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이미지–색채 조화를 위한 색채 선정과 이미지 보정

Image-Color Harmony: Key Color Generation and Image Recoloring

2018

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한 국 과 학 기 술 원

Korea Advanced Institute of Science and Technology

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Image-Color Harmony:
Key Color Generation and Image Recoloring

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The study was conducted in accordance with Code of Research Ethics[1].

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Abstract

In a variety of visual platforms, images and color elements are often involved together in order to elicit aesthetic and affective responses. Thus the harmonization of images and color elements is one of the basic requirements to create informative and persuasive design works. However, little knowledge is available on the method to achieve integrated aesthetics of image-color pairs and their practical applications. In this regards, this study aims to understand the harmony of image-color pairs, and developing computational methods and practical applications based on the understanding. To be specific, the process of color generation and image recoloring was firstly investigated through a set of qualitative research about design practice. The outcomes of design process were analyzed quantitatively to supplement the findings from the qualitative analysis. Based on the insights from design practice, techniques of image processing were reviewed and selectively adopted in order to develop methods to generate colors and to adjust image colors. User tests revealed that the proposed methods provide satisfactory outcomes in comparison with designers' works or existing methods. The methods were also adopted to applications of promotional contexts, and showed the image-color harmony could enhance promotional effects of visual contents or not. Lastly, the implications and probable applications of the proposed methods were widely explored while reviewing the limitations that the current study has.

Keywords image-color harmony, image-color pairs, key color generation, image recoloring

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1 INTRODUCTION

1.1 Background and Motivation
1.2 Research Aims and Objectives
1.3 Research Scope
1.4 Research Methodology
1.5 Definition of Terms
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1. INTRODUCTION

1.1 Background and Motivation

Over the past few years, creating, editing and sharing visual content have become everyday activities. Now people prefer taking pictures instead of writing a diary, post photographs rather than words in social network services and look for a killing shot rather than a catch-phrase. These changes largely increase both the frequency and the amount of visual contents people encounter throughout their daily life. When we look at visual content such as a photograph or a video, its colors play a pivotal role in eliciting aesthetic and affective responses toward the content. Accordingly, the ability to properly manipulate colors becomes important to communicate the visual content effectively. In order to ease the color manipulation of both novice and expert users, a wide range of tools and methods have been proposed in the fields of design, color science, computer visions and image processing. However, it still remains demanding or unaffordable for most of the users. What hinders the achievement of previous color studies from being alive in design practice? This dissertation starts from this question, and as a piece of design research, it has been motivated by following three backgrounds.

1.1.1 Lack of Understanding about the Practical Contexts

One of the prevalent color-related activities in visual design is adjusting colors of images or videos to create a particular look and feel. Many researchers have proposed methods to modify the image colors based on reference images, color palettes, and users' manual inputs. The methods named color transfer or color mapping have received an extensive attention due to its conceptual simplicity and the wide variety of techniques the method can employ. By transferring the colors of one image to another, these methods aim at resembling a look and/or a style of given examples.

In the practice of visual design, however, color adjustment is often performed with a distinct purpose in mind. For instance, designers are frequently asked to perform a series of design works related to a corporate identity or a brand (Ruzzier & De Chernatony, 2013; Stompff, 2003). In such tasks, the use of color is constrained by the brand identity (Jordá-Albiñana, Ampuero-Canellas, Vila, & Rojas-Sola, 2009; Melewar, Small, Whitelock, & Fastoso, 2007; Underwood, 2003). Figure 1.1 shows examples that a specific color or a color theme is dominantly used throughout the graphic works. As shown in the examples of UNICEF, using harmonious images with the identity color provides the coherent and aesthetic appearance and is effective to communicate their identity persuasively. Unlike UNICEF, the NYU website constantly changes the images to release recent news. In this case, manual image adjustments are rarely feasible. Thus the visual of NYU website looks less coherent than UNICEF. These examples imply the importance of image adjustment for harmony with a given color as well as its automation. However, a harmonious image adjustment has yet been investigated, despite its practicality and usefulness in various applications.

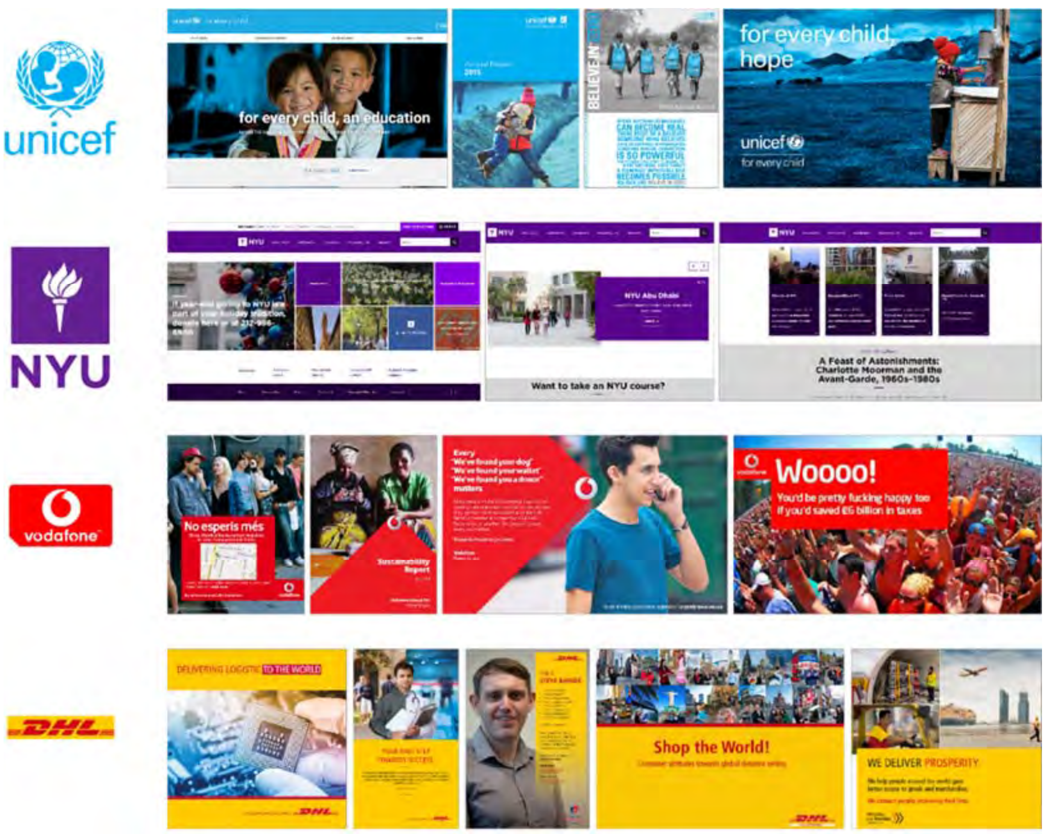


Figure 1.1 Design examples with fixed identity colors.
Each design case has a specific color theme depending on the brand identity colors. In the case of Unicef (top), images used for the design cases are carefully recolored to achieve harmony with the brand color.

The aforementioned case is a single instance that discloses a practical aspect of visual design activities that has rarely been considered. Although numerous color transfer or image colorization methods are available, as will be discussed in section 2.3, a suitable one is absent for everyday design activities. In this regards, this research starts from understanding the design activities of practitioners and aims at revisiting conventional color-related techniques with the perspective of design practice.

1.1.2 Lack of Understanding about Integrated Aesthetics of Images and Color

A broad range of aesthetic and affective responses can be elicited by either one or more colors. The aesthetic and affective meanings of color have been investigated in many fields, and such studies have expanded our understandings of color perception.

In the practice of media production, however, colors are rarely utilized solitarily. Instead of being isolated, colors are often accompanied by various visual content including images, videos and infographics. The combinations of colors and visual content can be easily found in book covers, commercial film, websites, and a variety of user interfaces (Figure 1.2). In these cases, the harmonization of colors and visual content plays a pivotal role in delivering informative and persuasive content. Accordingly, in the process of visual design, it is important to select a suitable color that can enhance the aesthetic and affective quality of

Figure 1.2 Color elements with accompanying visual content.
Colors are intentionally chosen to achieve harmony with the adjacent images in various applications.

accompanying content. However, little is known about the integrated aesthetics of colors and visual content and how such integration evokes affective responses. Lacking useful knowledge and methods, designers often resolve the color generation problems through expert intuition and/or repetitive trials. To novice users without sufficient knowledge, it becomes more inscrutable. To support efforts to create aesthetic image-color pairs, this research investigates the principles of harmony between images and color, and develops a computational method based on the principles discovered.

1.1.3 Lack of Understanding about Procedural Knowledge of Professionals

Due to the emergence of automatic design, designing has become the task of automatic design systems beyond the task of designers. The change raises a new issue about the extent of a computational method emulates the capability of expert designers. There have been several attempts to utilize outcomes of designers in order to develop methods which produce similar outcomes as designers' (Jahanian, Vishwanathan, & Allebach, 2015; Lin & Hanrahan, 2013). The rapid growth of technologies in machine learning encourages researchers to pay attention to a significant amount of outcomes rather than the process in order utilize them as a training set. As proven in current studies, researchers now can reproduce the drawing style of an artist without an understanding of the drawing process, patterns and characteristics of the artist (Gatys, Ecker, & Bethge, 2015; Joshi, Stewart, & Shapiro, 2017).

Although this dissertation also has a comparable goal to reproduce the outcome of designers, it takes a distinct approach. What does the process of designing say about the design outcome? Methodologically, this dissertation is a new attempt to emulate the process of designers, not their outcomes. Most of all, in terms of contributing to design practice and research, understanding the creative process of designers is intriguing and valuable to make use of procedural knowledge produced by designers. In this manner, it is expected that this study will inspire a new perspective of conventional research and promote a variety of related works that satisfy the tangible needs of industries and academia.

Throughout this research, an improvement or an invention of technique was not significantly considered. Instead, the researcher focuses on identifying novel and practical contexts within an integrated visual design process, and tries to adapt conventional techniques properly to assist or automate specific design activities. Thus the major contribution of this study does not lie upon the maturity and/or complexity of the developed methods. It rather has a strength on its approach to deal with a novel problem and the wise use of existing technologies based on the understanding of procedural knowledge of professionals.

1.1.4 Increases in Demand for Automatic Solution

The context of image-color harmony is prevalent in our everyday visual experience. To some extent, several applications provide automatic solutions for image-color harmony. Figure 1C shows exemplary cases presented by Google search. As shown, the dominant color of the mobile interface is automatically changed in response to the colors of displayed images.

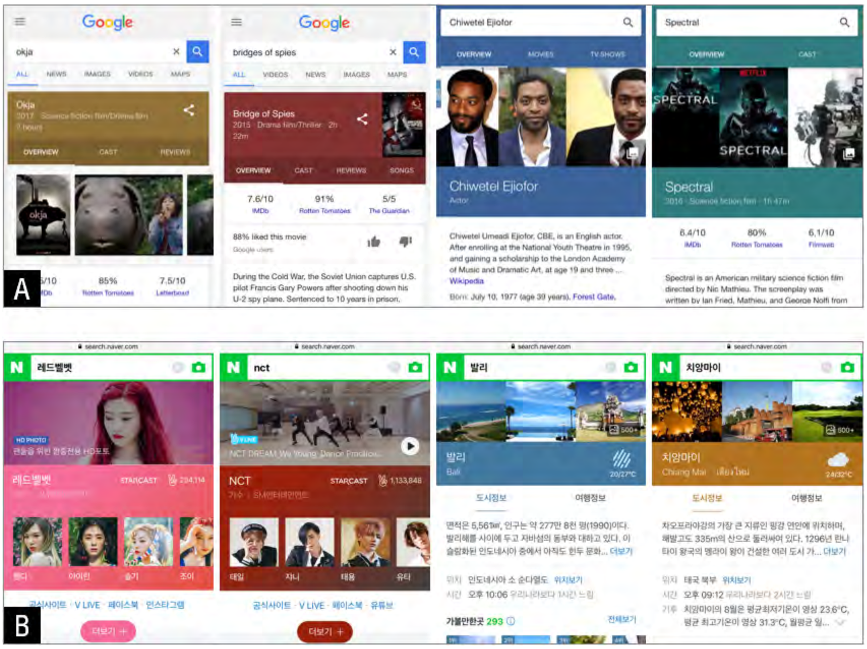


Figure 1.3 Examples of Automated Image-Color Harmony: Google (A) and Naver (B).
Both cases show the responsive color usage of web-based search platforms that changes the interface color depending on the images from a search result.

