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.
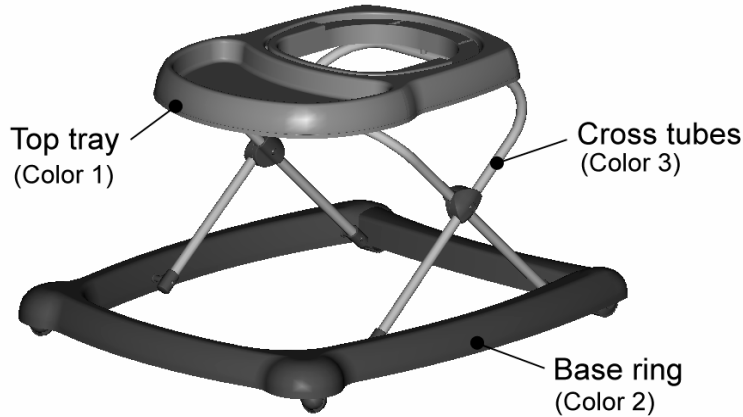

Fig. 1: Rendered 3-D model of baby walker with three-color appearance.

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 jth attribute (color) of the ith sample (color combination). The weighting factor function, f_{jk}, indicates the significance of the jth color to the kth 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 kth cluster of the ith 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:

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

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 $w_{EI} + w_{AI} = 1$.
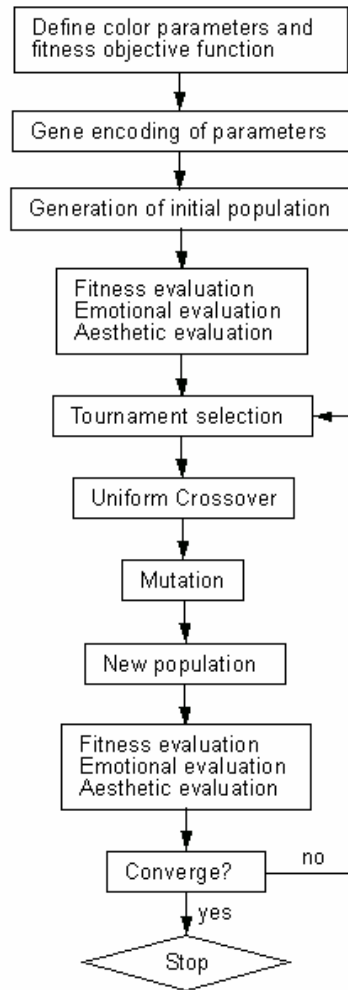
Fig. 2: Basic concepts of automated image prediction and color search mechanism.

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.
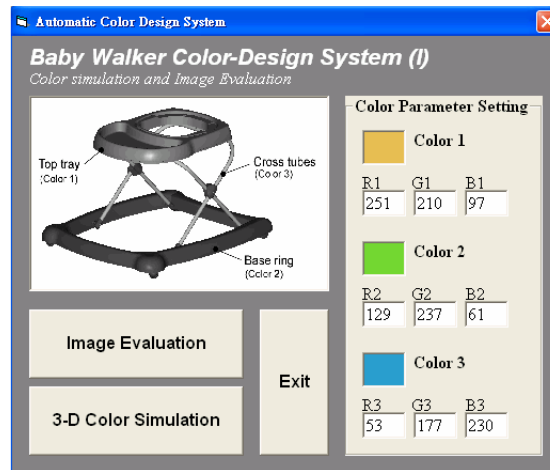

Fig. 3: Interface for constructing a 3-D color-rendered model and image prediction.
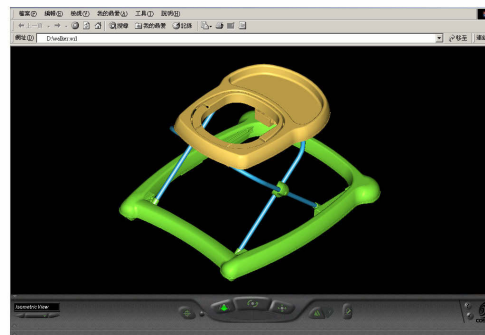

Fig. 4: Rendered 3-D model of Example I displayed on the Cosmo Player.

