行政院國家科學委員會專題研究計畫　成果報告

人工智慧輔助產品色彩計劃系統建立之研究(I)

計畫類別：個別型計畫
計畫編號：NSC94-2213-E-343-001-
執行期間：94 年 08 月 01 日至 95 年 07 月 31 日
執行單位：南華大學應用藝術與設計學系

計畫主持人：蔡宏政
共同主持人：洪嘉永

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中　華　民　國 95 年 10 月 17 日

人工智慧輔助產品色彩計畫系統建立之研究(I)

The Construction of an Artificial Intelligence Aided Product-Color Planning System (I)

計畫編號：NSC 94-2213-E-343-001
已執行期間：94 年 8 月 1 日至 95 年 7 月 31 日
主持人：蔡宏政 南華大學應用藝術與設計學系 助理教授
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1. 中文摘要

電腦輔助設計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 色彩系統為主。本研究以 CIE 色彩之三個主色光，紅(R)、綠(G)、藍(B)為基礎，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值，同時亦可進行目標意象之理想色彩組配搜尋。

關鍵詞：產品色彩設計、最佳化設計、遺傳基因演算法、人工智慧

1. 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

2. Objectives and introduction

Due to the remarkable advances in numerically–controlled machining technology 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, the apparent style of a product, i.e. its form and color, is of paramount 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 external components of a product, an enterprise can generate a wide variety of different product image perceptions. Adopting this approach, a product produced from a single mold can be offered in numerous color combinations so as to satisfy the diverse preferences of individual consumers [1].

Color plays an important role in determining the appeal of a product to its potential customers [2]. In an earlier study relating to a door lock design [3], the current author reported that the overall product image perception was dominated by the product color rather than the product form. Traditional products offered with a standard range of 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. As a result, if the competitiveness of a product is to be improved, designers must not only endeavor to understand the consumer's psychological needs, but should also learn how best to fully exploit and manipulate a database of limited color images compiled for product design and evaluation purposes.

Previous studies of color-image perception focused mainly on the image evaluation of single-color products. For example, Hsiao [4] applied fuzzy set theory to select the most suitable color for a car from a range of specified colors. In a later study [5], the same author proposed a systematic method for product-color design based on the Munsell color system. Choo and Kim [6] investigated the color effect in fashion fabric products using Munsell and PCCS color notations for the color variables. Nowadays, color designs based on the CIE color system can be easily rendered on 3-D CAD models in the color planning stage of product design. However, the color image models traditionally employed in such applications are generally based on the colors of the object rather than on the three primary colors of light (i.e. red, green and blue). Ou *et al.* [2] established color emotion and color preference models for single colors using the CIELAB color space. In a study investigating the evaluation of images comprising multiple colors in the interior design field, Shen *et al.* [7] proposed a linguistic-based evaluation model specified in terms of color harmony based on the CIE system. Meanwhile, the current author applied gray system theory [8] to develop a systematic method for evaluating the overall image perception of a product comprising components of different colors defined using RGB parameters [1].

The color-image studies outlined above considered the image evaluation of products with predefined color combinations. However, comparatively little attention has been paid to the inverse case, in which the aim is to identify the color combination which satisfies a specified color image evaluation requirement. Linguistic image-oriented auto-searching schemes for optimal color combinations must be supervised by appropriate color harmony theories since if such supervision is not applied, the search results are liable to be dull and uncoordinated even if the color combination is close to the specified linguistic evaluation goal.

The evaluation of aesthetics on a quantitative basis was originally considered by Birkhoff [9]. Subsequently, Moon and Spencer [10-12] applied Birkhoff's theory of aesthetic measurement to the problem of color harmony based on the Munsell system. The present study combines a color-harmony-based aesthetic measurement method with the gray-theory-based linguistic evaluation method proposed in a previous study by the current author [1] to evaluate the image sensations induced by different color combinations. In the proposed approach, 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 identify the near-optimal color combination which matches the specified image requirements expressed in terms of linguistic and aesthetic measures.

Unlike conventional problem-solving techniques, genetic algorithms converge towards the optimal solution from multiple directions. In the current application, the chromosomes produced during the population-based search method of the genetic algorithm represent the color-design candidates produced in a brainstorming process. Although optimal solutions generally exist for most engineering problems, it is frequently difficult to identify these solutions at the conceptual design stage. In most cases, a near-optimal solution represents the best solution which can reasonably be hoped for. However, in the current application, by carefully defining the color evaluation algorithms employed by the genetic algorithm, the designer can increase the likelihood of the final solution closely approximating the optimal solution.

