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(II)
研究成果報告(精簡版)

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計 畫 主 持 人：蔡宏政
共 同 主 持 人：洪嘉永
計畫參與人員： 碩士班研究生-兼任助理：陳惠文、廖冠棱

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人工智慧輔助產品色彩計畫系統建立之研究(II)

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

計畫編號：NSC 95-2221-E-343-004
已執行期間：95 年 8 月 1 日至 96 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
共同主持人：洪嘉永　國立成功大學工業設計學系 副教授

1. 中文摘要

色彩對於顧客喜好與否的決定性，扮演著重要的角色。當工業設計師進行產品色彩計畫時，需要將使用者對色彩之心理感覺納入考量，但是卻鮮少有電腦輔助設計系統可以協助這類相關的設計活動。如同第一年計畫之研究架構，以灰色理論與色彩調和論分別作為色彩配色之感性意象與美度評價法則，並進一步運用遺傳基因演算法搜尋接近最佳化之多色產品之色彩組配建議。然而，不同於第一年計畫運用 RGB 色彩參數建立色彩樣本之方式，本研究計畫以 CIELAB 色彩系統之 L^*, a^* and b^*三個直交色彩參數，建立多色彩產品之色彩計畫評價與配色搜尋系統。由實驗結果顯示，CIELAB 色彩參數所建立的色彩配色評價方法具有較佳之可靠度。本研究仍選用上一年度計畫所建構之熱水壺 3D 模型作為目標個案產品，藉以驗證、比較所建立評價法則之有效性。

關鍵詞：色彩、遺傳基因演算法、人工智慧、最佳化設計

1. Abstract

Color plays a key role for customers in determining what they like or dislike. Although many of the tasks performed by an industrial designer at the color-planning design stage involve the consideration of the user's perception of the product color, very few computer-aided design systems are available to support this set of particular design activities. With the same structure as the first-year project, a gray-theory-based emotional evaluation method and a color-harmony-based aesthetic evaluation method are combined to diagnose appropriate product-color schemes. In a reverse process, genetic algorithm is used to search for a near-optimal color-combination design for multi-colored products. The RGB color system was used for constructing basic color samples in the first-year research. However, A quantitative evaluation and search method based on the CIELAB color system, which is constituted by three orthogonal dimensions L^*, a^* and b^*, for multi-colored products is proposed in the current (second-year) project. According to the experimental results, using these three parameters is more robust for evaluating multi-color combinations. The same 3-D model of a thermos flask as the last project is chosen as the subject of the current investigation to demonstrate and compare the effectiveness of the proposed method.

Keywords: Color, Genetic algorithm, Artificial intelligence, Optimum design

2. Introduction

Nowadays, the functional aspects of many consumptive products used in daily life are fully matured. For products with similar functions, a product's style becomes an important factor in a consumer's decision-making process when deciding which particular product to purchase [1]. The overall image perception of a product's style is generally induced by its form and by its color. The current author [2] and Lai *et al.* [3] both indicated in their research that product color has a greater effect on the consumers' perception of a product than the product form. By providing products whose components are of different colors, enterprises are able to satisfy the particular tastes of each individual consumer. Therefore, developing products with various color plans for different consumer groups has become an essential strategy for many enterprises.

Most CAD product development systems only addressed the physical aspects of product design. However, an equally important element of the design process is the consideration of the psychological aspects of a product, including the emotional and aesthetic responses of an individual to the proposed product design. So far as we know, very few computer-aided design systems support the product color-planning activities, although many tasks performed by an industrial designer involve the consideration of the potential user's perception of the product color. Van Dijk Casper [4] mentioned that currently no CAD systems existed to satisfy the requirements of conceptual design. Generally, a designer carries out the color-planning activities of the product design based upon his or her individual experience, artistic sense, and subjective view, but this is not objective enough and very inefficient. If the designer possessed the facility to access a powerful tool to evaluate the image of the designed color schemes or to search for an ideal color combination, he or she could quickly display the appropriate product colors by using a customized interface linked with the CAD system during the conceptual design period.

In the field of color-image evaluation research, Ishihara *et al.* [5] attempted to build a Kansei Engineering expert system for single color images by using self-organizing neural networks. In the first-year project, the current author [6] applied gray theory [7] and Moon and Spencers' color harmony theory [8-10] to develop a quantitative method for evaluating the overall image perception of a product comprising components of two colors defined using RGB parameters. Although these methods can be used to evaluate product color images, they are unable to generate required color combinations or to search for the colors which best fit the designer's image requirements. However, the obtained 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 image goal. Ou and Luo [11] proposed a quantitative color harmony model based on the CIELAB color space. Tokumaru *et al.* [12] proposed a system which automatically composes color schemes which are in harmony with a color input in the system and correspondent to the user's image. Accordingly, this research develops a color design system which enables the designer to evaluate color images or to search for required color combinations for multi-colored products by combining the methods proposed previously on gray-theory-based image evaluation, color-harmony-based aesthetic evaluation and genetic-algorithm-based color search respectively.

The color harmony model proposed by Ou and Luo [11] was used in this research to evaluate the overall aesthetic image of a product. It would be much useful if this method can be extended towards more than two colors. In an attempt to remedy this situation, this research further focuses on the aesthetic evaluation method for multi-colored products. Finally, the genetic algorithm [16] is utilized to search for an ideal color design which matches the input emotional image requirement with an acceptable qualification of the aesthetic image.