These instances imply that engagement of automatic systems could be increased in various areas to provide better user experience regarding image-color harmony. Furthermore, it raises an issue about the extent of a tool or a system automates the achievement of image-color harmony without the engagement of professional designers or even general users. In case of selecting a harmonious color, it seems there are utilizable techniques in practice as Google and Naver adopted. However, in the perspective of image recoloring, little knowledge and techniques are available to achieve image-color harmony with a settled color. Thus, it is much more important to understand the latent principles of image-color harmony and develop a reversible method that allows both image and color can be interactively changed in response to each other.

1.2 Research Aims and Objectives

This research aims to develop computational methods that create harmonious image-color pairs by deploying the practical knowledge of designers. Of particular interest are color-related activities including image recoloring and color generation. The present study also intends to investigate applications and to estimate the practicality of developed methods in the practice of design. In a macroscopic view, this research **presents an automatic way of creating image-color harmony through key color generation and image recoloring.** Figure 1.4 illustrates the comprehensive framework of this research, and a series of research activities were performed with following four aims and related eight objectives.

Aim 1: Understanding the Process of Creating Image-Color Harmony

Objective 1: To understand the **process of color generation with a given image** to create a harmonious image-color pair.

Objective 2: To understand the **process of image recoloring with a target color** to achieve a harmony with the target color.

Figure 1.4 Research framework: Image recoloring and key color generation for image-color harmony.
This research focuses on two approaches – color generation and image recoloring - for image-color harmony.

Aim 2: Developing Computational Methods to Create Harmonious Image-Color Pairs

Objective 3: To **identify appropriate technical approaches** to emulate the designers' process to create image-color harmony.

Objective 4: To **develop a color generation method** that determines a color or a set of to achieve harmony with a given image.

Objective 5: To **develop a harmonious image recoloring method** that adjusts image colors to achieve harmony with a target color.

Aim 3: Evaluating the Performance of Developed Methods and their Practicality

Objective 6: To evaluate the performance of key color generation and image recoloring methods.

Objective 7: To **evaluate the practical benefits** and advantages of the proposed methods by applying them in practical applications.

Objective 8: To **discuss and envision applications and future research issues** that can be benefited from the developed methods and related technologies.

1.3 Research Scope

This research explores the latent principle of visual design activities in order to emulate it in automatic systems for aesthetic and affective user experience in relation to visual contents. Accordingly, the research activities of this study comprise understanding the visual design activities of professionals and developing automatic methods which are operable without users' assistance. To be specific, this research has particular interests on the color-related activities in the visual design process. Thus the scope of this research excludes the engagement of design factors such as shapes, layout and typography.

The scope of this research includes the following:

- To **discover the latent principles and tacit knowledge related to color-related visual design process** by analyzing the activities of professionals;
- To suggest conceptual frameworks that represent the significant principles and tacit of professionals;
- To **develop and suggest computational methods that automate image recoloring and color generation** by adopting appropriate existing technologies;
- To **ascertain the utility and practicality of the proposed methods** in the practice of visual design by implementing them in plausible applications;

The followings are beyond the scope of this research:

- To **investigate visual design activities that are not directly related to colors:** The present research focuses on color elements and colors of visual contents that significantly influence our perception and elicit emotional responses. In a comprehensive visual design process, a variety of factors is engaged such as shapes, layouts and typography. However, the entire dynamics and related principles are extensive and multifaceted to be disclosed by a single research or a series of research activities. Thus the scope of this research is delimited by embracing only color-related design activities.

- To **achieve a technical improvement in developing computational methods** of image recoloring and color generation: Methods to recolor images or to extract color from images have been proposed by many researchers in various disciplines. In the perspective of computer vision or image processing, developing a new method is often related to its improvement of optimization in its performance such as an increased computational speed, robustness of the outcomes and improved controllability. However, neither the aim nor the contribution of this research relies on the technical improvement or the technical novelty of the proposed methods. The research rather has a strength on its appropriate adaptation of existing technologies in novel and practical context and how such a new approach brings promising advantages in both design research and academia.

1.4 Research Methodology

Two major research activities are involved in this study. One is investigating the color-related design process of professionals. The other is developing computational methods to emulate the process in automatic systems. For the prior activity, a qualitative approach was mainly devised for data collection and analysis while quantitative analysis reinforces the findings from the qualitative analysis. To be specific, **a think-aloud and an interview method were adopted to collect verbal data** related to design activities of professionals, particularly their cognitive activities. The **collected verbal data was analyzed using a protocol analysis**.

Think aloud is a method to gather verbal protocols about thinking through a concurrent verbalization (Fonteyn, Kuipers, & Grobe, 1993; Someren, Barnard, & Sandberg, 1994). Several studies suggested that verbal protocols obtained through the think-aloud provide the valid and sufficient amount of information to understand the cognitive processes in a wide range of tasks (Ericsson & Simon, 1998; Russo, Johnson, & Stephens, 1989). Although some researchers argued its influences on design activities (Davies, 1995l; Lloyd, Lawson, & Scott, 1995), it has widely been utilized in the design researches which investigated the cognitive process of designers (Dorst, 2003; Gero & Tang, 2001; E. Kim & Kim, 2015; Self, Evans, & Kim, 2016). To compensate the limitation of concurrent verbalization, a retrospective verbalization – a post-hoc interview – was selectively utilized together. The details of the research activity are described in Chapter 3.

On the contrary, the later research activity – developing computational methods – primarily utilized quantitative methods to evaluate the validity and performance of its outcomes while deploying an interview method to explore potential advantages of the research outcomes. In particular, **a series of surveys were conducted to collect ratings and responses upon the developed methods**. Chapter 5 corresponds to the related research activity.

Methodologically, utilizing a survey is a common approach to collect responses and draws inferences from the data. However, employment of a qualitative method – a protocol analysis – characterizes this research in comparison with previous studies which have attempted to develop methods for automatic design (Gajos & Weld, 2004; Hunter, Slatter, & Greig, 2011; Jahanian et al., 2013a; Kuhna, Kivelä, & Oittinen, 2012). Most of the researchers have investigated the outcomes of designers or existing principles rather than the process to create such outcomes (Gajos & Weld, 2004; Jahanian, 2016; Kuhna et al., 2012; O'Donovan, Agarwala, & Hertzmann, 2014b). Although their attempts have achieved satisfactory outcomes, the studies have added little understanding of design process and highly relied on the given resources or principles. By investigating and reflecting the procedural knowledge of professionals, this research makes a unique contribution in the perspective of research methodology to develop and suggest computational methods for design automation.

In addition to the methods for major research activities, a comprehensive review of the literature and related works was conducted in order to identify the state-of-art services available in the market and to discover appropriate technical approaches for the study. Encompassing all the methods, Table 1.1 summarizes the research methodologies used in this research with corresponding sections and purposes.

Table 1.1 Methodologies used in this dissertation with related chapters and purposes.
Except for the literature review of Chapter 2, the rest of studies are empirical investigations to understand and evaluate practical knowledge and perception about image-color harmony. As the study progresses, the methodologies used become more quantitative-centric and decisive, while the early stage of the research majorly utilizes qualitative and explorative methodologies.

Chapter	Purpose	Methodology
2	To investigate prior knowledge about how people perceive images and colors To discover appropriate technical approach by understanding the state-of-art techniques and services	Review of literature and related commercial tools/services
3	To investigate the latent principles and knowledge of professionals and to create image-color harmony	Think-aloud & Interview Protocol analysis
4	To evaluate the performance of the proposed methods: key color generation and image recoloring	Survey & Interview
5	To evaluate the practicality of proposed methods in various applications	Survey

1.5 Definition of Terms

This section describes the definition of the key terms found in this dissertation. In general, the terms are not against their recognized definition in both academia and practice. Some of them deliver narrow and focused meaning, while others comprise broader interpretation than their conventional usages.

The term '**image-color pair'** indicates a set of an image and a color element, which is utilized together within a scene. The type of a color element is not limited to a certain shape, typography or usage. The color element rather indicates a design element with a specific color value that can be transformed into a part of visual design.

The recurring term '**image-color harmony**' throughout this dissertation refers to a satisfying balance or unity of an image-color pair. Image-color pairs that exist in harmony are aesthetically pleasing to the eye. Since the concept of image-color harmony itself is

A **'key color**' here refers to a single color that can be dominantly utilized in design while achieving robust harmony with an image. In terms of its significance and usage, a key color corresponds to a dominant color in graphic design.

'Color generation' is a term that describes a creative color selection process to achieve harmony with a given image. In the image processing discipline, color extraction is a widely-used term to represent a process to select representative colors of an image. However, the color selection for design is not limited to identify representative colors of an image. It encompasses more creative and generative explorations to find satisfactory harmony between an image and a color. Thus this study used the term generation to represent the notion explicitly.

The term a **'target color'** represents a color or a set of colors predefined to be used for design. The expression 'target' was intentionally chosen, since the color is a design constraint and also a pivot of image recoloring strategies to assure image-color harmony. A brand color is a representative case of a target color that the brand identity highly constrains color usage of design activities.

1.6 Structure of Dissertation

This dissertation consists of eight chapters that describe the entire research activities to develop and evaluate both of image recoloring and color generation methods, which aim to suggest a responsive and interactive way of presenting visual contents and colors. Following phrases delineate the contents of each chapter that constitutes this research.

Chapter 1 states the aims and objectives of this research on the basis of social and academic background and motivation. The scope and significant terms of this research are presented as well.

Chapter 2 reviews academic literature and commercial tools that are relevant to this research. The literature review encompasses not only the theoretical knowledge but also the techniques that have been developed by other researchers. Additionally, a variety of design tools and services are reviewed in order to delineate the up-front techniques that are available for the practice of design.

Chapter 3 describes the details of the investigation to understand the designers' principles and tactics of creating image-color harmony. In particular, the color generation process and image recoloring process

Figure 1.5 Structure of the Dissertation.
The major three research activities are described in Chapter 3 to 5 that include understanding (Chapter 3), Method Development (Chapter 4) and Evaluation (Chapter 5).

were investigated. The qualitative data collection and analysis procedures are presented as well as the findings from the professionals. The findings lead to identifying technical approaches to develop automatic methods including key color generation method and image recoloring.

Chapter 4 proposes two automatic methods including key color generation and image recoloring to create image-color harmony. Technical approaches to develop these methods were determined based on the findings from the experiments with designers. The approaches associated with specific techniques are described in details.

Chapter 5 presents a series of user tests to evaluate the performance of the proposed methods. In addition, user tests were conducted in order to evaluate the practicality of the proposed methods in the context of suggested applications. Based on the results of the user tests, the advantages and potential of the proposed methods are discussed as well as their limitations.

