人工智慧輔助產品色彩配色
Artificial Intelligence Aided Product-Color Combinations

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摘要

電腦輔助設計軟體系統在產品概念設計與色彩計畫上扮演著重要的角色，現今以電腦輔助產品色彩的表色方式主要以 CIE 色彩系統爲主。本研究以 CIE 色彩之三個主色光，紅(R)、綠(G)、藍(B)爲基礎，運用色彩調和理論與灰色理論發展出一套可量化的產品色彩美度計算及意象語彙評價的方法。此外，亦可依據設計師所需求的產品目標意象，在良好的色彩美度水準下，以基因演算法進行最佳產品色彩組配的反向搜尋。因此，本研究所架構之自動化設計系統，將可以協助設計師快速模擬產品色彩組配並評價其整體色彩意象値，同時亦可進行目標意象之理想色彩組配搜尋。

關鍵字：產品色彩設計、最佳化設計、基因演算法、人工智慧

Abstract

CAD systems play an essential role in product concept design and color planning. The representations produced in computer-based color simulations are generated mainly using the CIE color system. Accordingly, this study uses color harmony theory and gray theory to develop a quantitative aesthetic measurement and linguistic evaluation method based on the primary colors, i.e. R (Red), G (green), B (Blue), for the CIE color planning stage of product design. In an inverse process, genetic algorithms are applied to search for a near-optimal color combination which satisfies the designer's required product-color linguistic image on a qualified aesthetic level. The automatic design system proposed in this study enables designers to rapidly simulate the designed colors of a product and then obtain its corresponding image evaluation, or to search for the ideal color combination which generates the required image perception.

Keywords: Product color design, Optimum design, Genetic algorithms, Artificial intelligence

A. Introduction

Due to the remarkable advances in numerically–controlled machining technology for product manufacture in recent decades, the functional aspects of many of the consumptive products used in our daily lives are now fully matured. Subsequently, for enterprises seeking to develop new products in today's highly competitive marketplace, typically characterized by short product life cycles, the apparent style of a product, i.e. its form and color, is of an ever-increasing importance. Designing and manufacturing the wide variety of product forms required to meet the diverse requirements of individual consumers is both time consuming and expensive. However, by varying the color combinations of the visible components of a product, an enterprise can generate a wide variety of different product image perceptions. In this way, a product produced from a single fixed mold can be offered to the market in numerous color combinations so as to satisfy the individual consumers' various needs.

In an earlier study relating to a door lock design, the current authors [1] found that the overall product image perception was dominated by the product color rather than the product form. Colors play an important role for customers in making decisions on what they like or dislike [2]. Traditional products with specific color combinations generally fail to satisfy the diverse needs of the total consumer group. Therefore, developing products with particular color schemes targeted at specific consumer groups has emerged as an essential strategy for many enterprises. By providing products with components of different colors, enterprises have the ability to satisfy the particular tastes of each individual consumer group. Therefore, if a product's competitiveness is to be improved, designers need not only to understand the consumer's psychological needs, but also to learn how best to fully exploit and manipulate a database of limited color images for product design and evaluation purposes.

Previous studies of color-image perception focused mainly on the image evaluation of products of single colors. Hsiao [3] used fuzzy set theory to select the most suitable color for a car from a choice of specified colors. In a later study, the same author [4] proposed a systematic method for product-color design based on the Munsell color system. Ishihara *et al*. [5] attempted to build a Kansei engineering expert system for single-color images by using self-organizing neural networks. Choo and Kim [6] investigated the color effect in fashion fabric product images using Munsell and PCCS color notations for the color variables. Nowadays, color designs based on the CIE color system can be virtually rendered in 3-D CAD models in the color planning stage of product design. However, most previous color image models in this field considered the colors of the object rather than the colors of light. Ou and Luo [2] established color emotion and color preference models for single colors using the CIELAB color space. In a study investigating the image evaluation of multiple colors in the field of interior design, Shen *et al.* [7] proposed a linguistic-based image evaluation model of color harmony based on the CIE system. Meanwhile, the current authors [8] applied gray system theory [9] to develop a systematic method for evaluating the overall image perception of a product with components of different colors defined using RGB parameters.