The genetic algorithm has been successfully applied to many optimization problems. In the present study, the genetic algorithm is applied in a stochastic optimization technique to search for near-optimal color combination candidates. To facilitate genetic operations, the product colors are encoded with finite parameters. By defining the color parameters and the related fitness function as reasonable as possible, the chromosomes (color-design candidates) produced during the population-based search process would evolve towards an optimal color-design solution. A multi-colored thermos flask, the same example as the first-year project, is considered for the illustration purposes to demonstrate the feasibility of the proposed method.

3. Implementation Method

The color planning stage of a thermos flask design activity is used as an example to demonstrate the procedure adopted in this present study. A rendered 3-D model of the constructed flask is shown in Fig. 1. The implementation procedures are described in the paragraphs which follow.

3.1. Product Color Evaluation Using Emotional and Aesthetic Scales

3.1.1 Emotional image evaluation

As shown in Fig. 1, this thermos flask example consists of the main body, the lid, the lever, the handle cover, and the bottom. In this study, arbitrary colors are assigned to the primary components. In accordance with the color assignment method utilizing CIELAB parameters, the five designed colors for these components are denoted as Color 1 to Color 5, respectively.

Fig. 1. Rendered 3-D model of thermos flask with three-color appearance

The present research adopts the gray clustering operation of the gray theory in the evaluation of the emotional image for multi-colored products. The emotional objective equation is given by the following [7].

$$\sigma_{ik} = \sum_{j=1}^{m} f_{jk}(a_{ij})\eta_{jk} \qquad (1)$$

Further, the image intensities (σ_{ik}) of the color-emotion words can be fuzzified into a membership value (E_{EI}) for the overall emotional evaluation.

3.1.2 Aesthetic image evaluation

Since the color harmony model proposed by Ou and Luo has better reliability on aesthetic image evaluation through our color experiments. This research adopts their model as the aesthetic objective equation, which is shown below [11].

$$CH = -2.2 + 0.03L_{SUM} + H_{\Delta C} + H_{\Delta L} + 1.1H_H \qquad (2)$$

$$ae_{ij} = (CH + 5)/10 \qquad (3)$$

The normalization rules of the aesthetic measurement method for two-colored products were defined in Eq. (3). By using this previously proposed method, the aesthetic evaluation value (ae_{ij}) was obtained for the combination of Color i and Color j. However, in the color design system developed in the current study, a multi-color combination is considered. In order to aggregate the overall image, the overall aesthetic evaluation value (E_{AI}) is defined as:

$$E_{AI} = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} (\gamma_{ij} \cdot ae_{ij}) \qquad (4)$$

3.2 Color Combination Search Using Genetic Algorithm

Since the two emotional evaluation and the aesthetic evaluation models are built, it could be adopted as the fitness function when searching for an optimal color design to meet a required image target using a genetic algorithm. The basic concept of the color search mechanism is illustrated in Fig. 2. This mechanism is proposed in the current study begins with a randomly generated color-parameter sets, each of which is regarded as a chromosome and represents a color combination candidate. The fitness here is defined as:

$$\text{Fitness} = w_{EI} \cdot (1 - |E_{EI} - T_{EI}|) + w_{AI} \cdot E_{AI} \qquad (5)$$

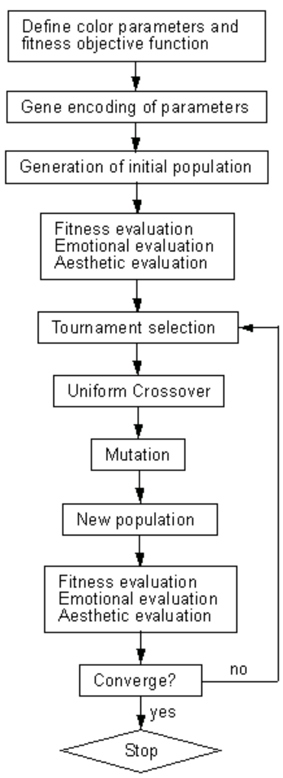

Fig. 2. Basic concepts of color search

4. Case Studies

4.1 Example I for emotional and aesthetic Evaluations

This example involves the design of a thermos flask and the prediction of its emotional and aesthetic image evaluation based upon an input set of color parameters. The interface presented in Fig. 3 illustrates the given values for the flask color-design. When all of the parameter settings had been specified, the "3-D Color Simulation" button was clicked to export the VRML file from the CAD system to the Cosmo Player, as shown in Fig. 4. After the design had been viewed dynamically and had been accepted as satisfactory, clicking the "Image Evaluation" button to predict the image scores. The predicted overall emotional and aesthetic evaluations of the flask are 0.26 and 0.53, respectively.

