The most harmonious hue components for the display

Ji Young Hong
Department of Visual Communication Design, Kyung Min College, Korea

Abstract This paper proposes a framework of colour preference control to satisfy the consumer's colour related emotion. A colour harmony algorithm based on two-colour combinations is developed for displaying the images with several complementary colour pairs as the relationship of two-colour combination. The colours of pixels belonging to complementary colour areas in HSV colour space are shifted toward the target hue colours and there is no colour change for the other pixels. The psychophysical experiments are conducted to investigate the optimal model parameters to produce the most pleasant image to the users in the respect of colour emotions.

Methods In this study, through the Munsellcolour system developed by human visual experiences, complementary colours are defined which create dynamic emotions and the related areas are established to examine the interactive relationship between the defined complementary colours.

The developed methodology shifts the hue component parameters of an input pixel belonging to the complementary colour area toward the most harmonious hue component points based on the complementary two colour pair with respect to colour emotion. The methodology is designed such that there is no colour discontinuity around the complementary colour boundary after the transformation.

Results According to the grades of the combination test, more than 30.86% of the judgments revealed that the transformed images are more harmonized than the corresponding original image. This result implies that the users can easily find their harmonized image by adjusting the most harmonious hue components of the developed methodology.

General Conclusion The previous studies are oriented toward the influences and preferences of single colours and of memory colours, whereas in this study, by applying colour combination through complementary colour contrast, dynamic emotions can be created from the original images by converting hue components into the most harmonious colour combination.

Keywords Complementary colour, Colour combination, Hue conversion

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Corresponding author: JiYoung Hong(placebo.joan@gmail.com)

1. Introduction

The nature and scope of the visual media is undergoing dramatic change as it enters the digital era. Portions of the formerly distinct photographic, electronic, software, television, computer, and printing industries are converging into a more generic imaging industry. Especially, there has been an explosion of new TV technologies to enhance the image quality but still now, consumers want more from “the visual media” and scientists and engineers still create technologies that expand the capabilities of the visual media. From now on, the visual media need to find something different to stir up the customer’s imagination and emotion. Among many factors which can affect the visual media, colours play an important role for customers in making decisions on what they like and dislike. The aspects, or qualities of colour, refer to colours and colour combinations that evoke certain emotional responses. This has triggered the development of various algorithms for colour processing and preference until now [1], [2], [3], [4] and has more recently resulted in a large number of psychophysical studies about colour emotions and colour preference. [5]

Simply, emotions are directly related to our colour attention. They limit what can attract and hold our attention. Emotions are triggered by personal interests and perspectives such that they address a practical concern associated with readiness to act. The abovementioned influence of colour on the way people feel and even human’s emotions and perceptions has been known for a long time. People often associate colours with their emotions, where light colours are known to help people feel more relaxed whilst dark colours create a more serious atmosphere.

Colour does not exist as a single entity. Single colours can be arranged sequentially according to their place in the spectrum. This is however not possible for colour combinations, as is obvious from a glance at different images. Therefore, consideration of colour harmony seriously affects the emotions. In visual experiences, colour harmony is something that is pleasing to the eye. It engages the viewer and it creates an inner sense of order, a balance in the visual experience. When something is not harmonious, it's either boring or chaotic. At one extreme is a visual experience that is so bland that the viewer is not engaged. The human brain will reject under-stimulating information. The human brain rejects what it can not organize, what it can not understand. The visual task requires that we present a logical structure. Colour harmony delivers visual interest and a sense of order. In summary, extreme unity leads to under-stimulation, extreme complexity leads to over-stimulation. Colour harmony is a dynamic equilibrium.

Comparing with the previous studies focusing on the preferences of single colours and memory colours of well known objectives based on patches, the pathway of the colourrelated the most harmonious colour combination in the actual image is studied.

The paper is organized as follows: The next section describes the definition of complementary colour harmony and boundary. Section 3 describes a colour combination methodology and psychophysical experimental results are shown in section4. Finally, the conclusion section closes the paper.

2. Definition of complementary colour and complementary colour boundary in HSV colour space

In the Munsellcolour wheel, a circle of the 10 regular hues can be arranged in the immutable order imposed bythe spectrum and Red begins at the top. Complementary colours can be defined as colour pairs
located at opposite directions. The term opposite is the preferred term in the MunsellColour System because it is simpleand self-explanatory, in which each hue on the opposite directionalong the circle will be found directly with respect to any chosen hue. Complementary colours which are opposite to each other provide great contrast and high visibility. Each two colours onopposite sides of the colour wheel, when placed next to each other, make both appear brighter and maximize thechromatic contrast. These colours always go well with each other, hence the term complimentary.

We define the pairs which can be complementary colours in terms of the Munsellcolour wheel. For example, ifthe defined colour is Red, the Red colour area is defined from the ending point of “Purple” to that of “Yellow Red.” In case of Blue Green, which is a complementary colour of Red, its colour area is defined as the area between “Green” and “Blue Green”. Similarly, Purple is defined as the area including “Purple Blue”. Meanwhile, the Blue Sky and Green Grass areas, which do not exist in Munsellcolourwheel, are defined by the patches that are prepared by the images collected from web site. The reason for integrating and defining 360 degrees of Hue, which is the overall area, is to prevent the effect of colour discontinuity from any types of impacts on the psychophysical experiment.