The color-image studies introduced above dealt with the image evaluation of products with predefined color combinations. Comparatively, little attention has been paid to the reverse case in which the aim is to search for the optimal color combination which satisfies a color image evaluation requirement. However, linguistic image-oriented auto-searching approaches for optimal color combinations must be supervised by appropriate color harmony theories. If not so, even though the obtained overall image may be close to the required linguistic image goal, the search results of such schemes tend to be dull and uncoordinated.

Birkhoff [10] was the first researcher to evaluate aesthetics on a quantitative basis. Moon and Spencer [11,12] applied Birkhoff's theory of aesthetic measurement to the problem of color harmony based on the Munsell system. The present study combines the color-harmony-based aesthetic measurement method with the gray-theory-based linguistic evaluation method proposed previously by the current authors to co-evaluate the image sensations of different color combinations. The Munsell-based color parameters of the aesthetic measurement scheme are transformed into RGB parameters such that the evaluation results can be integrated with a CAD system. Subsequently, genetic algorithms [13] are employed to search for the near-optimal color combinations which match the input image requirements based on the proposed aesthetic and linguistic evaluation method.

Unlike conventional problem-solving techniques, genetic algorithms converge towards the optimal solution from multiple directions. In the population-based search method employed by the genetic algorithms, newly evolved chromosomes are equivalent to the continuously generated color-design candidates produced in a brainstorming process. Although it is recognized that optimal solutions do exist for most engineering problems, it is frequently difficult to identify this optimal solution at the conceptual design stage, and therefore a near-optimal solution probably represents the best solution which can reasonably be hoped for. Nevertheless, by defining the color evaluation algorithms as appropriately as possible, the designer can increase the possibility that the obtained solution will closely approximate the optimal solution.

The automatic design system presented in this study takes the case of the color design of a thermos flask for illustration purposes. The proposed system comprises two sub-systems, namely an image prediction sub-system and a color-combination search sub-system. In the proposed approach, color parameters are input to the image prediction sub-system and are output from the color-combination search sub-system. Meanwhile, the predicted/desired image evaluation is output from the image prediction sub-system and is input to the color-combination search sub-system. Using the proposed system, the designer is able not only to determine the likely consumer reaction to any color scheme proposed for a product, but can also search for an ideal (near-optimal) color-combination which will likely satisfy the required product-color perception. The customized interfaces of the proposed system can be integrated with the I-DEAS system such that the designer can view real-time 3-D colored models rendered with the assigned input color parameters, or can search for color schemes which satisfy a set of image evaluation targets.

B. Aesthetic and Linguistic Image-based Genetic Searching

This study implements the aesthetic measurement method, gray theory, and genetic algorithms to develop a computer-aided automatic product color image prediction and color-combination search system. The proposed system comprises two fundamental mechanisms, namely: (1) an aesthetic and linguistic color image prediction function using the aesthetic measurement method and gray theory, and (2) a search function for optimal two-color combinations using genetic algorithms. The basic concepts of these two functions are presented in Fig. 1. The aesthetic and linguistic image prediction function establishes a model from which the likely consumer reaction to a product color image can be predicted by giving a set of input color parameter values. The color combination search function performs essentially the reverse operation, i.e. it provides the designer with the ability to search automatically for a near-optimal color combination for a product based upon a set of specific image perception requirements. Gray theory is employed to establish the relationship between the linguistic image and the color parameters, and the aesthetic measurement method is applied to evaluate the aesthetic degree with regard to color harmony during the image prediction phase. Finally, genetic algorithms are used to perform an evolutional search for elite color combinations, which are then evaluated by the aesthetic and linguistic image prediction function.