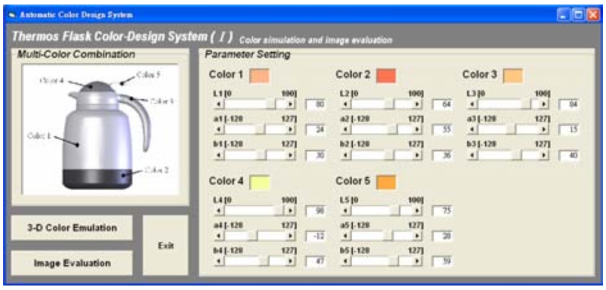

Fig. 3. Interface for constructing 3-D model and performing color-image prediction

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

4.2 Example II for color combination searching

This example represents the inverse operation to that described above. The interface shown in Fig. 5 is used to generate an ideal color combination by specifying targets for the emotional and aesthetic properties of the thermos flask. The designer specifies a target emotional evaluation (feminine–masculine) of 0.8, an emotional weight of 0.4, an aesthetic weight of 0.6, and a 5-color combination. The number of iterated generations is set to 1000, which indicates that the optimization system must process the fitness function evaluation 10000 times since the population size is set by default to 10. In the maximization problem indicated in Eq. (5), the larger the fitness value, the more the evolved color combination fits the desired image. The final search result is shown in the search result window illustrated in Fig. 6, which indicates the actual and the emotional and aesthetic target evaluation ratings, the CIELAB parameters for the best-fitted colors, and the overall fitness of the evolution-terminated generation. It is noted

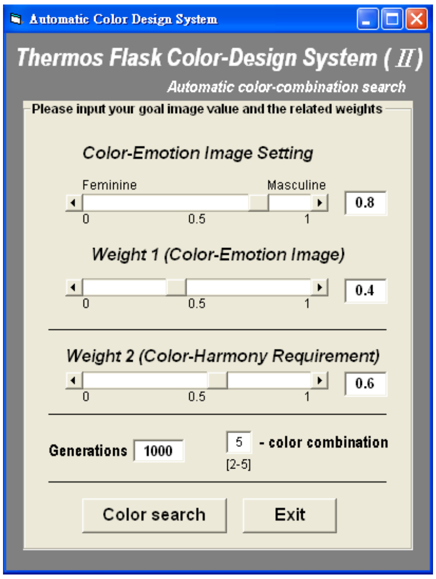

Fig. 5. Interface for product color combination search

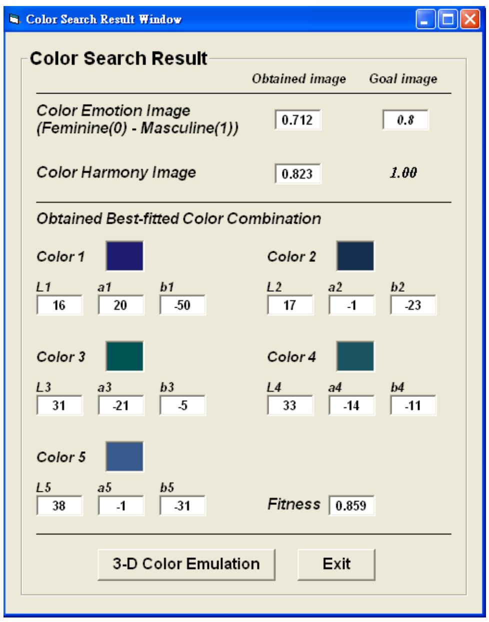

Fig. 6. Search-result window presenting evolved color variables of best-fitted colors and corresponding image data

that this dialogue window also permits the designer to click the "3-D Color Emulation" button to view a 3-D image of the flask rendered in the best evolved color combination.

5. Conclusion

However, it is not fully satisfactory because designers often tend to be restricted by their stereotypes and previous design experiences. Design is considered as an intelligent activity, within which new concepts are found to produce creative solutions. 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 crucial importance. The benefits of an automatic brainstorming system that works in real time would be of great interest for economic reasons and for design performance reasons. Consequently, this study has introduced a method which uses gray theory, aesthetic measurement and a genetic algorithm to generate and evaluate color-design candidates automatically. The customized color design system in this study provides a designer with a valuable indication of the image tendencies of his/her design. The designer can also establish an ideal color scheme for a given set of image demands.

The current scheme uses the CIELAB color system to define the product colors and to display the rendered product on the monitor. However, color-design results expressed in terms of L, a^* and b^* values can not be applied directly to product coloring. A color matching method might provide a feasible means of resolving this problem. For example, the colors rendered on the PC monitor can be matched with physical color patches (such as Munsell samples) under controlled viewing conditions. In this approach, the physical color patches are presented within a viewing cabinet positioned next to the computer screen and the illumination level of the monitor is adjusted such that it is equivalent to that within the viewing cabinet. The desired colors shown on the monitor can then be matched directly with the physical samples presented within the viewing cabinet.

6. References

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7. 成果自評

(1) 原第一年期「雙色產品」所運用 Moon & Spencer 的色彩調和模式，當運用在第二年期「多色產品」時，其可靠度較差，經運用並正規化 Ou 與 Luo 所提出之色彩調和模式後，由實驗驗證得知其可靠度大幅改善。

(2) 建立一「多色產品」之色彩計畫系統，不僅可正向評價多色產品之色彩意象與色彩調和美度，亦可逆向搜尋符合目標意象之最佳化色彩組配，研究成果符合原第二年計畫之預期。

(3) 本研究計畫成果已發表刊登於設計相關之 SCI / EI 國際期刊論文 2 篇，知名國際研討會論文 2 篇，另有 1 篇投稿於 SCI 之期刊論文審查中。各項成果列示如下：

[第一年期]