HSV colour space is represented by three components; Hue, saturation and value. Those three constituent components are operated independently of each other. Also, HSV encapsulates information of a colour in terms that are more familiar to humans. Each component of HSV is independently controllable and easy to be embodied. Conceptually, the HSV colour space is a cone shape. Viewed from the circular side of the cone, the hue components are represented by the angle of each colour in the cone relative to the 0 degree line assigned to red.[6]The Hue component is equal to the ratio of each primary (RGB) colour to the other. By definition, complementary colours have their own colour boundary of the hue components in HSV colour space.
By Munsellcolour conversion, we can find X, Y, Z values for each complementary colour and predict values for the hue components boundary in HSV colour space. The hue component boundary values of six complementary co-

lours are summarized in Table 1, under standard illuminant D65.

Table 1 Hue Boundary Values of Six Complementary Colours

Red	Blue Green	Blue Sky	Green Grass	Yellow	Purple Blue
0°~40°, 305°~360°	138°~182°	183°~228°	69°~137°	41°~68°	229°~304°

Table 2 CIE Standard Illuminant D65 (Observer 2°)

X	Y	Z
95.047	100.000	108.883

3.Colour combination methodology

The proposed colour combination methodology consists of two steps; 1) Judgment of the complementary colour area and 2) Hue component shifting of paired colour. For the complementary colour area judgment in HSV colour space, the design is such that the input colours detected as complementary colours are gradually transformed toward the most harmonious target hue component located inside the complementary colour boundary while there is no colour change in the case of hue components located outside of the boundary. Therefore any complementary colours in the image will be shifted toward the predetermined most harmonious hue component points as a pair. Hue component shifting is conducted after judgment of the complementary colour area.

For the judgment of complementary colour areas, the input hue component value is compared with the hue component boundary values shown in Table 1.

In transforming the input hue components toward the most harmonious hue component, it is most important to prevent abrupt colour discontinuity. For continuous hue component transformation, the distance between input hue component and the most harmonious hue component point is considered and the proposed hue component transformation is as follows;

$$\begin{aligned}&\text{if } H_{in} < H_t\\&H_{out} = H_t - (H_t - H_{in})^2 \cdot \frac{s}{H_{width}} - (1-s)\cdot(H_t - H_{in})\\&\text{if } H_{in} > H_t\\&H_{out} = H_t + (H_{in} - H_t)^2 \cdot \frac{s}{H_{width}} + (1-s)\cdot(H_{in} - H_t)\end{aligned} \quad (1)$$

Where H_{in} and H_t and H_{out} are input hue component, the most harmonious hue component point and transformed hue component values, respectively. In the Eq. (1), H_{width} is the distance between the boundary hue component value and the most harmonious hue component value. According to the position of the input hue component between two boundary values, H_{width} is found.

$$\text{if } H_{in} < H_t \; H_{width} = H_t - H_{lower}$$

$$\text{if } H_{in} > H_t \; H_{width} = H_{upper} - H_t$$

As shown in Eq. (1)., the continuous hue transformation is applied according to the difference between input and target hue value and H_{width} . That is, gradual hue transformation is applied to prevent the abrupt colour discontinuity. In Eq. (1), s is the strength of hue transformation, ranging between 0 and 1. If, s = 0, there is no hue transformation while s = 1 means maximum hue transformation.

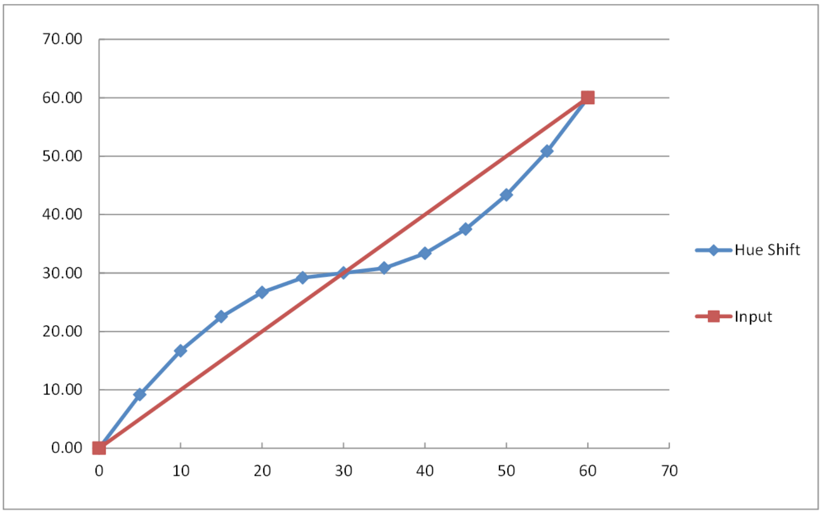

Figure 1 The continuous hue component transform method

4.Psychophysical Experiments

Three sets of psychophysical experiments were conducted to investigate the most harmonious hue component parameters and the degree of colour combination. Firstly, the most harmonious hue component parameters were found and secondly, it was investigated if there are any emotion changes by applying the developed methodology. The Paired-comparison method was used for all those experiments.