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.
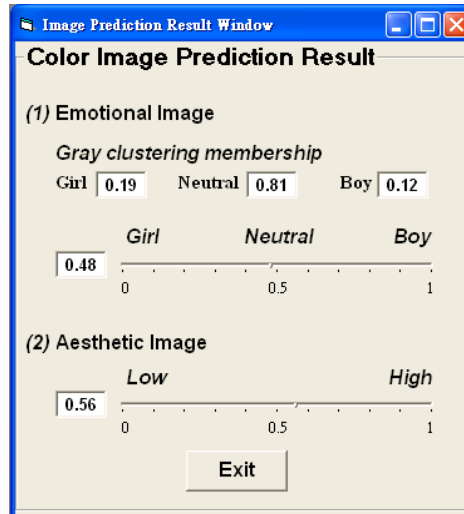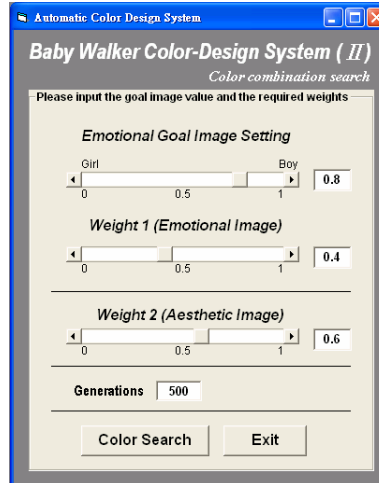
Fig. 5: Color-image prediction window.

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.
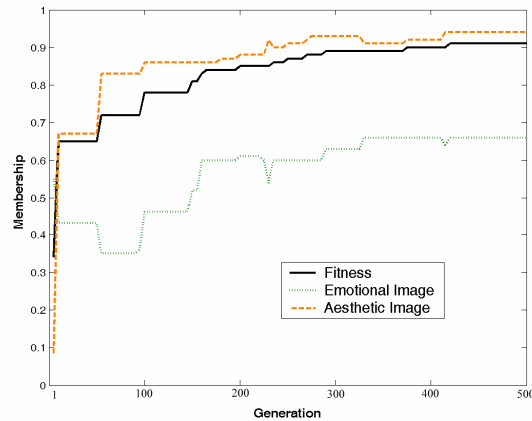

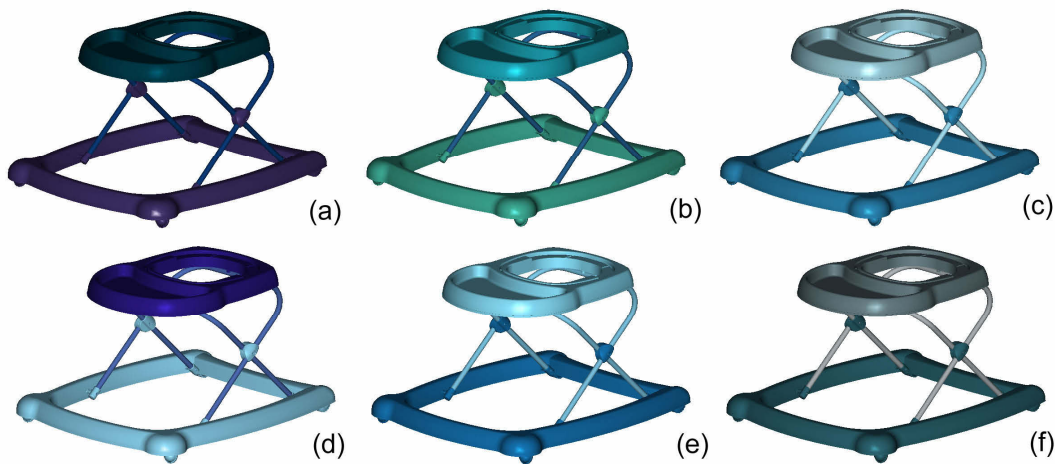Fig. 7: Trends for each image and improvement of fitness during search process

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

5. ACKNOWLEDGEMENTS

6. REFERENCES
[1]   Hsiao, S.-W.; Tsai, H.-C.: Use of Gray System Theory in product-color planning, Color Research and Application, 29(3), 2004, 222-231.
[2]   Tsai, H.-C.; Hsiao, S.-W.; Hung F.-K.: An image evaluation approach for parameter-based product form and color design, Computer-Aided Design, 38(2), 2006, 157-171.
[3]   Lai, H.-H.; Lin, Y.-C.; Yeh, C.-H.; Wei, C.-H.: User-oriented design for the optimal combination on product, International Journal of Production Ergonomics, 100(2), 2006, 253-267.