1. **<u>H-C Tsai</u>***, J-R Chou. 2007/9, *Automatic design support and image evaluation of two-colored products using color association and color harmony scales and genetic algorithm*. **Computer-Aided Design**; 39(9): 818-828. **(NSC94-2213-E-343-001) (SCI)**

2. **<u>H-C Tsai</u>***, C-Y Hung, F-K Hung. 2007/7, *Automatic product color design using genetic searching.* **The 12th International Conference on Computer-Aided Architectural Design**, pp513-524, University of Sydney, Sydney, Australia. **(NSC94-2213-E-343-001)**

[第二年期]

1. **<u>H-C Tsai</u>***, C-Y Hung, F-K Hung. 2007/6, *Computer aided product color design with artificial intelligence.* **Computer-Aided Design & Applications**; 4(1-4): 557-564. **(NSC95-2221-E-343-004) (EI)**

2. **<u>H-C Tsai</u>***, C-Y Hung, Fi-K Hung. 2007/6, *Computer aided product color design with artificial intelligence.* **2007 International CAD Conference and Exhibition**, Honolulu, Hawaii. **(NSC95-2221-E-343-004)**

3. 另一部分成果已投稿於設計相關之 SCI 國際期刊。

出席國際學術會議心得報告

計畫編號	NSC 95-2221-E-343-004
計畫名稱	人工智慧輔助產品色彩計畫系統建立之研究(II)
出國人員姓名 服務機關及職稱	蔡宏政 應用藝術與設計系 助理教授
會議時間地點	2007 年 6 月 25 日 –29 日 夏威夷
會議名稱	2007 International CAD Conference and Exhibition (CAD ’07)
發表論文題目	Computer Aided Product Color Design with Artificial Intelligence

一、參加會議經過

6/25：至大會舉辦地點（Waikiki Beach Resort）辦理註冊，並出席 keynote speech: Programmable Graphics Processors in CAD 之演講。

6/26：參加 Shape Modeling 與 Geometric Design 兩個 Sessions。

6/27：於 17:25 在 Session H (Product Modeling) 發表個人的研究內容. 晚上同全體與會人員一同餐敘，並與相關發表成員交換心得。

6/28,29：陸續參加 Product Modeling 與 Shape Modeling 相關的 Sessions。

二、與會心得

本次會議為第五屆國際電腦輔助設計研討會，由國際上在 CAD 領域頗富盛名的 Les A. Piegl 擔任主席。計有來自世界各國的百餘篇論文參與發表，台灣亦有不少學者（南華大學、中正大學、逢甲大學與台灣大學等）與會。會中曾與來自香港、新加坡、美國、英國、日本與韓國的研究學者交換各方面的意見與經驗，並接獲韓國延世大學崔教授的學術合作與研究生互換邀約，不只個人收穫頗豐，亦不失為一次成功的國際交流。

香港的各主要大學皆以全英文的方式上課，與國際接軌相當的成功，而且其學者的外文表達與溝通能力，明顯優於台灣學者。而許多台灣的學者因為英文程度不足，加上經費補助不足，導致怯於國際交流。因此，政府機構（國科會等）與學校應多鼓勵研究人才走向國際，並給予足額的經費補助，並將此績效列入升等、續薪等績效考核評量，以增進台灣的國際研究能量。

Computer Aided Product Color Design with Artificial Intelligence

Hung-Cheng Tsai[1], Chia-Young Hung[2] and Fei-Kung Hung[3]

[1]Department of Applied Art and Design, Nanhua University, tomtsai@mail.nhu.edu.tw
[2]Department of Industrial Design, National Cheng Kung University, maxhong.family@msa.hinet.net
[3]Department of Information Management, WuFeng Institute of Technology, feigo@mail.wfc.edu.tw

ABSTRACT

Color plays a key role for customers in determining what they like or dislike. Although many of the tasks performed by an industrial designer at the color-planning design stage involve the consideration of the user's perception of the product color, very few computer-aided design systems are available to support this set of particular design activities. A quantitative evaluation and search method based on the RGB (i.e. R(Red), G(Green) and B(Blue)) color system within the product design cycle is proposed in this article. The questionnaire-based process which is traditionally employed to obtain objective color psychology tends to be time-consuming. Accordingly, this study proposes the use of gray system theory to overcome this problem. Using these additive primaries to simulate specific basic color samples is an efficient means of investigating single color image on a personal computer. Subsequently, a gray-theory-based emotional evaluation method and a color-harmony-based aesthetic evaluation method are combined to diagnose appropriate product-color schemes. In a reverse process, genetic algorithm is used to search for a near-optimal color-combination design for multi-colored products. A three-colored baby walker is chosen as the subject of the current investigation to show the effectiveness of the proposed method.

Keywords: Color, Gray theory, Genetic algorithm, Artificial intelligence, Optimum design.

1. INTRODUCTION

Nowadays, the functional aspects of many consumptive products used in daily life are fully matured. For products with similar functions, a product's style becomes an important factor in a consumer's decision-making process when deciding which particular product to purchase [1]. The overall image perception of a product's style is generally induced by its form and by its color. The current author [2] investigated the overall image of a product, and the results showed that the overall image perception was dominated by the product's color rather than by its form. Lai *et al.* [3] also indicated in their research that product color has a greater effect on the consumers' perception of a product than the product form. It is wasteful and expensive for an enterprise to attempt to design the wide variety of product forms which would be required to meet the needs of each individual consumer. However, enterprises can vary the color matches of product's individual components in order to generate a wide variety of product image perceptions. To Design and manufacture the wide variety of product forms required to meet the diverse requirements of individual consumers is both time consuming and expensive. By providing products whose components are of different colors, enterprises are able to satisfy the particular tastes of each individual consumer. Therefore, developing products with various color plans for different consumer groups has become an essential strategy for many enterprises.