Chapter 6 provides a comprehensive and integrated discussion of this dissertation. It firstly presents implication of understanding the designers' practice in perspectives of both industry and academia. Then, it discusses the advantages and pitfalls of the proposed methods, and suggests a variety of probable and prospective applications that could be benefited by the proposed methods.

Chapter 7 is the conclusion of the research that summarizes procedures, findings and remarks on its contribution and further studies. ■

2 RELATED WORK

2.1 Overview
2.2 Perception of Colors
2.3 Methods to Recolor Images
2.4 Methods to Extract Colors from Images
2.5 Images and Colors in Practice
2.6 Summary

2. RELATED WORK

2.1 Overview

Aiming at developing image adjustment and color extraction methods, previous studies and relevant tools were reviewed in relation to any of these factors: color, images and visual design. Based on these studies, four main contexts for this research were identified: 1) the perception of color and its harmony, 2) methods to adjust image colors, 3) method to extract colors from images, and 4) tools and services for visual design. The rest of this chapter will discuss the relevant works of each context while categorizing them according to their purposes or technical approaches.

2.2 Perception of Colors

Color is one of the most important factors that have a strong influence on human perception. Hence understanding the perception of colors was long been an interest of researchers. Since this study mainly investigates color, two fundamental topics – color emotion and color harmony – that have been studied by numerous researchers were reviewed.

2.2.1 Color Emotion

The choice of color has a complex but strong relationship with the aesthetic and affective experience of design. Hence, the perception of color and color combinations has attracted interests of many researchers. For instance, Osgood et al. (Adams & Osgood, 1973; Osgood, Suci, & Tannenbaum, 1957) revealed the cross-cultural universality of affective feelings about colors. They associated colors with perceptual dimensions such as evaluation, activity, and potency. According to their study, red is active and strong, while gray is passive, bad and weak. Wright and Rainwater (Wright & Rainwater, 1962) suggested six connotative factors including happiness, showiness, forcefulness, warmth, elegance and calmness. These six factors were the most susceptible to the changes in saturation, and the least influenced by the hue. Similarly, several studies have reported that saturation and value evidenced the strong and consistent effects on emotions (Suk & Irtel, 2010; Valdez & Mehrabian, 1994).

Since color is rarely perceived in isolation, there have been many investigations on color combinations as well. Ou et al. (2004) developed three-dimensional color-emotion space with axes of color activity, color weight, and color heat. By applying the same space to single color and color combinations, they confirmed that emotion induced by a combination of two colors could be predicted by the mean of single color emotions.

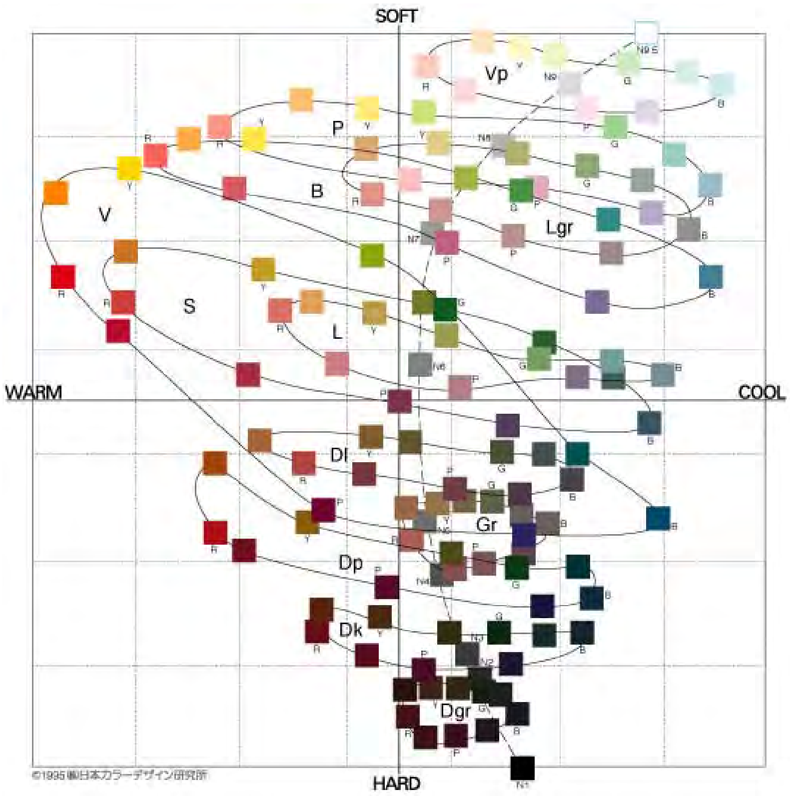


Figure 2.1 Single color image scale. Reprinted from Kobayashi (1991).
A total of 180 colors were investigated in terms of their affective or emotional quality, and mapped on a two-dimensional image scale map with soft-hard and warm-cool axes.

Kobayashi (1981, 1991) examined the meaning of color and color combinations, and he developed the Color Image Scale. The scale correlated single colors, 3-color themes, and 180 affective keywords together on the image scale map and provided the relationship between affective keywords and colors. Figure 2.1 shows the Single Color Image Scale proposed in Kobayashi's book (1991). A total of 180 colors are located on the two-dimensional map characterized by warm-cool dimension and soft-hard dimension. Because the color image scale explains the associations between affective words and colors, several studies have utilized the scale to measure or estimate the affective quality of a certain color (Shin & Kim, 2010; Solli & Lenz, 2010; X. Wang, Jia, & Cai, 2013).

2.2.2 Color Harmony

In addition to the perception of color combinations, many early studies concentrated on identifying principles of harmonious color combinations. The early studies (Goethe, 1971; Itten & Birren, 1970; Munsell & Birren, 1969) has suggested generic and global principles, while more recent studies (L. C. Ou et al., 2012) have differed the emotions that colors can convey. Like Goethe (1971), Munsell (1969) viewed balance as a key to creating harmonious color combinations. Based on the Munsell color system, various color harmony principles were suggested, and the quantitative measure developed by Moon and Spencer (Moon & Spencer, 1944a) was one of them. Itten (Itten, 1961) designed a new color wheel of twelve hues and introduced relative positioning of hues that would harmonize together. Based on Itten's wheel, Matsuda (1995) suggested a set of hue templates that defines harmony among colors.

Figure 2.2 shows Matsuda's eight types of hue template that create harmony among colors. If the relative hue relationship among colors fits one of the hue templates, the colors create a harmony. The template demonstrates the desire of people to formulate a rule of color harmony as well as the significance of hue feature. The template has been used by several researchers to construct harmonious color schemes or to harmonize colors of an image (Cohen-Or, Sorkine, Gal, Leyvand, & Xu, 2006; Tang, Miao, Wan, & Wang, 2011).

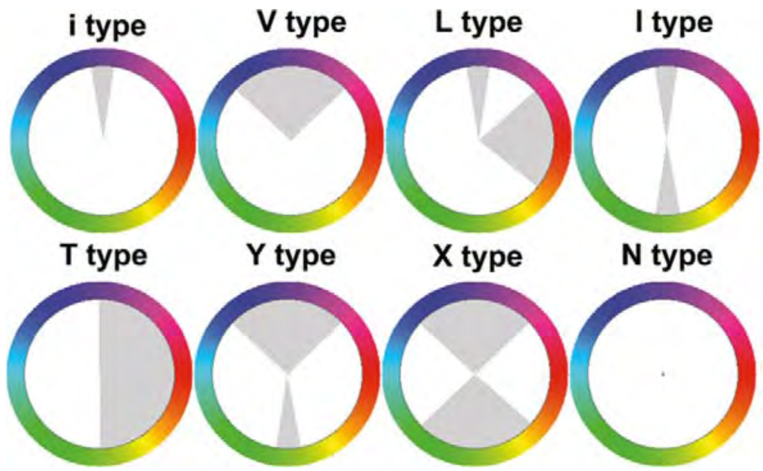


Figure 2.2 Matsuda's harmonious hue templates. Reprinted from Tang et al. (2011).
If the hue relationship among colors fits one of the hue templates, the colors create a harmony.

Given the principles and theories of these studies, a variety of tools have been developed to support color selection process. Hu et al. (2014) presented a tool that helps users to interactively explore and generate color schemes based on color harmony principles. Specifically, they devised the rule of familiarity and a rhythm span to determine a set of harmonious colors. Based on the given rule, their tool allows users to adjust colors of the scheme and demonstrate them on pattern design. Moretti (2013) developed a 'color harmonizer' that automates the generation of harmonious color schemes and showed its application in GUI design. Meier et al. (2004) developed a toolset, Interactive Palette Tools, that enables browsing, breeding, and displaying of color palettes.

2.3 Methods to Recolor Images

Color adjustment of images has received a considerable amount of attention in both academia and industries recently. For instance, color adjustment to reduce differences between two images often serves as a fundamental pre-processing to edit the images further. Matching the colors among images is essential to stitch multiple images into a panorama scene (Brown & Lowe, 2007; Hasler & Süsstrunk, 2004), to smoothly connect two scenes from different cameras (Y. Chen, Ma, & Cai, 2010; Doutre & Nasiopoulos, 2009), and to reproduce an artistic style in other contents (Haeberli, 1990; Kang, Lee, & Chui, 2009).

The color adjustment techniques appear under various names including color transfer, color mapping, and color correction. As such, their algorithms and applications also vary. From a macroscopic point of view, however, they share the goal to change the colors of an original image by transferring those of a reference. This study also has a shared ground with previous works in terms of recoloring an image, while its purpose and applications are distinguishable. A comprehensive study of Faridul et al. (2014) suggests three categories into which a majority of color transfer studies fit. They are geometry-based, statistical, and user-assisted approaches. Based on their classification, we have constructed a frame to review previous works with an emphasis on the features each method mainly deployed. In general, the methods can be grouped into three categories: image recoloring using color features (Section 2.3.1), methods using color and spatial features (Section 2.3.2), and methods assisted by user input (Section 2.3.3). The order of the three categories is aligned with the increase of the complexity and richness of the input information. The related tools and applications were reviewed as well in order to outline the available service in the market.

2.3.1 Image recolorings Using Color Features

Transferring statistical color properties is one of the most accessible and affordable techniques that can be executed without defining a direct correspondence between two images. In these methods, color information of the image is considered solely and independently from the spatial information that each pixel has.

A histogram is a commonly used descriptor to represent a distribution of color features. For instance, the study of Senanayake and Alexander (2007) uses RGB histograms to align color distribution of two different images. For the histogram of each dimension of RGB, they calculated the histogram maxima which indicate multiple dense regions within the dimension. Then they aligned maxima of two corresponding histograms via a polynomial warp. Since they match the maxima only, the color transfer results were robust to size variability of regions or objects depicted in the original image. A series of studies conducted by Pouli and Reinhard (2010, 2011) also take comparable approaches that transfer coarse color features selectively. By doing so, these approaches avoid the rigidness caused by a full histogram transfer.

Another frequent problem of full histogram transfer is color region mixing. To resolve this issue, Pitie and colleagues (2007; 2005) proposed a one-to-one mapping between two images by using an N-dimensional probability density function. They viewed the input images as sets of color sample in 3-dimensional color space and transform the original samples to a new set that exhibits the same probability density function as the reference sample has. They also demonstrated that their method allows transferring the not only the statistical characteristic, but also the feel of the reference image even the color range of two images are very different. The study of Neumann and Neumann (2005) is another example that utilized a probability density function to match the 3D histograms of hue, luminance, and saturation between two images. Aiming at reproducing the color gamut of the reference image, they applied a conditional probability density function in order of hue, hue-dependent lightness, and hue and lightness-dependent saturation histograms.