The automatic design system developed in this study is illustrated using the color design of a thermos flask as an example. 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 either input to the image prediction sub-system or output from the color-combination search sub-system. Meanwhile, the predicted/desired image evaluation is output from the image prediction sub-system and input to the color-combination search sub-system. Using the proposed design 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 desired product-color perception. The customized interfaces of the proposed system are integrated with the I-DEAS system to enable the designer to view 3-D colored models rendered with the assigned input color parameters or to search for suitable color schemes which satisfy a particular set of image evaluation targets.

3. Linguistic and aesthetic image-based genetic searching

This study integrates 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) a linguistic and aesthetic color image prediction function based on gray theory and Moon and Spencers' aesthetic measurement method, respectively, and (2) a search function for optimal two-color combinations based on genetic algorithms. The basic concepts of these two functions, and the interrelationships between them, are illustrated in Fig. 1. The linguistic and aesthetic image prediction function enables the likely consumer reaction to a product color image to be predicted for any given set of input color parameter values. Meanwhile, the color combination search function performs essentially the inverse operation, i.e. given a set of image perception requirements, this function searches automatically for the near-optimal color combination which satisfies these requirements. Gray theory is employed to establish the relationship between the linguistic image evaluation and the color parameters, and the aesthetic measurement method is applied to evaluate the aesthetic degree of the color combination in terms of its color harmony. During the search procedure, genetic algorithms are used to perform an evolutional search for elite color combinations, with the suitability (fitness) of each candidate solution being evaluated by the linguistic and aesthetic image prediction function.

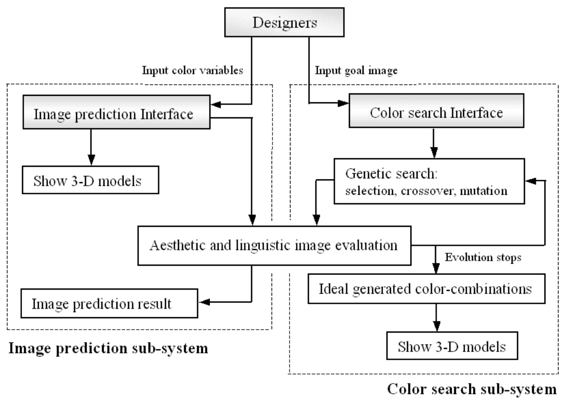

Fig. 1. Basic concepts of automated image prediction and color search mechanism

4. Implementation procedures

This study verified the effectiveness of the automatic color design system outlined in Section 2 by considering the case of the color design of a thermos flask. The detailed procedures involved in implementing the color system are described below.

4.1. Create basic single-color samples
4.2. Construct 3-D model of thermos flask with two-color appearance
4.3. Carry out product-color linguistic and aesthetic image evaluation experiments
4.4. Establish evaluation model for linguistic image measurement mechanism
4.5. Establish evaluation model for aesthetic image measurement mechanism
4.6. Demonstrate reliability of proposed color evaluation model by performing further image experiments
4.7. Establish genetic algorithm-based product color combination search model
4.8. Construct operational system for linguistic and aesthetic image prediction and color-combination search
   - Interface for product-color image evaluation
   - Interface for product-color search

5. Product color design case studies

5.1 Example 1

This example considers the image evaluation prediction of a thermos flask with assigned color parameters. In the interface shown in Fig. 2, the RGB color parameters

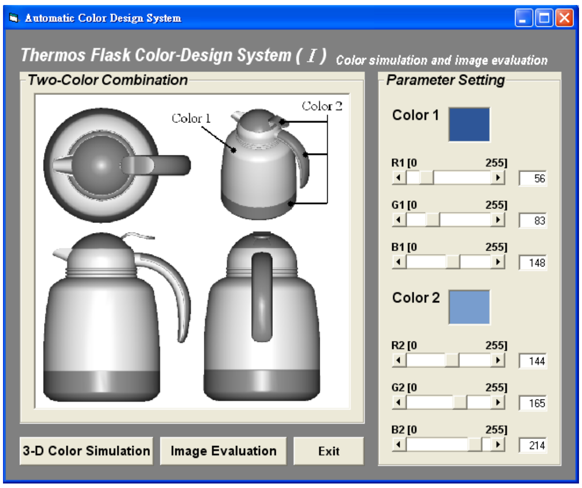

Fig. 2. Interface for constructing 3-D model and performing color-image prediction