Most CAD product development systems only addressed the physical aspects of product design. However, an equally important element of the design process is the consideration of the psychological aspects of a product, including the emotional and aesthetic responses of an individual to the proposed product design. So far as we know, very few computer-aided design systems support the product color-planning activities, although many tasks performed by an industrial designer involve the consideration of the potential user's perception of the product color. Van Dijk Casper [4] mentioned that currently no CAD systems existed to satisfy the requirements of conceptual design. Generally, a designer carries out the color-planning activities of the product design based upon his or her individual experience, artistic sense, and subjective view, but this is not objective enough and very inefficient. If the designer possessed the facility to access a powerful tool to evaluate the image of the designed color schemes or to search for an ideal color combination, he or she could quickly display the appropriate product colors by using a customized interface linked with the CAD system during the conceptual design period.

In the field of color-image evaluation research, Hsiao [5,6] proposed a systematic method of fuzzy set theory for color planning during the product design stage. Ou *et al.* [7] established color emotion models for single colors based on word-pair scales using the CIELAB color space. Ishihara *et al.* [8] attempted to build a Kansei Engineering expert system for single color images by using self-organizing neural networks. In the interior design field, Shen *et al.* [9] proposed a linguistic-based evaluation model specified in terms of color harmony based on the CIE system. Meanwhile, the current author [1] applied gray theory [10] to develop a quantitative method for evaluating the overall image perception of a product comprising components of different colors defined using RGB parameters. Although these methods can be used to evaluate product color images, they are unable to generate required color combinations or to search for the colors which best fit the designer's image requirements. However, the obtained 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 image goal. Tokumaru *et al.* [11] proposed a system which automatically composes color schemes which are in harmony with a color input in the system and correspondent to the user's image. The current author [12] presented an automatic design support system for two-colored products to search for ideal color schemes which satisfy the required image goal using the genetic algorithm. Accordingly, this paper develops a color design system which enables the designer to evaluate color images or to search for required color combinations for multi-colored products by combining the methods proposed previously on gray-theory-based image evaluation and genetic-algorithm-based color search, respectively [1,12].

The aesthetic measurement method proposed by Moon and Spencer [13-15] was used in [12] to evaluate the overall aesthetic image of a product with a limitation of two apparent colors. It would be much useful if this method can be extended towards more than two colors. In an attempt to remedy this situation, this research further focuses on the aesthetic evaluation method for multi-colored products. Finally, the genetic algorithm [16] is utilized to search for an ideal color design which matches the input emotional image requirement with an acceptable qualification of the aesthetic image.

The genetic algorithm has been successfully applied to many optimization problems. In the present study, the genetic algorithm is applied in a stochastic optimization technique to search for near-optimal color combination candidates. To facilitate genetic operations, the product colors are encoded with finite parameters. By defining the color parameters and the related fitness function as reasonable as possible, the chromosomes (color-design candidates) produced during the population-based search process would evolve towards an optimal color-design solution. A three-colored baby walker is considered for the illustration purposes to demonstrate the feasibility of the proposed method.

2. IMPLEMENTATION METHOD

The color planning stage of a baby walker design activity is used as an example to demonstrate the procedure adopted in this present study. A rendered 3-D model of the constructed walker is shown in Fig. 1. The implementation procedures are described in the paragraphs which follow.

2.1 Product Color Evaluation Using Emotional and Aesthetic Scales

2.1.1 Emotional Image Evaluation

As shown in Fig. 1, a typical baby walker consists of a top tray, a base ring, and a pair of cross tubes. In this study, three arbitrary colors are assigned to the primary components. In accordance with the color assignment method utilizing RGB parameters, the three designed colors for these components are denoted as:

- Color 1 (R1, G1, B1), top tray,
- Color 2 (R2, G2, B2), base ring,
- Color 3 (R3, G3, B3), cross tubes.

Consumers commonly purchase a walker whose color image appearance is most suitable to their baby's sex. Therefore, the color-emotion words considered within the study are specified as "girl ← neutral → boy". The evaluation judgment is ranged from 0 to 1, where 0 denotes an entirely girl-like image perception, 0.5 denotes a neutral image perception, and 1 denotes an entirely boy-like image perception. As defined in the current author's previous research [1], 125 basic color samples were generated by regularly adjusting the constituent RGB parameters with a fixed equi-gap of 64 units within the range of 0-255. Then the 125 color samples were successively rendered on the 3-D model and shown to the subjects to perform a questionnaire investigation.