Instead of taking the color distribution of reference image, several studies utilized color palettes or color category distribution of images to perform a color transfer. Ha et al.(2011) proposed a local color transfer method using 11 color categories. Once an original image is categorized according to color categories, they decided the degree of transferring the color properties of a reference – a region of an image or a color swatch – based on a modified color influence map. The modified map assigns different weights to lightness and chroma depending on the characteristics of the original image. Thus it has less color distortion in the resulting image. The study of Kim et al. (2009) also adopted the 11 color categories in order to group and prioritize the colors to be transferred.

A number of studies have taken a palette-based approach. Yoo et al.(2013) extracted a set of dominant colors from both original and reference images and determined the correspondence between two sets based on the saliency. Other studies have tried to perform a color transfer via using a color palette instead of a reference image (Chang, Fried, Liu, DiVerdi, & Finkelstein, 2015; Nagai, Uchida, Myodo, & Sakazawa, 2013; B. Wang, Yu, Wong, Chen, & Xu, 2010). Wang et al. (2010) presented a method that utilizes a color mood space to quantify the difference between the original image and the target color palette, and assign a color of the palette to a large area with a similar color in the original image. Nagai et al. (2013) proposed a color transfer that ensures a full transfer of a given color palette with a spatial coherence. They viewed

Figure 2.3 Exemplary outcomes of the palette-based recoloring method proposed by Chang et al. (2015). According to the new color assignment to the color palette of the original image, the recoloring method adjusts image colors according to the one-to-one palette membership.

the color assignment as a labeling problem and employed the concept of offset to ensure the synchronization of the same semantic regions while minimizing the cost of color transformation. A study by Chang et al.(2015) provides a more user-controllable method that can result both local and global changes. Once a color palette is extracted from an original image, their method allows users to change the palette colors to any of desired colors directly. Figure 2.3 shows examples generated by their recoloring method.

A noteworthy issue related to color feature-based methods is which color space is suitable for color transfer. Especially when a color transfer is executed for each color dimension individually, the selection of color space has a significant impact on the outcomes. A generally accepted principle is that less correlated color dimensions produce a better quality of transfer results. The study of Reinhard and Pouli (2011) provides a detailed explanation and evidence about this question. In short, they concluded that *CIE1976 L*a*b** (CIELAB) color space with illuminant E works best for color transfer.

2.3.2 Image recoloring Using Both Color and Spatial Features

Image adjustment based on color information requires a less computational power than other methods, and allows a color transfer between two images with dissimilar structures. However, it often produces unsatisfactory outcomes with color distortion and provides a limited control over the features to be transferred. In order to improve the robustness of the results, spatial information has been utilized to match corresponding regions between images (Chiou & Hsu, 2009; Greenfield & House, 2003; Roettger, Bauer, & Stamminger, 2005; Q. Wang, Sun, & Wang, 2009).

Roettger et al. (2005) proposed a color transfer that extends the existing histogram based method by incorporating spatial information of a 3D volume to the histogram. Their method classifies the histogram into several classes based on spatial information and assigns a unique color to each class. Then, the statistical information of the histogram such as gradient is used to define the opacity of the color to be transferred. The method developed by Chiou and Hsu (2009) uses multiple reference images to determine the best region for each region of the target image. To do so, they firstly segment input images into region levels and look for best matches based on not only the features of the region but also the spatially adjacent relationships among regions.

When transferring colors region to region, feature detection methods are often employed in order to identify corresponding regions between original and target images. A texture feature is one of the most frequently used characteristics (Luan et al., 2007a; Qu, Wong, & Heng, 2006; Song & Liu, 2016; B. Wang et al., 2010). Luan et al.(2007a) proposed a colorization method specialized in natural images that groups not only neighboring pixels but also distant pixels with a similar texture. By integrating text and color features, the method by Song and Liu (2016) offers a transfer of appearance that involves both color and texture features. Similar to the appearance transfer, Zhang et al.(2013) proposed a style transfer algorithm via a novel component analysis approach, considering the content and style separately. The study mainly aimed at transferring the style of an artistic image to real photographs.

As mentioned previously, color region mixing is one of the most frequently found problems in a color transfer. Utilizing an edge map could be a reliable solution to the color mixing issues around region boundaries. For instance, by extracting edges between object boundaries, Huang and colleagues(2005) suggested a method to color a grayscale image that avoids wrong colorization and over-propagation.

2.3.3 Image recoloring Assisted by Users' Input

The techniques previously mentioned offer an automatic color transfer for which no additional input is required. However, the success of automatic methods highly relies on the selection of reference images. If the original and output images are overly different regarding their structures or contents, automatic methods often fail to deliver the desired outcomes. To overcome these limitations, various user-assisted methods have been suggested.

The study of Wen et al. (2008) presented a multiple local color transfer method in which users' strokes define corresponding regions. Their method supports not only indicating regions to be adjusted, but also specifying the regions to preserve. This feature allows users to selectively transfer colors while maintaining the original features of a specific area. Similarly, Luan and colleagues (2007b) suggested a technique that utilizes two types of strokes. One defines the corresponding regions for color transfer, and the other indicates a region in which to maintain the original colors. Figure 2.4 illustrates the stroke-based color transfer method suggested by Luan et al. (2007b). The yellow stroke defines the region to preserve the original colors, and the green and red strokes correspond the regions to transfer colors from the source to the original image.

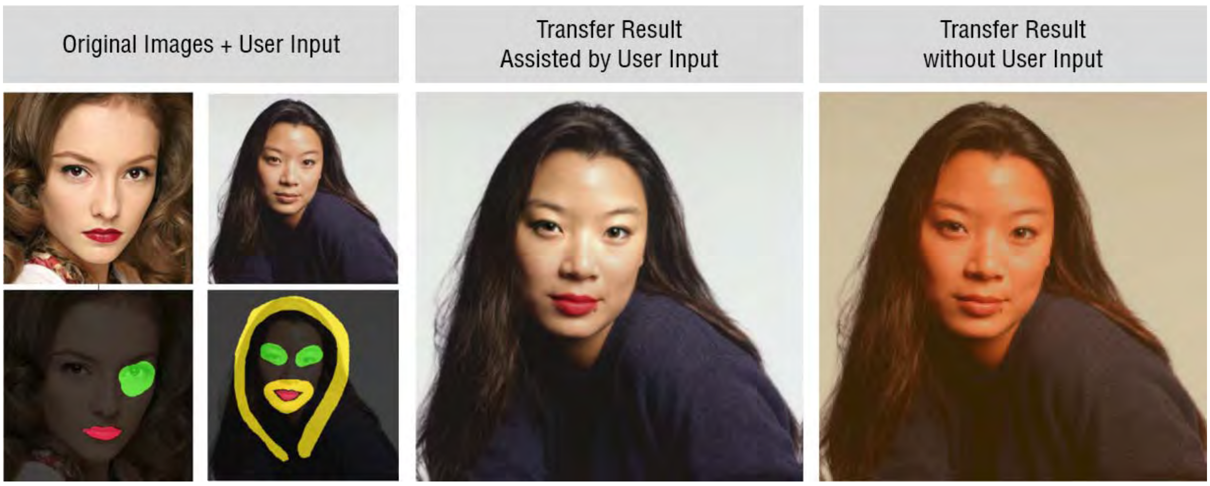


Figure 2.4 Stroke-based color transfer method. Reprinted from Luan et al. (2007).
The yellow stroke defines the region to preserve the original colors, and the green and red strokes correspond the regions to transfer colors from the source to the original image.

As a user provides more strokes, the quality of color transfer improves (Figure 2.4). Despite its apparent benefits, the manual input could be cumbersome for novice users. To minimize users' effort, several techniques have been suggested. An and Pellacini (2010) presented a color transfer method that propagates the color transfer to the rest of image according to the spatial distance from the strokes. Since the method propagates transfer results of a stroke to the global appearance of an image, users can easily decide whether additional strokes are required or not to achieve a desired look. By doing so, it retains both user-controllability and qualities of the results with minimal user efforts.

Instead of a pair of strokes, Welsh et al. (2002) used rectangular swatches to match areas of original and reference images. They particularly investigated the issues related to colorization of gray images. Once transferring the chromaticity values from the reference swatch to the one of the original images, the method utilizes the colored swatch within the original one in order to colorize the remaining regions. This feature characterizes their method in the aspect of considering internal correspondence to propagate the initial color changes by users' input.

Although manual user interactions largely relieve the extensive dependence on the reference image, it is still difficult to find a reference image that comprises all of the desired color compositions over regions. Regarding this problem, the work of Levin et al. (2004) provides a simple and intuitive method by using colored strokes instead of a reference image. Users only need to choose a color directly and annotate the region to be colored by placing a stroke. Then the method automatically propagates the stroke color based on the premise that neighboring pixels with similar intensities have similar colors.

One of the most outstanding benefits of user-assisted methods is the exquisite control over semantic aspects. Since users specify region correspondence between the original and reference images, the results often free to the improper color propagation across the dissimilar semantic regions.

2.4 Methods to Extract Colors from Images

In the image processing field, extracting representative colors from images has long been an interest of several researchers. The purpose of color extraction was widely distributed over image abstraction (Kyprianidis & Döllner, 2008), image indexing (Solli & Lenz, 2010), color transfer (Chang et al., 2015; Nagai et al., 2013) and creating color schemes for design (Hsiao & Tsai, 2014). The technical approaches also varied from clustering algorithms (Y.-C. Hu & Lee, 2007; Sulaiman & Isa, 2010), splitting algorithms (Cheng & Yang, 2001; Heckbert, 1982; Wu & Witten, 1985; Yang & Lin, 1996), histogram thresholding (Siang Tan & Mat Isa, 2011; Sural, Qian, & Pramanik, 2002) and even to computational learning algorithms (Lin & Hanrahan, 2013). Among them, methods using clustering approaches are reviewed in section 2.4.1, methods using splitting algorithms are reviewed in section 2.4.2, and finally, data-driven approaches are summarized in section 2.4.3.

2.4.1 Color Extraction Using Clustering Approaches

Clustering approaches are commonly used to extract dominant colors of a given image by segmenting the entire pixel colors into a fixed number of clusters according to their color similarity (Scheunders, 1997). Once clusters are identified, dominant colors are determined by extracting the color value of the center of each cluster. Technically, k-means clustering algorithm (T.-W. Chen, Chen, & Chien, 2008; Y.-C. Hu & Lee, 2007; Sulaiman & Isa, 2010; Weeks & Hague, 1997) and c-means clustering algorithm (Cai, Chen, & Zhang, 2007; Siang Tan & Mat Isa, 2011; Sural et al., 2002) have been frequently adopted in color extraction studies.

Weeks and Hague (1997) proposed a HSI space-based image segmentation in order to reflect the characteristic of human visual perception. Their method separately segmented the hue components followed by segmentation of the two-dimensional saturation and intensity. By doing so, the hue component plays a key part in their segmentation method as a human visual system does. Similarly, Lim and Lee (1990) developed a two-stage color image segmentation technique based on the thresholding and fuzzy c-means clustering. Both k-means and c-means clustering require iterative computation to identify the final cluster. The study of the Cannon et al. (1986) directly deals with the issue by suggesting an approximate version of an algorithm that can reduce the computational overhead. Keller and Carpenter (1990) used a modified version of fuzzy c-means clustering for image segmentation. The cluster centers were updated using a fuzzy c-means formula, but the new membership values for each pixel were calculated using an S-type function based on the feature value of each point and the fuzzy means. Clustering algorithms are commonly accepted as optimal approaches to extract colors, but are also known as very time-consuming ones. Also, although they are optimal, clustering algorithms suffer from their dependence on initial clusters.