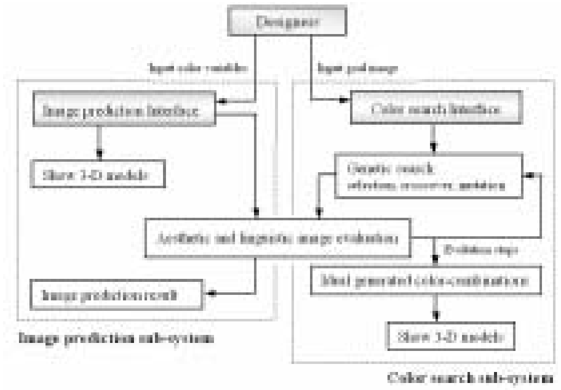

Fig. 1. Basic concepts of automated image prediction and color search mechanisms

C. Implementation Procedures

This study implements an automatic color design system and verifies its effectiveness by considering the case of the color design of a thermos flask. A rendered 3-D model of the constructed flask is shown in Fig. 2. In this study, two arbitrary primary colors are assigned to the two color categories of the model's apparent components. The detailed procedures involved in establishing the color system are described below:

(1) Define the color parameters for the two color categories.
(2) Create basic single-color samples rendered on 3-D models.
(3) Carry out product-color aesthetic and linguistic image evaluation experiments.
(4) Establish evaluation models for the aesthetic and linguistic image measurement mechanism.
(5) Establish the genetic algorithm-based product color-combination search model.
(6) Demonstrate the reliability of the proposed color evaluation model using a further image experiment. (Table 1)
(7) Construct an operational system for the aesthetic and linguistic image prediction and color-combination search, including:
    (a) an interface for product color image prediction
    (b) an interface for product color search

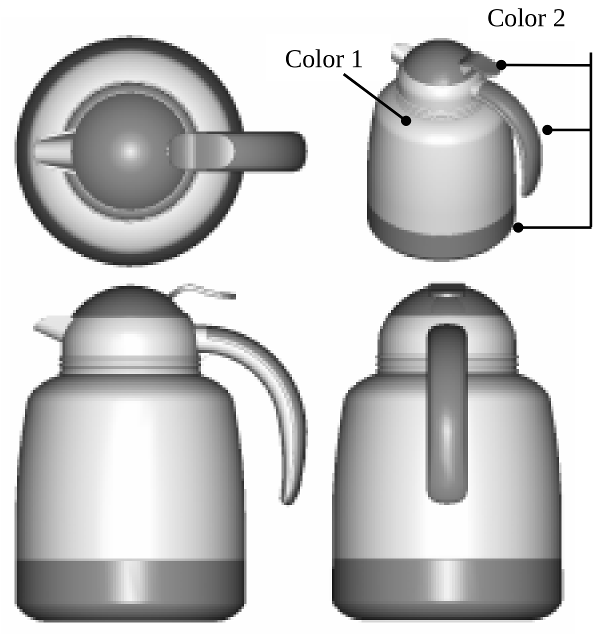

Fig. 2. Rendered 3-D model of constructed flask

D. Case Study for Product Color Design

1. Example 1

This example considers the color design of a thermos flask and the prediction of its image evaluation given an input set of color parameters. The interface presented in Fig. 3 illustrates the given values of each color parameter. When all of the parameter settings have been specified, the “3-D Color Simulation” button is clicked to export the VRML file to the Cosmo Player, as shown in Fig. 4. After the design has been viewed dynamically and determined to be satisfactory, the “Image evaluation” button is clicked to display the color-image prediction window illustrated in Fig. 5 to check the aesthetic and linguistic tendencies of the image.

Table 1. Comparison of image prediction results with experimentally verified data

No	Color 1			Color 2			Proposed model		Verified target value	
	R_1	G_1	B_1	R_2	G_2	B_2	LI	AI	LI	AI
1	56	83	148	144	165	214	0.61	0.92	0.70	0.78
2	159	173	93	127	181	199	0.55	0.48	0.72	0.63
3	228	232	46	232	145	46	0.46	0.38	0.47	0.51
4	237	129	229	235	65	229	0.25	0.61	0.22	0.58
5	84	55	28	204	213	250	0.60	0.55	0.63	0.52
6	230	106	157	206	248	226	0.32	0.30	0.33	0.12
7	235	169	71	246	238	8	0.45	0.24	0.40	0.44
8	219	235	173	37	134	20	0.53	0.76	0.52	0.81
9	31	61	123	207	236	122	0.67	0.81	0.69	0.59
10	255	239	241	239	255	243	0.45	0.23	0.39	0.55
…										
20	243	13	13	207	253	253	0.43	0.76	0.40	0.51