[4]   Van Dijk Casper, G. C.: New insights in computer-aided conceptual design, Design Studies, 16 (1), 1995, 62-80.

[5]   Hsiao, S.-W.: Fuzzy set theory on car-color design, Color Research and Application, 19(3), 1994, 202-213.

[6]   Hsiao, S.-W.: A systematic method for color planning in product design, Color Research and Application, 20(3), 1995, 191-205.

[7]   Ou, L.-C.; Luo, M.-R.; Woodcock, A.; Wright, A.: A study of colour Emotion and colour preference. Part I: colour emotions for single colours, Color Research and Application, 29(3), 2004, 232-240.

[8]   Ishihara, S.; Ishihara, K.; Nagamachi M.; Matsubara Y.: An automatic builder for a Kansei expert system using self-organizing neural networks, International Journal of Industrial Ergonomics, 15(1), 1995, 13-24.

[9]   Shen, Y.-C.; Chen, Y.-S.; Hsu, W.-H.: Quantitative evaluation of color harmony via linguistic-based image scale for interior design, Color Research and Application 21(5), 1996, 353-374.

[10]   Deng, J.-L.: Essential topics on gray system: theory and applications, Huazhong University of Science and Technology Press, Wuhan, China, 1987.

[11]   Tokumaru, M.; Muranaka, N.; Imanishi, S.: Color design support system considering color harmony, Proceedings of the IEEE Internal Conference on Fuzzy Systems, 2002, 378-383.

[12]   Tsai, H.-C.: Automatic Product Color Design of Two-Colored Products Using Genetic Algorithms, The Conference on Applied Art and Design, 2006, 109-115.

[13]   Moon, P.; Spencer, D. E.: Aesthetic measure applied to color harmony, Journal of the Optical Society of America, 34(4), 1944, 234-242.

[14]   Moon, P.; Spencer, D. E.: Geometric formulation of classical color harmony, Journal of the Optical Society of America, 34(1), 1944; 46-59.

[15]   Moon, P.; Spencer, D. E.: Area in color harmony, Journal of the Optical Society of America, 34(2), 1944, 93-103.

[16]   Goldberg, D. E.: Genetic algorithms in searching, optimization and machine learning, Addison-Wesley, Massachusetts, 1989.

[17]   Vico, F. J.; Veredas, F. J.; Bravo, J. M.; Almaraz, J.: Automatic design synthesis with artificial intelligence techniques, Artificial Intelligence in Engineering, 13 (3), 1999, 251-256.
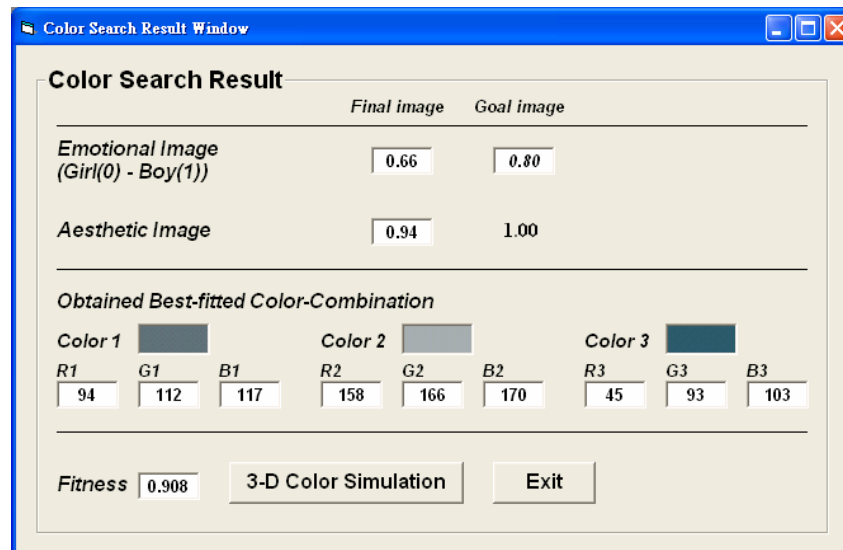
Fig. 9: Search result window presenting best-fitted color combination and corresponding image data.