2.4.2 Color Extraction Using Splitting Approaches

Contrary to the clustering algorithms that divide image pixels into a fixed number of groups, splitting approaches split the color space of an image into two disjoint groups according to splitting criteria of each method has. Then the splitting is again performed to the two groups. The splitting procedures are repeated until the image colors are divided into a desired number of groups. Finally, the center of each group is chosen for a color of a palette.

There is a variety of method to split the image colors. For instance, Heckbert (1982) devised a median cut method in order to reproduce high-quality images with 8 or fewer bits per pixel with little subjective degradation. Similar to the Heckbert's approach, Wu and Witten (1985) utilized a mean cut method to split the color space of images with a moderate computational cost. Their method showed excellent results for a large dataset where a conventional clustering method becomes computationally unmanageable. Yang and Lin (1996) suggested a radius weighted median cut method in order to construct a color palette. The method was based on hierarchical divisive approach, and each two-class partition used the centroid and the radius weighted mean.

The variance-based splitting algorithm is frequently appealed in splitting approaches. A color quantization study by Wan et al. proposed a multidimensional data clustering method, termed variance-based algorithm, which aims at minimizing the sum-of-squared error between the original image and the quantized image. The experimental results showed that their method adequately reduced the number of colors used to represent a given image, and the error measure was consistent with the perceived quality of the quantized images. Other approaches that take into account the human visual perception were introduced in splitting algorithms as well (Balasubramanian & Allebach, 1991; Balasubramanian, Allebach, & Bouman, 1994).

Compared to the clustering approaches, splitting algorithms were fast and required a low computational cost. However, the majority of the splitting methods showed a disadvantage that no global optima were obtained because of the irreversibility of a split decision throughout the successive split process.

2.4.3 Color Extraction Driven by Data

O'Donovan and Hertzmann (2011) used a DIRECT algorithm to extract a robust color theme from an image and then employed a lasso regression to identify the significant features that provide a high-quality theme. These features constructed a guideline to optimize an initial theme by searching similar themes with high rating scores in the crowd-sourced theme database. Their method was good at enhancing the quality and aesthetical values of the extracted theme. Moreover, their approach is distinguished with others by employing a crowd-sourced databased constructed by numerous users.

A study of Lin et al. (2013) focused on the saturated phenomenon of the optimized theme to extract a better theme from an image. Not only have the color features of each theme color, they but also utilized features such as the size and the foreground-background contrasted during the process of theme training. They also created a factor graph in order to describe the relationship among colors in a color theme. In other research, Lin and Hanrahan (2013) used color themes extracted by human from real images as references. They attempted to extract color themes similar to humans' choices. To do so, they devised a theory of significance in order to evaluate the importance of different regions in the image. Similarly, Jahanian et al. (2015) adopted the measure of saliency in order to extract a palette from an image. By doing so, their method creates a palette composed of visually significant - salient - colors.

Wang et al. (2010) proposed a special data-driven model which can handle both the color and texture features. They built a texture database for frequently-found textures and combined the mood features with the texture in order to transfer colors along with the textures.

2.5 Images and Colors in Practice

Due to the rapid growth in its popularity and importance, the use of the visual content is now prevalent throughout media and platforms. A variety of visual contents such as images and videos are now engaged in the communication process to convey informative and/or emotional messages. Accordingly, a variety of services has been introduced in the market in order to support users who want to create personalized and aesthetic visual contents. In correspondence with the scope of this dissertation, three types of tools and services were reviewed; tools and services for image recolorings, for color generation, and for design automation.

Due to the increased popularity of visual communication, editing images or videos now becomes common to most users who want to communicate via visual contents. Without a systematic training, however, utilizing a software like Adobe Photoshop is either demanding or unaffordable for most of the users. To support image editing tasks of novices, several applications have been introduced in the market. For instance, VSCO® is a mobile application specialized in editing scenery photos, which provides various predefined filters that automatically adjust the look and feel of an input image(Company, 2016). Figure 2.5 is a part of VSCO® application to explore preset and adjust the strength of the selected filter. Snapseed is a mobile application developed by Nik Software, a subsidiary of Google, and provides extended functions that allow users to manipulate details of adjustment (Google+, 2016). The right side of Figure 2.5 shows a UI snapshot of Snapseed version 2.13 for selecting and changing features of an image. AUTODESK offers a web-based image editor named Pixlr, and it provides a comprehensive set of editing tools that satisfy not only the needs of novices but also the professionals (AUTODESK, 2016).

Despite these applications largely improve the usability of users, the purpose of their editing remains the adjustment of given images only. Hence additional edits are required to create a design work like a book cover. Thus repetitive and cumbersome trials are inevitable.

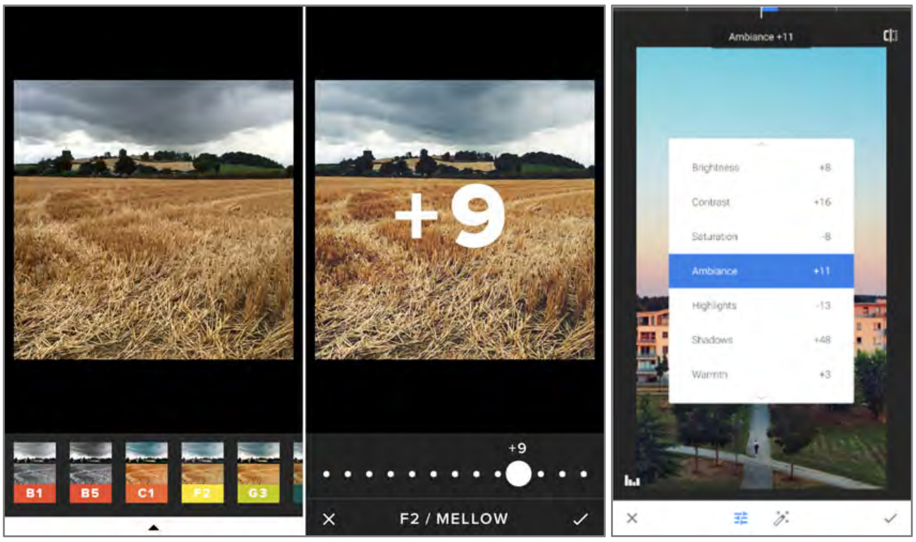


Figure 2.5 Commercial applications to adjust image colors: VSCO(left) and Snapseed.
The applications provide easy and quick color editing of photographs on the mobile environment. However, their pre-define editing filters mainly concentrate on enhancing the aesthetic quality of photographs. Thus the outcomes from these applications do not fully satisfy the needs in graphic design.

Inspired by the findings of color harmony research, a number of tools have been suggested to support the generation of harmonious color combinations and its applications to specific design contexts (G. Hu et al., 2014; Meier et al., 2004; Moretti et al., 2013). For instance, Meier et al. (Meier et al., 2004) developed a toolset, Interactive Palette Tools (IPTs) that enables various activities including browsing, breeding, displaying of color palettes. Hu et al. (G. Hu et al., 2014) presented a tool that helps users to generate color themes based on the principles of familiarity and rhythmic span. The tool enables users to manipulate individual colors of a theme and to preview the color theme applied to a pattern. Studies by Hsiao et al.(Hsiao & Tsai, 2014) and Jahanian et al. (Jahanian et al., 2013a) both utilized the image colors to construct a color theme and applied the theme for graphic and product design. Compared to the tools that only generate color schemes, the tool developed by Hu et al., Hsiao et al. and Jahanian et al. provides a more situated and extensive ability by allowing a direct utilization of a color theme in design practice (Hsiao & Tsai, 2014; G. Hu et al., 2014; Jahanian et al., 2013a).

Among commercial tools, Adobe Color CC (2017b) and COLOURlovers (2017c) are well-known services due to the academic contribution of their database. Both services provide a tool to generate color themes and a platform to share the color resources. Figure 2.6 illustrates the mobile interface of Adobe Color CC that presents a color theme of an image and allows the user to manipulate the individual color of the palette. Adobe Capture CC (2017a) is one of the most notable applications that supports the color design process. In addition to color theme generation, it covers a wide range of design applications based on the platform of Adobe Systems. A theme databased crawled from Adobe Color CC has been used by several studies as a reference to model the human perception of color themes in terms of their aesthetic and affective qualities (E. Kim & Suk, 2015; O'Donovan et al., 2011; O'Donovan, Agarwala, & Hertzmann, 2014a).

Although these tools have assisted an easier way of tailoring colors, their applications are limited to color combinations instead of the integration of colors and visual contents. In the present study, it was tried to provide a novel and practical insights by investigating implications for graphics tools used in the integrated color design process.

Figure 2.6 Mobile interface of Adobe Color CC (2017b).
Adobe Color CC, formerly known as Adobe Kuler, offers a platform to capture or create a color theme and share the theme with other users.

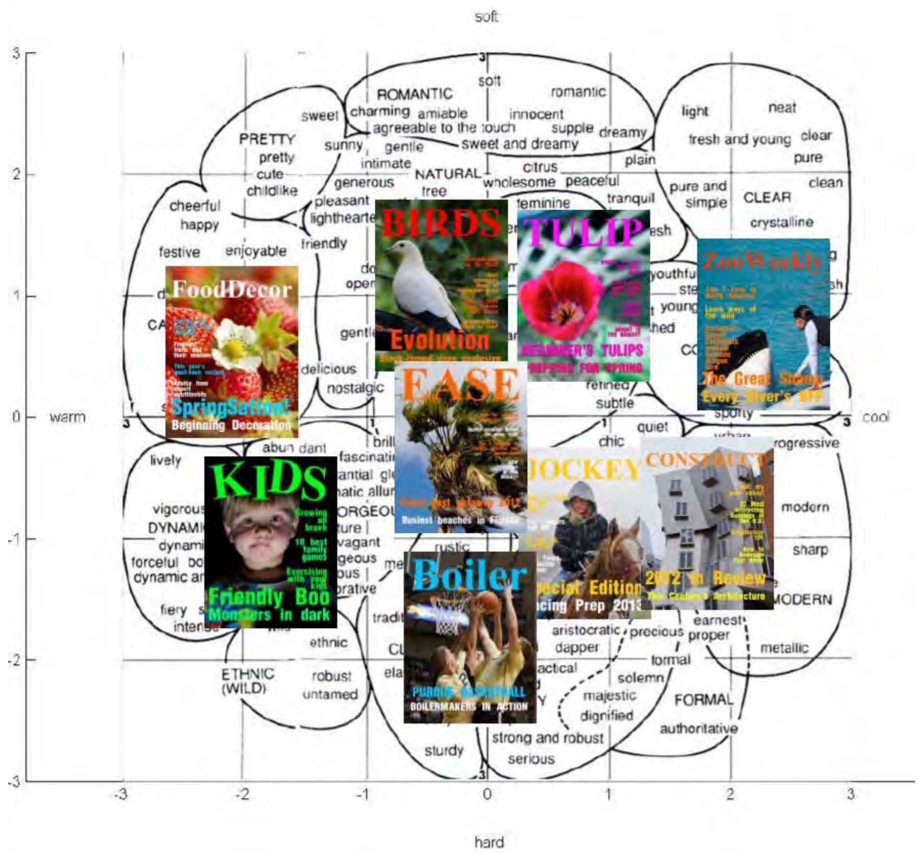


Figure 2.7 Magazine covers designed by the automatic system. Reprinted from Jahanian et al. (2013).
Based on the keyword map of Kobayash (1991), the study developed a system that automatically suggests a color for the title words and layout of the font.