RMSE: 0.069 (LI / Proposed model → Verified target value)
0.172 (AI / Proposed model → Verified target value)
LI:Linguistic (feminine–masculine) image, AI: Aesthetic image

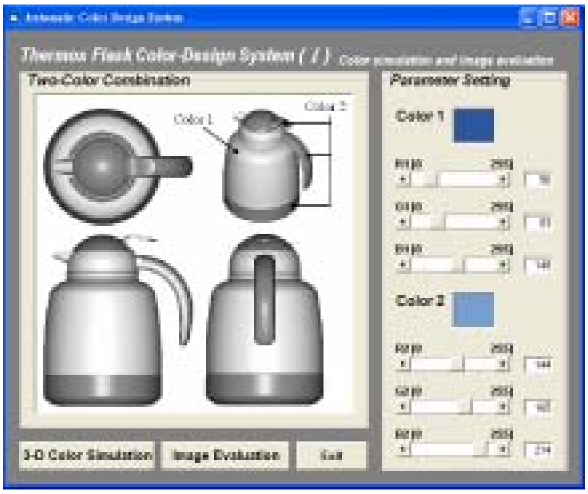

Fig. 3. Interface for constructing 3-D model and performing color-image prediction

Fig. 4. 3-D VRML file presented on Cosmo Player

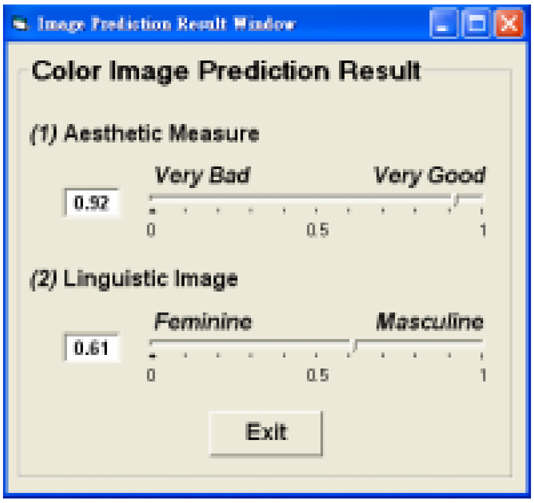

Fig. 5. Color-image prediction window

2. Example 2

This example considers the inverse operation to that described above. The interface shown in Fig. 6 is used to generate an ideal color-combination given target linguistic image evaluation value, e.g. feminine–masculine (0.2) for the aesthetic requirement, with related weights, e.g. 0.5 and 0.5, respectively. The number of iterations is set to 100, which implies that the optimization system will perform the fitness function evaluation process 1000 times (i.e. since $N_{population}$ = 10). Fig. 7 illustrates the trend for the aesthetic and linguistic images, and demonstrates the improvement of the overall fitness over the evolution of the search process. Fig. 8 illustrates the best-fitted color combinations for the 1st, 20th, 40th, 60th, 80th and 100th generations. The evolution statuses of the product colors as they converge towards the target image evaluation specification are clearly shown. The final search result is presented in the search-result window shown in Fig. 9, which presents the evolved color parameter variables of the best-fitted colors and the associated evolution-terminated data.