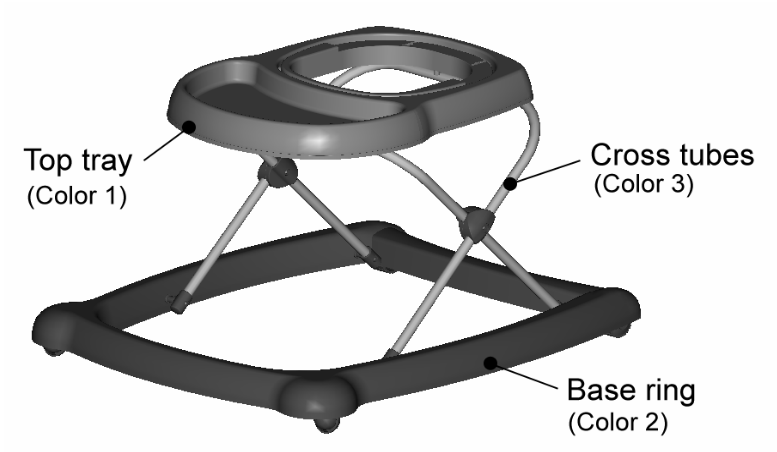

Fig. 1: Rendered 3-D model of baby walker with three-color appearance.

The present research adopts the gray clustering operation of the gray theory in the evaluation of the emotional image for multi-colored products. The objective equation is given by the following [10].

$$\sigma_{ik} = \sum_{j=1}^{m} f_{jk}(a_{ij})\eta_{jk} \tag{1.1}$$

where a_{ij} represents the judgment membership with the *j*th attribute (color) of the *i*th sample (color combination). The weighting factor function, f_{jk}, indicates the significance of the *j*th color to the *k*th cluster (color-emotion word), and η_{jk} is the weighting factor coefficient of the corresponding f_{jk}. Finally, σ_{ik} denotes the evaluation value for the *k*th cluster of the *i*th sample.

Further, the image intensities (σ_{ik}) of the color-emotion words can be fuzzified into a membership value (E_{EI}) [12] for the overall emotional evaluation.

2.1.2 Aesthetic Image Evaluation

The normalization rules of the aesthetic measurement method for two-colored products were defined by the current author in [12]. By using this previously proposed method, the aesthetic evaluation value (ae_{ij}) was obtained for the combination of Color *i* and Color *j*. However, in the color design system developed in the current study, a multi-color combination is considered. In order to aggregate the overall image, the overall aesthetic evaluation value (E_{AI}) is defined as:

$$E_{AI} = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} (\gamma_{ij} \cdot ae_{ij}) \tag{1.2}$$

where γ_{ij} is the area coefficient within the range [0,1], and the sum of all γ_{ij} is equal to 1.

2.2 Color Combination Search Using Genetic Algorithm

Since the two emotional evaluation and the aesthetic evaluation models are built, it could be adopted as the fitness function when searching for an optimal color design to meet a required image target using a genetic algorithm. The basic concept of the color search mechanism is illustrated in Fig. 2. This mechanism is proposed in the current study begins with a randomly generated color-parameter sets, each of which is regarded as a chromosome and represents a color combination candidate. The fitness here is defined as:

$$\text{Fitness} = w_{EI} \cdot (1 - |E_{EI} - T_{EI}|) + w_{AI} \cdot E_{AI} \quad (2.1)$$

where E_{EI} is the evaluated emotional image value, E_{AI} is the evaluated aesthetic image value, T_{EI} is the required emotional target value, w_{EI} and w_{AI} are the normalized emotional and aesthetic weights, respectively, and $w_{EI} + w_{AI} = 1$.

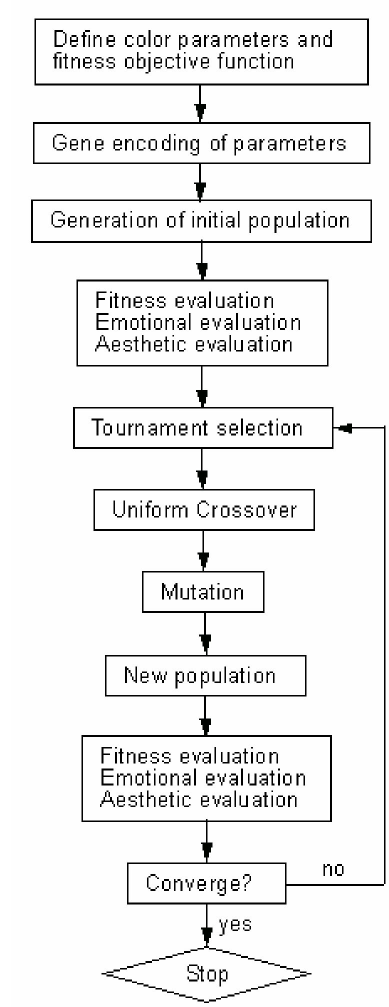

Fig. 2: Basic concepts of automated image prediction and color search mechanism.

3. CASE STUDIES

3.1 Example I for Emotional and Aesthetic Evaluations

This example involves the design of a baby walker and the prediction of its emotional and aesthetic image evaluation based upon an input set of color parameters. The interface presented in Fig. 3 illustrates the given values, i.e. Color 1 (251, 210,97), Color 2 (129, 237, 61) and Color 3 (53, 177, 230), for the walker color-design. When all of the parameter settings had been specified, the “3-D Color Simulation” button was clicked to export the VRML file from the I-DEAS CAD system to the Cosmo Player, as shown in Fig. 4. After the design had been viewed dynamically and had been accepted as satisfactory, clicking the “Image Evaluation” button displays the predicted image evaluation window shown in Fig. 5. For the emotional words, i.e. girl, neutral and boy, the image scores are 0.19, 0.81 and 0.12, respectively. It demonstrates a highest image score of 0.81, which corresponds to the word "neutral", which represents the closest emotional evaluation of the walk color-design. Alternatively, the predicted overall emotional and aesthetic evaluations of the walker are 0.48 and 0.56, respectively.