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

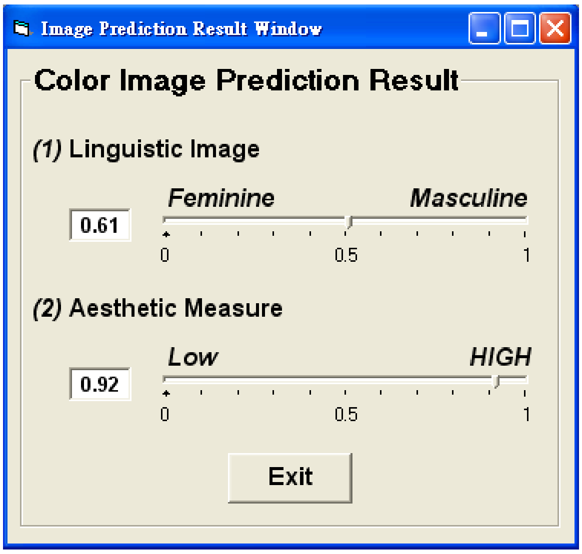

Fig. 4. Color-image prediction window

are specified as: Color 1 (56, 83,148) and Color 2 (144, 165, 214). Clicking the "3-D Color Simulation" button reveals the 3-D model rendered with the corresponding colors (see Fig. 3). Alternatively, clicking the "Image Evaluation" button displays the predicted image evaluation window shown in Fig. 4. In this example, it is found that the predicted linguistic and aesthetic evaluations of the two-colored flask are 0.61 and 0.92, respectively.

5.2 Example 2

In this example, the designer specifies targets for the linguistic and aesthetic properties of the two-colored flask, and then uses the design system to search for an appropriate two-color combination. Using the interface shown in Fig. 5, the designer specifies a target linguistic evaluation (feminine–masculine) of 0.2, a linguistic weight of 0.5, an aesthetic weight of 0.5, and 100 iterations in the search routine. Note that the latter setting implies that the optimization system will execute the fitness function evaluation process 1000 times since the population size is set by default to 10.

Fig. 6 shows the trends of the fitness of the candidate solutions over the evolution of the search process and indicates the corresponding variations of the linguistic and aesthetic evaluations. It can be seen that as the generation number increases, the linguistic and aesthetic evaluations vary irregularly in order to maximize the fitness value, i.e. to obtain a color combination which increasingly fits the goal image. Fig. 7 indicates the best-fitted color combinations at the 1st, 20th, 40th, 60th, 80th and 100th generations, respectively. The final search results are presented in the window shown in Fig. 8. As shown, the window indicates both the actual and the target linguistic and aesthetic evaluation ratings, the RGB parameters for the two best-fitted colors, and the overall fitness of the final two-color design. Clicking, the "3-D Color Simulation", the designer is presented with a 3-D image of the flask rendered in the best-fitted color combination.

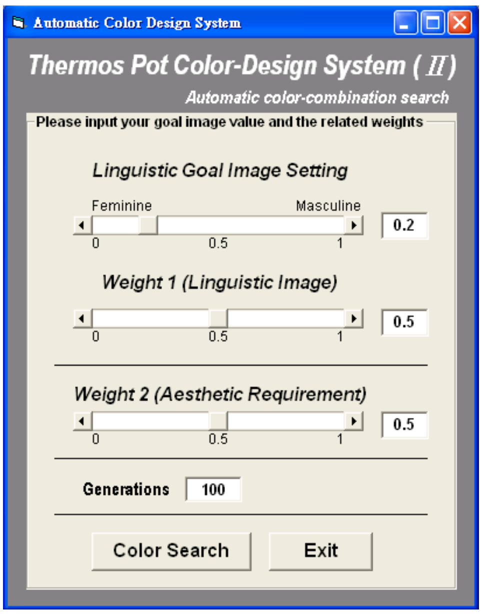

Fig. 5. Interface for product color combination search

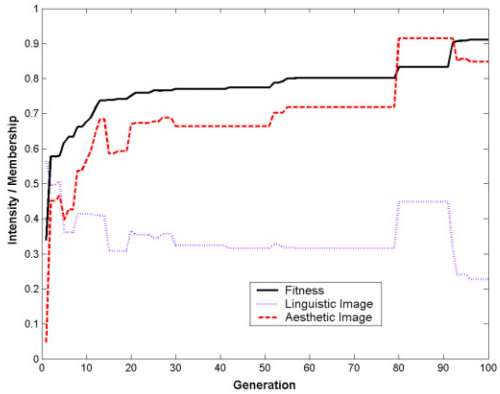

Fig. 6. Trends of fitness function and image evaluation ratings during search process

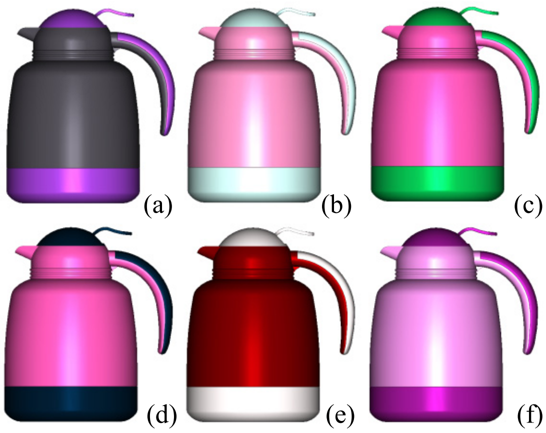

Fig. 7.Color evolution: best-fitted color combinations at: (a) initial, (b) 20th, (c) 40th, (d) 60th, (e) 80th and (f) 100th generation