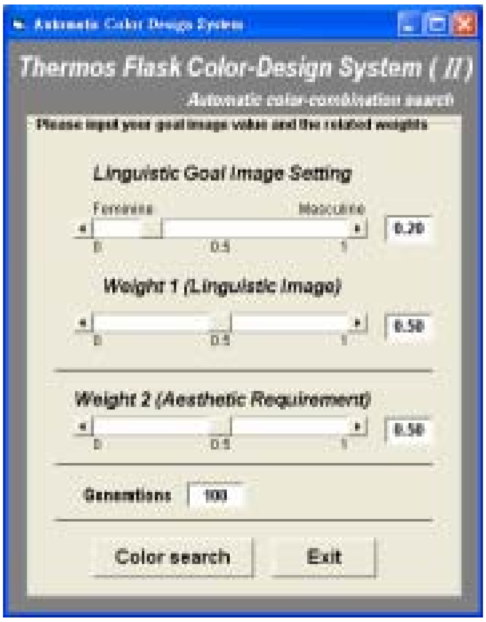

Fig. 6. Interface for product color-combination search

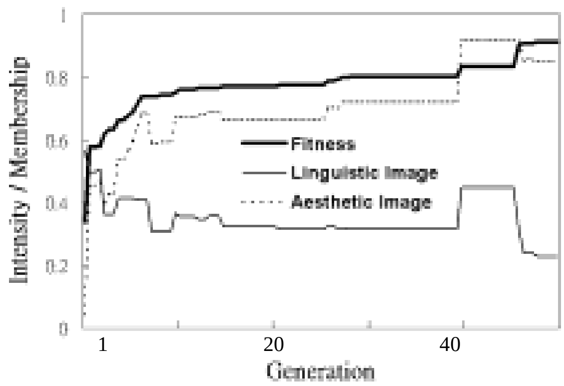

Fig. 7. Trend for each image and improvement of overall fitness in evolution of search process

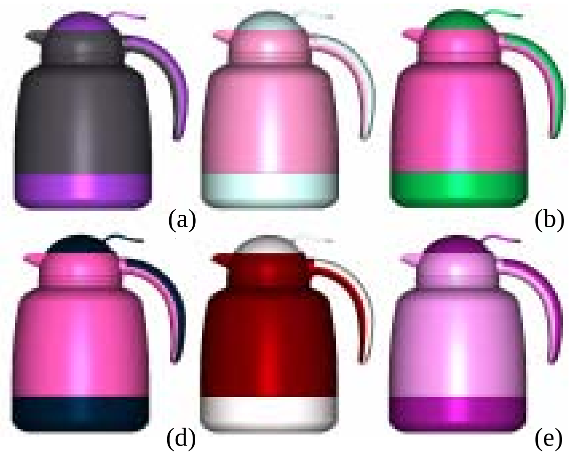

Fig. 8. Color evolution: best-fitted color combinations of: (a)initial, (b)20th, (c)40th, (d)60th, (e)80th and (f)100th generation

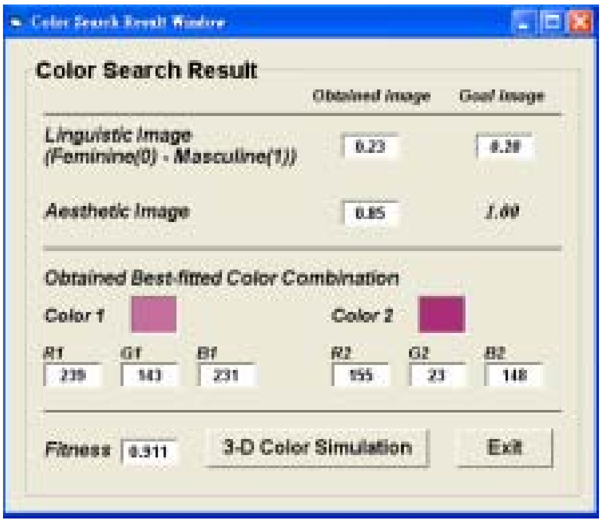

Fig. 9. Search-result window presenting evolved color variables of best-fitted colors and corresponding image data

E. Conclusion

In the conceptual product design stage, designers traditionally tend to carry out their color-planning activities based on general stereotypes and their previous design experience. Therefore, developing a color-searching method which is capable of generating a large number of diverse color-combination ideas, and which can then identify the most appropriate color design solution, is of crucial importance. Consequently, this study has introduced a method integrating the aesthetic measurement method, gray theory and genetic algorithms to generate and evaluate color-design candidates automatically. The proposed method provides a PC-based, or even web-based, system for product color design and image evaluation prediction. With the assistance of this system, the designer can quickly obtain an optimal color scheme for a given set of image evaluation targets, or can obtain the predicted image evaluation results for a set of input color values. This study has taken the case of a thermos flask color design for illustration purposes. However, the proposed method can be readily extended to the design and development of other products.

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