	0.15	0.06	-0.28	0.42	0.23
		121	0	0	0.56	-0.18	-0.02	-0.31	0.15	0.35	0.65
		15	13	39	0.4	-0.68	-0.35	-0.24	0.05	0.62	0.54
Scheme 2		30	23	17	0.43	-0.56	0.45	0.37	0.29	0.84	0.32
		241	241	227	0.62	0.54	0.35	0.48	0.27	-0.45	-0.42
		225	192	225	0.74	0.42	0.41	0.39	0.19	-0.32	-0.36
		172	224	205	0.53	0.37	0.26	0.27	0.08	-0.61	-0.38
		20	93	128	0.65	0.12	0.07	0.19	0.28	0.19	-0.15
		14	33	42	0.31	-0.26	0.35	0.6	0.55	0.64	0.48

Visual Studio is used to develop the prototype system, this paper adopts single point intersection method, and a system for population size is 6, with 0.8 crossover probability and 0.8 mutation probability. User select different color image vocabulary and set three parameters relative weights of different color image points, the user score and color harmony degree for different color scheme. For example, when a user is an experienced color-matching design staff, it can appropriately increase user evaluation weight to get personalized color-matching scheme. When a user is non-professional match colors design personnel, it can appropriately increase weight image points and color harmony degree, getting some more moderate color-matching scheme. Interface is as shown in figure 4, the user first score and evaluate image vocabulary in each new generation color-matching scheme by typing '- 5-5' integer values. Then click 'next generation', the system makes genetic optimization on last generation. Repeat the process until the user satisfaction of color design is obtained. Figure 4 shows the part product genetic evolution results.

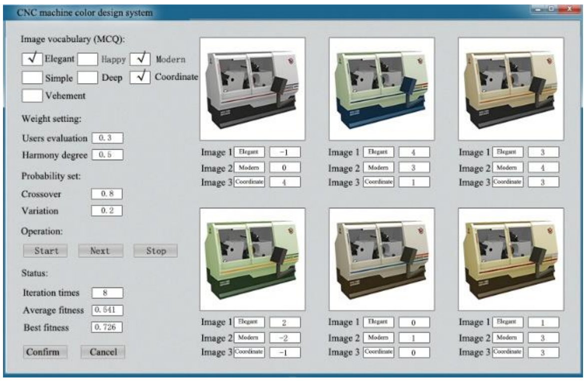

Figure 4. CNC machine color design interactive genetic operation interface

When making the color design, the use of different image words can obtain different color design. Select 'elegance' and 'happiness' image vocabulary can obtain the results shown in figure 5.Select the image of 'simplicity' and 'depth' words can obtain the result shown in figure 6. The results showed that due to the effect of the user's different values, the same image vocabulary will have different the evolution directions, thus different color matching results are obtained. All color matching results under the same image vocabulary showed obvious similarity, but their specific color combinations are not completely the same.

Figure 5. Evolution Results of 'Elegant' and 'Happy'

Figure 6. Evolution Results of 'Simple' and 'Deep'

7 CONCLUSION

This article combines the Kansei method and interactive genetic engineering method providing a new method for product color design, first extract the color scheme from the source two-dimensional image; Then use the mapping model of modeling element and image vocabulary in Kansei engineering to build the mapping model of each separate color and image vocabulary in color configuration scheme to gain the contribution factor of each individual color. Based on this, interactive genetic operation is made to get product color design meeting Kansei demands of users. Finally, product color design of numerical control number is taken as an example of the method is verified. This method combines the advantages of Kansei technology, getting product color design meting Kansei demands of users and expanding the application range of the Kansei engineering method; The genetic evolution is a simple operation, reducing the dependence on professional knowledge for color design. Therefore, this article provides an effective method to improve the efficiency of product color design.

8 ACKNOWLEDGEMENTS

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