Figure 2 illustrates the test pattern shown to the observers during the experiments and test images. The image was shown in the center of a screen with a black background. Each observer selected the preferred image or assigned emotional adjectives to selected images. The sizes of the images were adjusted to a size of 13.5cm (W) × 13.5cm (H) for target hues and 13cm (W) × 8.5cm (H) for adjectives test.

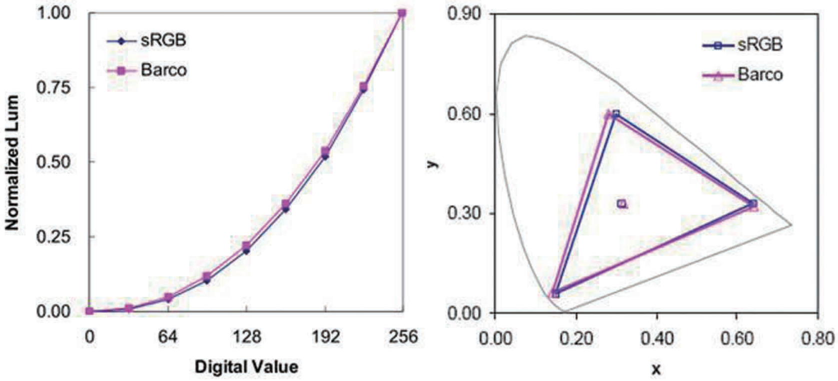

Figure 3 Characteristics of the Barco monitor used in the experiment.

Also, the monitor had a colour gamut similar to sRGB and the gamma value of the tone curve was 2.3. The monitor also had a good additivity.
For each experiment, the pair of images was randomly displayed to each observer in a dark room and 10 observers participated in the experiments. The distance between the screen and the eye was recommended to be 30 cm and observers can move their position.

The most harmonious hue component points were examined by comparing images reproduced using 9 uniformly distributed target points inside the complementary colour boundary. The strength s is fixed to 1 and there are no saturation and luminance changes.

Two pictures of each pair were selected as test images. For example, test images were chosen for Red and Blue Green colour as a pair in this experiment. Eighteen comparisons were made for each test image. The original image was not used for the experiment.

By data analysis, we found that the most harmonious hue component points are (Red, Blue Green) = (356°, 139°), (Blue Sky, Green Grass) = (213°, 104°), (Yellow, Purple Blue) = (58°, 256°).It should be noted that the selected hue component values are meaningful only for the specific Barco monitor used for the experiment. Moreover, HSV is a device-dependent colour space. Thus, the same HSV values may reproduce different colours on different monitors as well.

The performance of the developed methodology was tested by investigating the degree of colour combination.A total of 14 test images were selected and ten observers participated at the experiment. During the experiment, each transformed image was compared with the original image by the observers. The observers did not know which ones are the original and the degree of colour combination is measured by the likert scale. The likert scale is a bipolar scaling method measuring either positive or negative response to a statement. Each respondent is asked to rate each item on a scale. For instance, each item was rated on a 1-to-5
response scale where:

1. Extremely harmonious
2. Very harmonious
3. Moderately harmonious
4. Quite harmonious
5. Just perceptibly harmonious

Table 3 Psychophysical Experiment Result

Image	Original	CH Applied
1	3	4
2	3	5
3	3	4
4	3	5
5	2.9	4
6	2.8	5
7	3	4
8	2.9	5
9	3	4
10	2.8	5
11	3	5
12	3	5

13	3	4
14	3	4
Average	2.96	4.50
%	59.14	90.00

The result shows that 30.86 % of the transformed images were betterharmonized than the original when the most harmonious hue component values are applied.

5.Conclusion

In this study, colour combination methodology is proposed for improving dynamic emotions through hue component conversion. Through the Munsellcolour system developed by human visual experiences, complementary colours are defined which create dynamic emotions and the related areas are established to examine the interactive relationship between the defined complementary colours.

The developed methodology shifts the hue component parameters of an input pixel belonging to the complementary colour area toward the most harmonious hue component points based on the complementary two colour pair with respect to colour emotion. The methodology is designed such that there is no colour discontinuity around the complementary colour boundary after the transformation.

Psychophysical experiments are conducted to investigate the most harmonious hue component parameters and test the grade of colour combination. The most harmonious hue component points in HSV colour space are investigated in the psychophysical experiment.

According to the grades of the combination test, more than 30.86% of the judgments revealed that the transformed images are more harmonized than the corresponding original image. This result implies that the users can easily find their harmonized image by adjusting the most harmonious hue components of the developed methodology. The previous studies are oriented toward the influences and preferences of single colours and of memory colours, whereas in this study, by applying colour combination through complementary colour contrast, dynamic emotions can be created from the original images by converting hue components into the most harmonious colour combination.

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