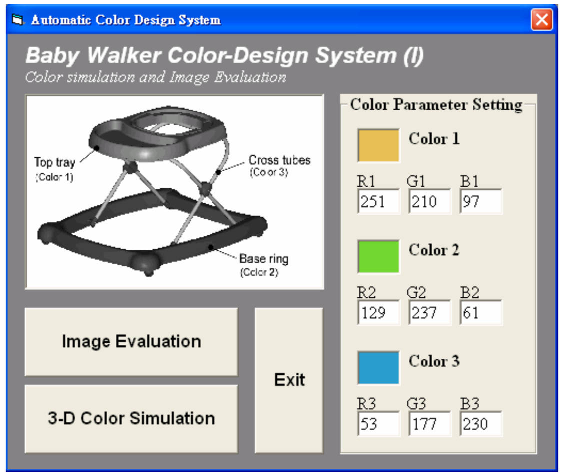

Fig. 3: Interface for constructing a 3-D color-rendered model and image prediction.

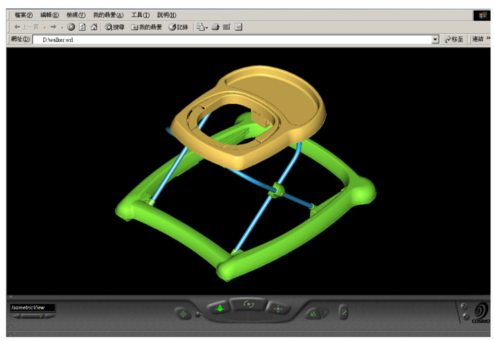

Fig. 4: Rendered 3-D model of Example I displayed on the Cosmo Player.

3.2 Example II for Color Combination Searching

This example represents the inverse operation to that described above. The interface shown in Fig. 6 is used to generate an ideal color combination by specifying targets for the emotional and aesthetic properties of the baby walker. The designer specifies a target emotional evaluation (girl–boy) of 0.8, an emotional weight of 0.4, an aesthetic weight of 0.6. The number of iterated generations is set to 500, which indicates that the optimization system must process the fitness function evaluation 5000 times since the population size is set by default to 10. Fig. 7 illustrates the trend for the fitness improvement over the evolution of the search process. In the maximization problem indicated in Eqn. (2.1), the larger the fitness value, the more the evolved color combination fits the desired image. Therefore, it can be seen that as the generation number increases, the emotional 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. 8 illustrates the best-fitted color combinations at the 1st, 100th, 200th, 300th, 400th and 500th generations, respectively. The figure clearly shows the evolution statuses of the elite color combination towards the target image evaluation requirement. The final search result is shown in the search result window illustrated in Fig. 9, which indicates the actual and the emotional and aesthetic target evaluation ratings, the RGB parameters for the three best-fitted colors, and the overall fitness of the evolution-terminated generation. It is noted that this dialogue window also permits the designer to click the "3-D Color Simulation" button to view a 3-D image of the walker rendered in the best evolved color combination.

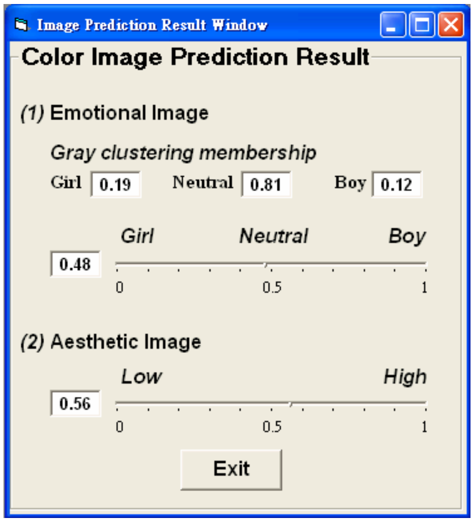

Fig. 5: Color-image prediction window.

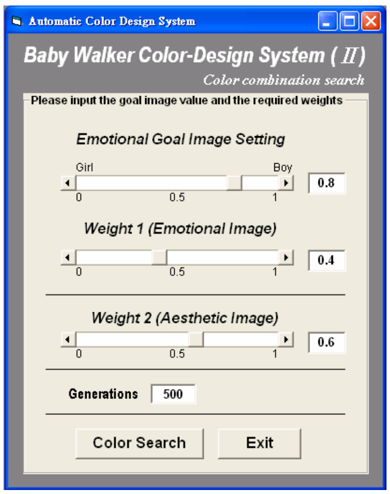

Fig. 6: Interface for product color combination search.

4. CONCLUSION

Most products comprise several groups of components, each with different colors, and hence it is not easy to use the results of single color experiments to predict their overall image evaluation. In this research, the algorithms, constructed in quantitative measures of the gray system model, help to establish the relationship between multi-colored products and their images. Unlike general statistical methods which require a very large number of samples and calculations, gray theory adopts simple processes to study complex systems and provides reliable analytical results. Specifically, for systems with incomplete information or which contain variables with uncertain relations, the gray forecasting model can be used to predict the unknown data or to measure the grade of relation from known data.