In order to aid design process for novice users, a wide range of automatic design functions and systems have been proposed. In visual design, features related to color, typography and layout have been the main focus of the investigation. In the case of the layout to locate textual and graphical elements in a format of documents, the study by Hunter et al. (2011) proposed a web-based magazine layout design platform and Kunha et al. (2012) presented a system for automating magazine layout. The semi-automatic system by Kunha et al. (2012) was based on a set of content-based image feature algorithms and the system automatically crop images, overlay tests and creates a color palette for images.

About design automation for magazine covers, a series of studies propose a way to compute aesthetics of images and apply the knowledge on the visual design process (Jahanian et al., 2013a; Jahanian et al., 2013b). For instance, a study by Jananian et al. (2013a) proposed an automatic color generation system for magazine covers in consideration of color harmony between the background image and the text colors. Their system was developed based on the investigation of color theories to quantitatively measure the aesthetic values of color themes and the semantics of colors. By doing so, their method was able to suggest a set of text which ensures enough legibility of textual elements while considering the color semantics of a cover image. Shows magazine covers generated by their system mapping on the Color Image Scale developed by Kobayashi (1991).

2.6 Summary

Though the review reveals a partial profile of works in image recoloring and color generation, it shows the wide variety of solutions that purpose distinctive improvements and applications. Some approaches aim at automating the entire process while others allow users' intervention to enhance users' controllability. To reduce the strong dependency of transfer quality on a reference image, several researchers have attempted to utilize multiple reference images or utilize a color palette instead of an image. Various types of user input have also been incorporated in the process of color transfer in order to assign a specific color to the original image or to assist the correspondence between images.

Although these studies have achieved technical advancement and widen the application area of color-related design tasks, few studies have investigated the integrated aspect of color elements and images, and how they could be interactive and responsive to each other in digital platforms. Accordingly, little information is available on how to provide aesthetically and affectively pleasing experience to users by adjusting either of a color or an image.

In this regards, this research makes a novel contribution by investigating the integrated aesthetic and affective quality of image and color, and by developing automatic methods that automate a color editing of a given image or a color generation from a given image to create satisfactory image-color pairs. ■

3 IMAGE-COLOR HARMONY

3.1 Overview
3.2 Method
3.3 Data Analysis
3.4 Color Generation of Designers
3.5 Image Recoloring of Designers
3.6 Discussion
3.7 Summary

3. IMAGE-COLOR HARMONY

3.1 Overview

In cases of color extraction or color transfer problems, usually there is a desired state that a method aims to. For instance, a good color extraction method is an algorithm that produces a set of colors that represent the dominant and perceptually important colors of an image. In the case of image-color harmony, however, it is difficult to define the desired state. What is a good color to achieve harmony with an image? How an image can achieve harmony with a given color? Before developing methods to create image-color harmony, understanding the principle and strategy to create image-color harmony should be preceded. With this aim in mind, experiments were performed to understand how designers create image-color harmony through color generation and image recoloring. This chapter provides the details of the experimental settings and the results. Figure 3.1 depicts the position of this chapter within the comprehensive research framework.

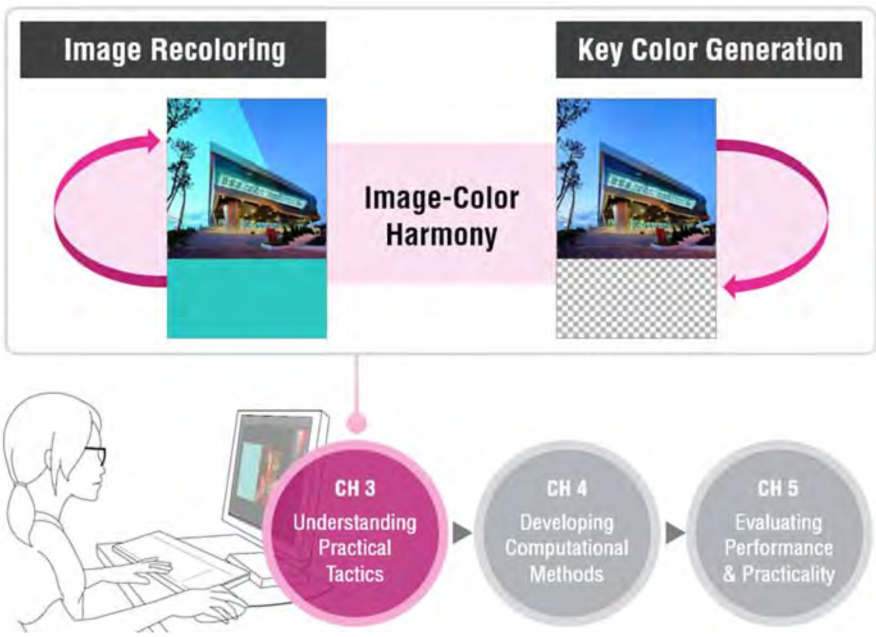


Figure 3.1 Research framework: Understanding tactics of designers to create image-color harmony
Chapter 3 describes the investigation to understand practical knowledge of designers regarding image recoloring and key color generation. The contents correspond to the first part of the major research activities.

3.2 Method

In order to understand how designers create image-color harmony, two sets of experiments were conducted. The first experiment focuses on the color generation process when images are specified, and the second experiment focuses on the context that a certain color dominates so that images are needed to be recolored to achieve harmony with the color.

3.2.1 Understanding Designers' Color Generation Process

A series of experiments was conducted with designers in order to understand the process of manipulating colors in the context of visual content generation. Aforementioned, a qualitative method was mainly devised in this investigation.

3.2.1.1 Participants

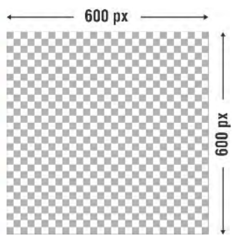
A total of 30 designers participated in the four sets experiment. All of them were holding a bachelor's degree in industrial or graphic design major and are currently enrolled in a graduate school of industrial design. The participants' mean age was 28.6, ranging from 26 to 31. In terms of the level of expertise, the half of experimental set 1 and 2 participants were professionals who currently work in editorial / graphic design field more than three years of experience.

3.2.1.2 Materials

For the experiments, we prepared a set of square images (600 by 600 or 1000 by 1000) and style keywords that deliver a specific emotion or affective image. Images were copy-right free photographs that portray various topics including people, objects, animals, plants, and landscapes downloaded from Pixabay.com (2016). The objective of this study was understanding how designers create affective image-color pairs as well as aesthetic image-color pairs. We thus specified the desired style of each image-color pair for the three experiments among four. The style keywords have been adopted from both of PAD theory (Russell & Mehrabian, 1977; Valdez & Mehrabian, 1994) that suggested a dimension of emotion and Color Image Scale (Kobayashi, 1991) which investigated the emotion that colors can deliver.

Table 3.1 summarizes the information of stimuli of all four experiments. For each experiment, we employed a different set of images and style keywords in order to investigate designers' color generation process in various conditions. In the stimuli, some images were presented more than once with different style keywords. This experimental design allowed us to investigate how designers' color choice could be differed according to the changes of design contexts.

Table 3.1 Stimuli used for the experiments to understand the color generation process.

Outcomes	Image-Color pairs			
Experimental Set	1	2	3	4
No. of Participants	10 designers (5 graduates + 5 professionals)	10 designers (5 graduates + 5 professionals)	5 designers (5 graduates)	5 designers (5 graduates)
Style Keywords	-	4 keywords: Active, Aggressive, Depressed, Relaxed	10 keywords: Chic, Enjoyable, Clean, Intellectual, Modern, Pastoral, Peaceful, Placid, Sporty, Youthful	10 keywords: Cheerful, Fresh, Friendly, Graceful, Healthy, Polished, Restful, Simple, Tender, Wholesome
No. of Images for Each Keyword	14 images	30 images	5 images	5 images
Stimuli Layout				
Total No. of Outcomes	140 image-color pairs	1,200 image-color pairs	250 image-color pairs	250 image-color pairs

3.2.1.3 Procedure

The experiment was conducted individually in an isolated room that disguised as an office environment with a desk, a chair and a desktop computer. Figure 3.2 shows a brief look of the experimental setting. When the experiment began, one of the images was presented with a style keyword. The designers were instructed to decide a color that is harmonious with the image as well as delivers the style suggested by the keyword. As a design outcome, they asked to present an image-color pair by filling the selected color into a rectangle located under or beside the images as described in Table 3.1. The entire design process was performed with Adobe Photoshop, which is a well-known and familiar tool to designers. The color-selection task was described as a part of graphic design, but the researcher did not specify its use in order to explore general and unbiased behaviors of designers that could be applied to a wider range of applications.

Throughout the experiment, we also asked them to think-out-loud their thoughts and concerns as much as they can. However, the researcher did not strongly enforce them to keep speaking in order to minimize its influence upon the design activities. Instead, we conducted a post-hoc interview to retrieve the details of their thoughts by reviewing the design outcomes together.

Figure 3.2 Experimental setting and an exemplary task given to the designers.
The task was generating a color which is harmonious with the given image and the style keyword using Adobe Photoshop.

3.2.2 Understanding Designers' Image Recoloring Process

The experiment was performed aiming at understanding the image adjustment process to achieve harmony with a color. Thus only the aesthetic quality of image-color pairs was considered without considering affective styles of each combination.

3.2.2.1 Participants

A total of 22 designers (thirteen males and nine females) participated in the workshop to adjust 10 to 17 photographs according to a given color. The mean age of the designers was 28.93, with a standard deviation of 5.61, and every designer had received at least three years of design education. Among the participants, five designers (four males and one female) are professional designers who have been working in graphic design industry more than five years.

Figure 3.3 Stimuli of the experiment with designers to understand the image recoloring process.
Each stimulus is composed of a set of a target color and an image. The image was recolored by designers to achieve harmony with the accompanying target color.

3.2.2.2 Materials

A stimulus consisted of an image and a target color, which was presented as a solid color that fills a rectangle. Both the image and the color were 600 pixels wide and 600 pixels tall and located adjacent to each other in order to facilitate visual interplays between them. Copyright-free photographs were used as an image dataset throughout the entire process of this research, including this formative study. All images were downloaded from Pixabay.com (2016). Photographs generally possess rich and complex color features in comparison with other images such as illustrations, drawings, and clip art. We thus suppose that the use of photographs provides an advantageous condition to develop a method for various types of images. Figure 3.3 shows examples of stimuli used in this study. Each stimulus is composed of a rectangle filled with a target color and an original image that should be recolored by designers. Although the images that individual designers received were partially overlapped, the researcher made each stimulus distinctive by matching each image with a different color among uniformly sampled colors in the CIELAB color space with $\Delta E^{*}ab$ = 30 (Thomas, Colantoni, & Trémeau, 2013).

The experiment was conducted in a room under fluorescent illumination of 575 lux, which falls into the satisfactory lighting condition for indoor workplaces (EN, 2011; ISO, 2002). The sRGB LCD monitor used in the experiment was calibrated by an ICC profile using X-rite i1 Pro spectrophotometer and LaCie Blue Eye Pro software. Throughout the experiment, the viewing distance was not strictly regulated but was maintained approximately 40cm from the monitor to the eyes of participants.

3.2.2.3 Procedure

Figure 3.4 shows an exemplary case of the experimental setting and image adjustment task given to designers. The task was performed using Adobe Photoshop CC2014, a well-known and familiar software to designers. The image-adjustment task was described as a part of graphic design, but the researcher did not specify its use in order to explore general and unbiased behaviors of designers that could be applied to a wider range of applications. During the experiment, they were asked to voice their thoughts and concerns as much as they could. One of the researchers attended the experiment in order to monitor the entire process of the designers, to encourage the designers to keep thinking aloud, and to verbally indicate the beginning and end of the image-adjustment for each stimulus.