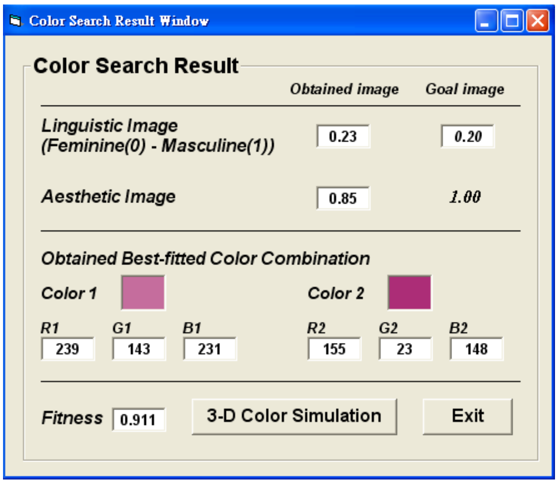

Fig. 8. Search-result window presenting evolved color variables of best-fitted colors and corresponding image data

5. Conclusion

In the conceptual product design stage, designers tend to carry out their color-planning activities based on general stereotypes and their previous design experience. Therefore, developing a color-searching method capable of automatically generating a large number of diverse color-combination schemes and then identifying the most appropriate color design is of considerable benefit.

However, if the search for an optimal color combination fails to take account of the aesthetic properties of the color design, the colors specified in the final color scheme may be unharmonious. Consequently, this study has developed an automatic design method based on aesthetic measurement, gray theory and genetic algorithms to generate and evaluate color-design candidates. Although the prediction performance of this system regarding the aesthetic properties of the color design is not as high as that for the linguistic properties of the design, the system is nevertheless capable of evolving color-design candidates with a high degree of aesthetic appeal. Significantly, the predicted aesthetic evaluation of the two-color design considered in Case Study 1 (0.92) is significantly higher than the experimentally derived aesthetic evaluations of the corresponding single colors, i.e. 0.49 for Color 1 and 0.37 for Color 2. This result indicates that achieving a good color harmony increases the aesthetic appeal of the two-color design significantly compared to designs created using the constituent single colors only. However, the predicted linguistic evaluation for the two-color combination (0.61) lies between that of the two single-colored linguistic evaluations, i.e. 0.77 for Color 1 and 0.52 for Color 2. This result implies that the two-color linguistic image blends the respective linguistic images of the two constituent single colors.

The design method presented in this study makes possible the creation of a PC-based, or even web-based, system for product color design and image evaluation prediction. Using this system, a designer can quickly establish an optimal color scheme for a given set of image evaluation goals, or can obtain the predicted image evaluation results for a set of input color parameters. This study has considered the color design of a thermos flask for illustration purposes. However, the principles of the proposed method can be readily extended to the design and development of other products.

6. References

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7. 成果自評

(1) 建立可正向評價色彩意象，亦可逆向搜尋最佳化之雙色產品色彩組配系統，研究成果符合原計畫第一年之預期目標。
(2) 具色彩配色需求之消費性產品可適用之。
(3) 研究成果已投稿至設計相關之 SCI 期刊。

附件二

可供推廣之研發成果資料表

□ 可申請專利　　■ 可技術移轉　　　　　　　　　　日期：95 年 07 月 31 日

<table>
<tr><td>國科會補助計畫</td><td>計畫名稱：人工智慧輔助產品色彩計劃系統建立之研究（I）
計畫主持人：蔡宏政
計畫編號： NSC 94-2213-E-343-001　學門領域：工業工程與管理</td></tr>
<tr><td>技術/創作名稱</td><td>產品自動化配色</td></tr>
<tr><td>發明人/創作人</td><td>蔡宏政</td></tr>
<tr><td rowspan="2">技術說明</td><td>中文：
現今以電腦輔助產品色彩的表色方式主要以 CIE 色彩系統為主。本研究以 CIE 色彩之三個主色光，紅(R)、綠(G)、藍(B)為基礎，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值，同時亦可進行目標意象之理想色彩組配搜尋。</td></tr>
<tr><td>英文：
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<tr><td>可利用之產業
及
可開發之產品</td><td>具色彩配色需求之消費性產品。</td></tr>
<tr><td>技術特點</td><td>1. 以「語彙意象」與「色彩美學」為基礎的自動化配色系統。
2. 可結合 3D CAD 軟體進行配色模擬。
3. 可正向評價色彩意象，亦可逆向搜尋最佳化之色彩組配。</td></tr>
</table>

推廣及運用的價值	1. 優良的產品色彩配色，可增加消費者對產品的滿意度，強化產品的競爭力。 2. 一般消費型產品均可適用。

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