However, it is not fully satisfactory because designers often tend to be restricted by their stereotypes and previous design experiences. Design is considered as an intelligent activity, within which new concepts are found to produce creative solutions. 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 crucial importance. The benefits of an automatic brainstorming system that works in real time would be of great interest for economic reasons and for design performance reasons [17]. Consequently, this study has introduced a method which uses gray theory, aesthetic measurement and a genetic algorithm to generate and evaluate color-design candidates automatically. The customized color design system in this study provides a designer with a valuable indication of the image tendencies of his/her design. The designer can also establish an ideal color scheme for a given set of image demands.

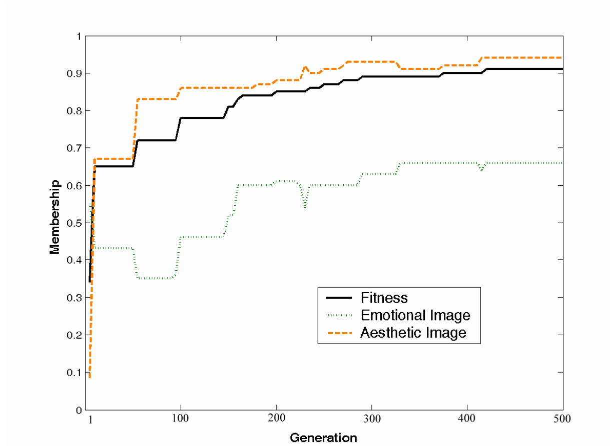

Fig. 7: Trends for each image and improvement of fitness during search process

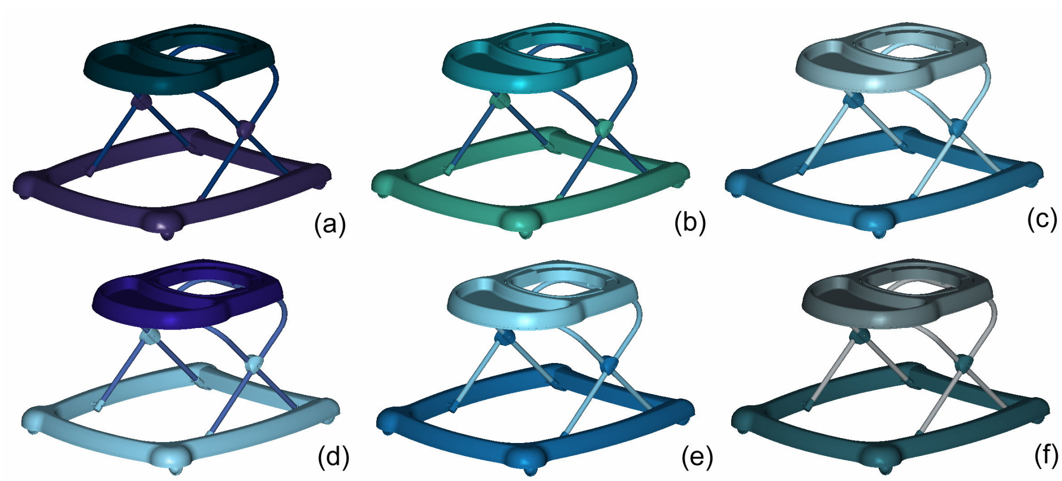

Fig. 8: Best-fitted color combinations at (a) initial, (b) 100th, (c) 200th, (d) 300th, (e) 400th and (f) 500th generation.

5. ACKNOWLEDGEMENTS

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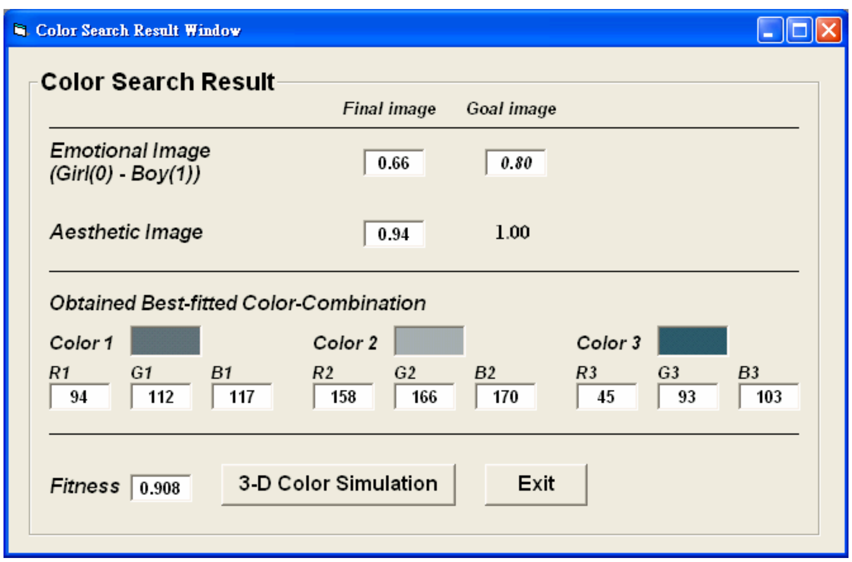

Fig. 9: Search result window presenting best-fitted color combination and corresponding image data.