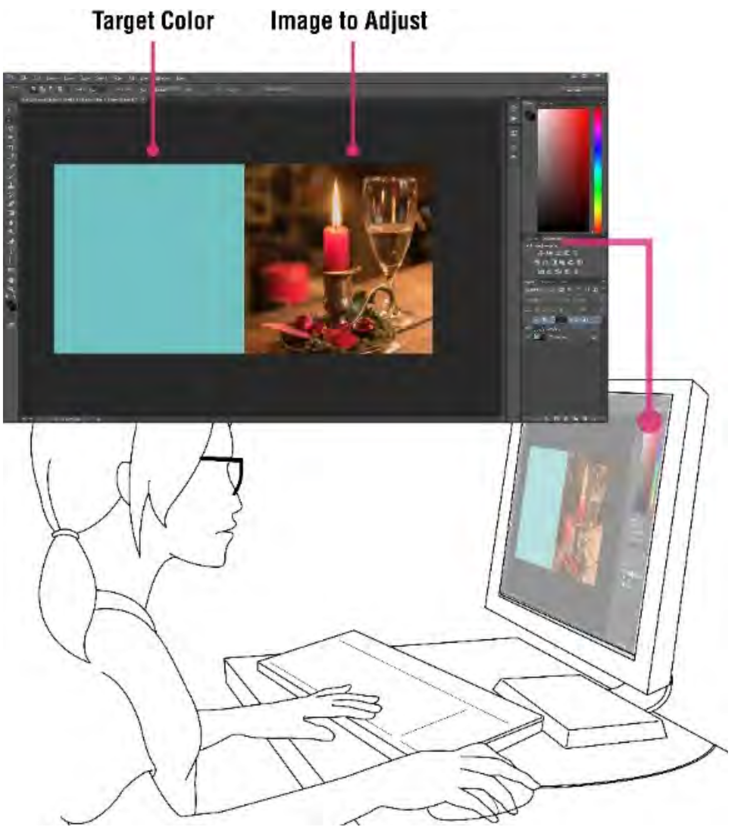


Figure 3.4 Experimental setting and a task given to designer.
The task was adjusting image colors to achieve harmony with the adjacent target color by using the functions of Adobe Photoshop CC2014.

3.3 Data Analysis

For each experiment, two types of data were obtained from the experiment. In the case of color generation experiment, we obtained design outcomes - 1,840 image-color pairs - and verbal protocols from think-aloud and post-hoc interviews. In the case of image recoloring experiment, one was the transcripts of designers' verbal expressions, and the other was 260 image-color pairs created through image recoloring. To disclose the latent principles and knowledge of designers' process, a qualitative analysis was mainly utilized while a quantitative analysis of design cases was supported.

3.3.1 Qualitative Analysis of the Verbal Protocols

For both experiments, the verbal protocols were transcribed verbatim, and the transcripts were used for the analysis. Since we had a sound perspective on the objects of investigation, we conducted closed coding with a predefined coding scheme. The initial coding scheme was developed based on our research question as suggested by Miles and Huberman (1994) and had revised and confirmed during the two repetitive pre-coding practices. Figure 3.5 shows the entire coding procedure to construct the final coding scheme and analyze the verbal protocols. The pre-analysis consists of two phases of coding practices to develop a solid and comprehensive coding scheme. With an initial coding scheme, one of the researchers analyzed one-third of the protocols and revised the coding scheme. During the first practice, a code that comprehends image, color and style were added to the scheme. In the second practice, the researcher coded another one-third of protocols using the revised scheme and developed layers of the final coding scheme by specifying the subcategories of Image code. At last, the final coding scheme was validated by revisiting the protocols that have analyzed in the first practice. In the validation process, an external coder, who has more than three years of experience in qualitative studies, was invited to review the final coding scheme along with the protocols.

Figure 3.6 shows the structure of the final coding scheme. According to the factor that designers mainly considered, we classified the segments of protocols into one of the seven codes (A~G). The categories from A to C include verbal expressions that participants solely designate an individual factor such as Style keyword (A), Image (B) or Color, respectively. In the cases of Image (B) and Color (D), subcategories were

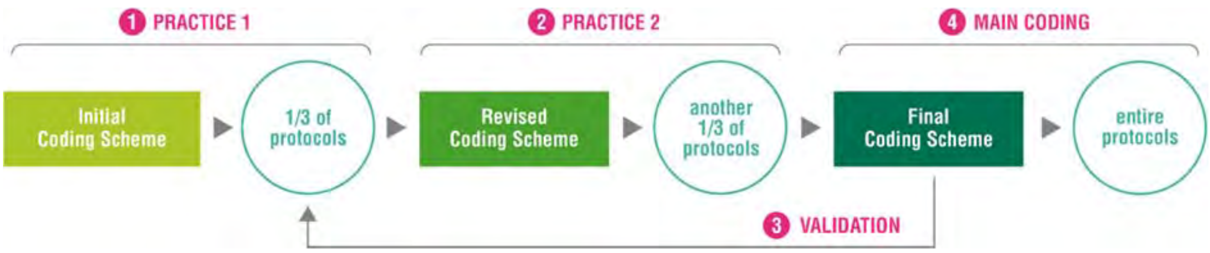


Figure 3.5 Entire coding procedure to analyze the verbal protocols of designers
In order to assure develop a precise and comprehensive coding scheme, two partial codings (Practice 1 and 2) were done prior to the main coding.

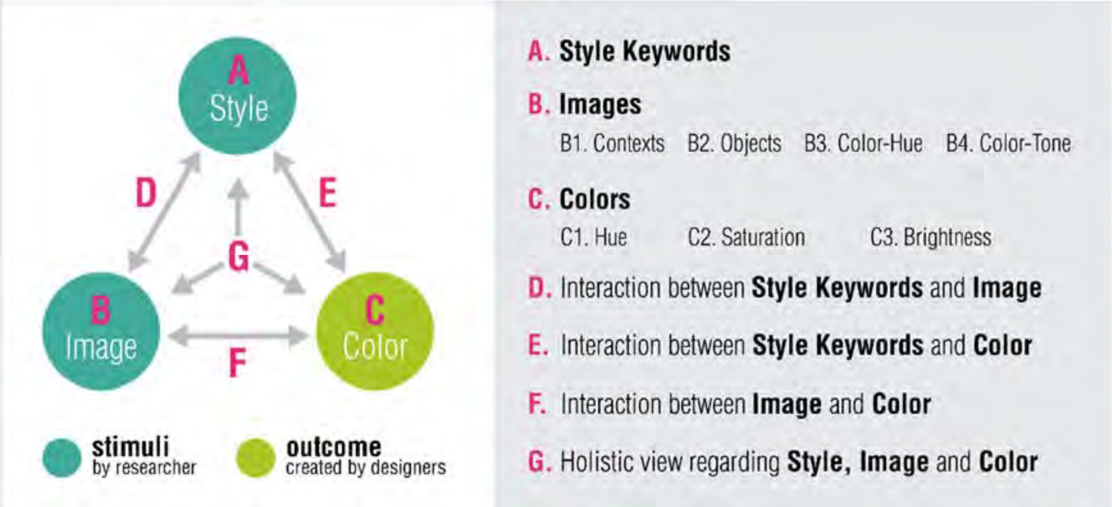


Figure 3.6 Final coding scheme used to analyze the verbal protocols of designers
With three major categories – Style, Image and Color – the final coding scheme has a total of seven coding categories that describe interactions and engagement of different types of design constraints or components.

utilized in order to discern the intricate changes in designers' perspective. The rest of four categories encompasses designers' cognitive activities regarding interactions between Style-Image, Style-Color, and Image-Color as well as the holistic view of Style-Image-Color. The qualitative analysis enables the researcher to understand the cognitive process of designers to create integrated aesthetics using images and colors. The results were interwove with the design outcomes which visualize the last decision of designers. In the following section 3.4 and 3.5, we will discuss the findings that have been revealed and confirmed by both qualitative and quantitative analysis.

3.3.2 Quantitative Analysis of Designers' Outcome

Since a majority of Adobe Photoshop functions adjust multiple features, the researcher set a threshold to define which feature was significantly changed with an apparent intention. To describe color features, we utilized both of HSV and CIELAB color spaces. HSV color space was employed because it is one of the most familiar color space to designers that they often encounter in a majority of design tools and interfaces. The notation and terms of HSV color space are also well-recognized among designers. Thus we viewed the use of HSV color space could be a good supplementary source to cross reference the verbal data of designers.

Figure 3.7 General color generation process of designers and related tools and factors.
The color generation process of designers consists of three major activities including 1) understanding images, 2) selecting and crafting colors, and 3) creating integrated visual content.

In the case of CIELAB space, it has a stronger advantage in describing the color differences and the amount of changes due to its perceptual uniformity. In other words, the same amount of color difference calculated on CIELAB color space should produce the same amount of changes in visual importance. This characteristic of CIELAB color space could be a benefit to formulate a mathematical function for color generation and image recoloring methods. Thus the CIELAB color space was utilized selectively to analyze the outcomes of designers.

3.4 Results: Color Generation of Designers

Through the observations during the experiments, the researcher noticed that the procedures of generating desired colors are much alike among designers. In short, it consisted of three activities. They have started the practice by identifying representative one from a mass of colors in an image. In most cases, designers employed the Eyedropper tool for the sorting-out activity. Once they identified a good starting point to proceed, they moved to articulating the initial color. In this step, the Color Picker has been mainly explored to identify better alternatives. While selecting a proper color for the image, they also considered the integrated visual effect generated by the combination of the image and the color they selected. Figure 3.7 is a diagram that summarizes the color design process by locating principal cognitive activities in parallel with the use of design tools. The process was visualized as a linear flow for its clarity though the reality was a mixture of parallel and synchronous activities.

3.4.1 Perception of Images during Color generation Process

The analysis of the protocols revealed two different perspectives that designers perceive and understand given images. The first perspective was color-focused perspective and the second one was semantic-focused. When a new image was presented to them, designers tended to deploy one of the perspectives predominantly, while both engaged in the perception of images mutually in most cases. Following sections provide the descriptions of each perspective with supportive instances from both verbal protocols and design outcomes.

Since the design task was generating a color for an image-color pair, designers naturally exhibited a primary focus on the color features of images. A majority of descriptions of a new stimulus – an image and a keyword - has begun with stating noticeable color features that an image possesses. We compiled the descriptions of images and had unfolded two characteristics in relation to designers' perception of colors in an image.

3.4.1.1 Color-Focused: Image as a Collection of Hues

First, the nomenclatures appeared in the descriptions attested designers' intent and delicate views on the hue rather than the value or saturation of an image. To be specific, terms related to hues were identified far more than those of saturation or value. Table 3.2 provides the average percentage of the terms used per designer, and representative expressions for each category. Throughout the transcripts of 15 designers, 87.10 % of denotations were selected in consideration of hues, while the terms regarding tones only took 12.90 %. Since the hue feature has more definitive nomenclatures to describe its condition than tone, it is difficult to directly compare the quantity of comments. Despite the difficulties of the direct comparison, it is considered that the frequent mentions of hue features imply the rich and exquisite capacities of designers in hue perception.

Designers firstly explored the existing colors of the given image to find a good starting point. During the exploration, we noticed that designers paid more attention to the chromatic than the achromatic region.

Table 3.2 Expressions used to describe color features of images.

	Expressions of Hue	Expressions of Tone
Examples	Yellow, Red, Brown, Blue.. (color names), Warm, Cool, Blu*ish*, Green*ish*, *Nuance* or *Hint* of ~, *Shades* of ~…	Monotone, Neutral, Pastel, Vivid, Dark, Dull, Lightness…
Average % of its frequency	87.10 %	12.90 %

Namely, the very light and the very dark area were often ignored during the color sampling process, despite the relatively large portion of an image. Figure 3.8 is a good example that illustrates such behavior of designers. Although the white-bluish wall occupies the majority of image spatially, designers tended to select colors from the colorful table. For instance, the following mentions of designer 7 clearly demonstrate his perception of the image.

> *"Oh, this picture was relatively simple and easier than others. The dark red from the table is apparently the theme."*

As shown in Figure 3.8, colors selected by five designers are strongly converged into a reddish hue regardless of emotions. This supports the perceptual importance of the chromaticity to be utilized in the color generation process.

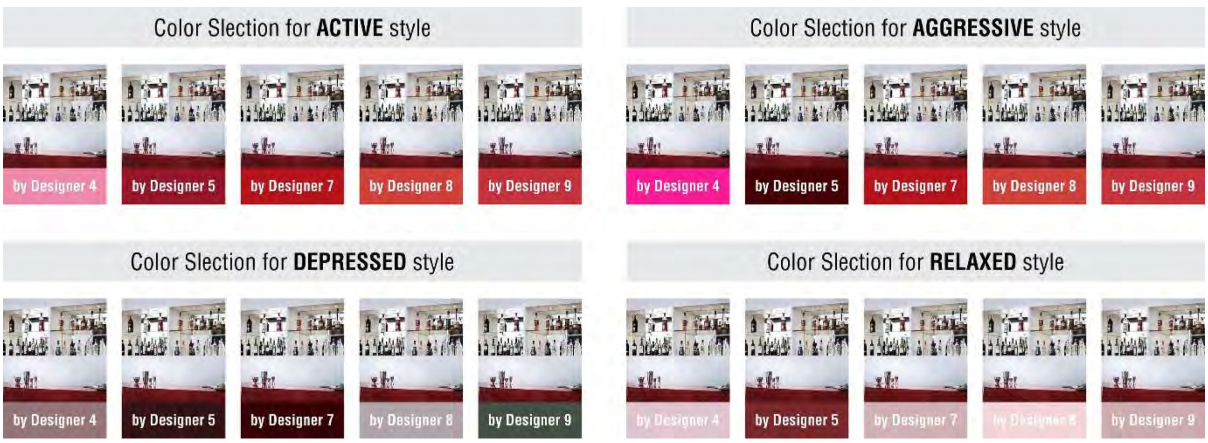


Figure 3.8 Image-color pairs by five designers that demonstrate the significance of chromaticity
Although the light gray wall takes the greatest portion of the image, the designers rather focus on the chromatic area in order to pick a key color.

In addition to the sufficient chromaticity, two distinctive measures were identified which are devised by designers in order to discern meaningful colors among image colors. One measure is the dominance of colors named **color-dominance**, and the other is the saliency of colors named **color-saliency.** Figure 3.9 shows images and all colors selected by designers in consideration of different style keywords. Depending on the color distribution of images, designers tended to selectively devise one of the two measures in the perception of images.

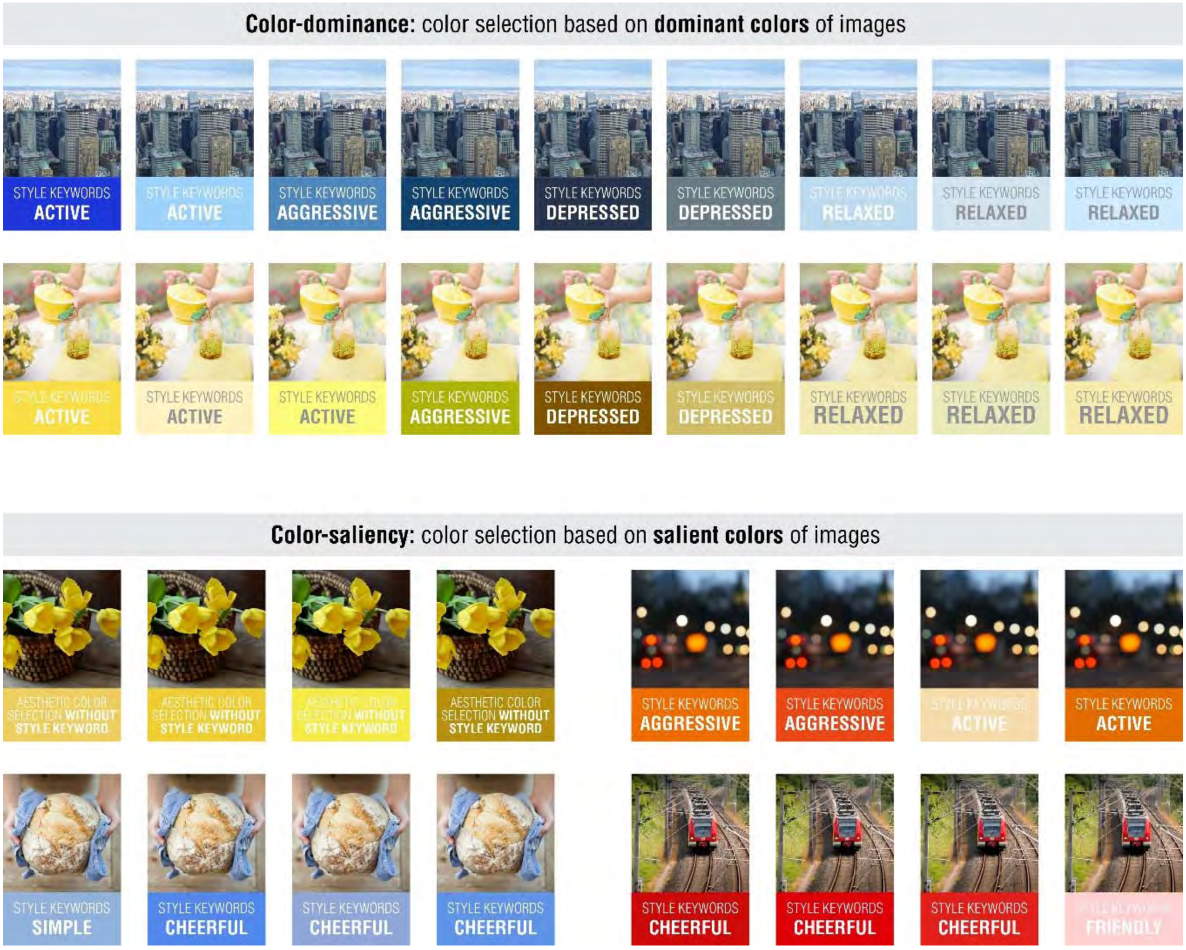


Figure 3.9 Images and selected colors demonstrating color-focused perspectives in perception of images
Designers devised two measures to select an perceptually-important color from an image. The upper cases demonstrated the use of color-dominance perspective when a specific hue or tone of colors dominantly take a considerable portion of a given image. The lower cases demonstrate the deployment of color-saliency when there is a color remarkably distinctive from others.

The measure of **color-dominance** was typically devised when an image is perceived as a single color feature that holds the global tone or hue of the image. The upper part of Figure 3.9 is an example that illustrates the apparent color-dominance and its impact upon the color generation of the designer. As shown, the images are recognized in relation to blue or yellow respectively, and the majority of designers' colors follows the dominant hue in general. The verbal protocol of designers supported the involvement of color-dominance measure. Words such as *'Bluish gray', 'Light blue',* and '*Blue tone'* were utilized to depict the left picture while *'Yellowish'* and *'Lemon'* were repetitively appeared in the comments regarding the right one.

Contrary to such decision-making process, participants also utilized the measure of **color-saliency** to grasp representative colors. Like the lower cases of Figure 3.9, several images had salient color segments that are much more distinctive and noticeable than the rest. In these cases, participants tended to refer the salient colors by using specific color names. Opposite to the salient region, the rest often described as a background. In terms of color generation, however, designers exhibited comparable use of background color depending on their intention or desired styles.

3.4.1.2 Semantic-focused: Meanings of Objects

The *semantic-focused* perspective is related to the **object-semantics** that describe the properties and/or sentiments of objects in given images. The focus of object-semantics is local and individual instead of embracing the entire features of an image, and exhibits interactivity with the color features of the object.

Figure 3.10 shows four image-color pairs that have been mentioned by designers with the view of object-semantics. The first image was presented with keyword *Cheerful* in experiment 3, and D11 described, *"In this image, yellow-green or the color of the rail load is dominant, but I'd like to use the red from the train. Somehow I can feel cheerfulness from the train, such as an excitement of a journey."* The designer related the perceived semantic of the train with cheerfulness. In the case of second images, D8 thought of the sunshine as the most *Pastoral* thing of the image. Hence she utilized the color of the sunlight in order to represent Pastoral mood in her image-color pair.

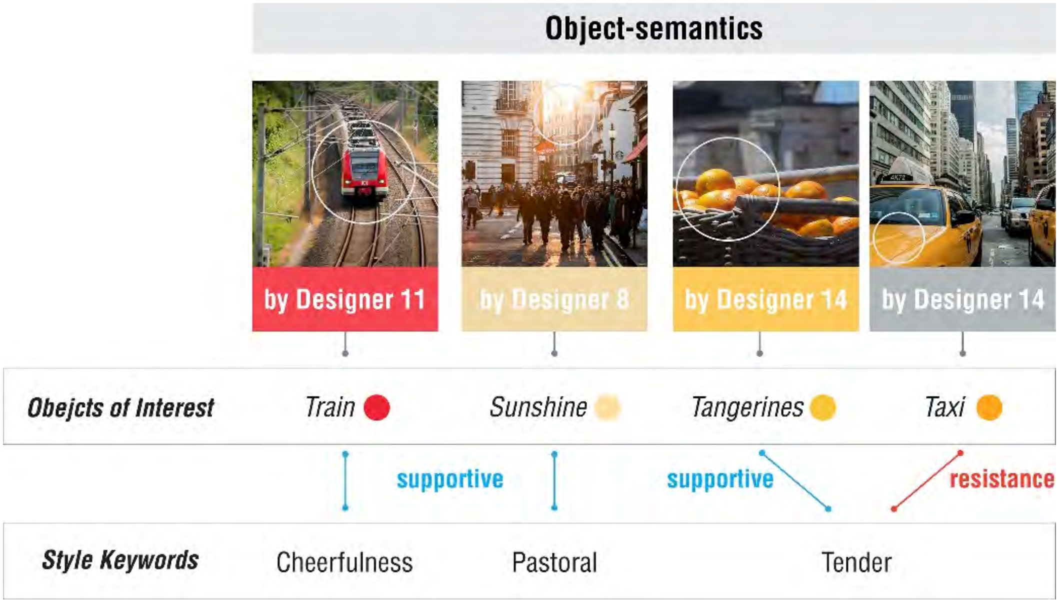


Figure 3.10 Exemplary image-color pairs that demonstrate the engagement of object-semantics. Three examples from the left show that colors of the objects of interest support the style keywords. The right case is conflicting case that the object-semantic does not match with the style keyword.

The last two images of Figure 3.10 demonstrate how object-semantics can vary the perceived meanings of colors. Both images have similar color distribution – main objects with yellow color and grayish background. When the two images presented individually with the same keyword *Tender*, D14 made different choices. Yellow was selected for the picture of tangerines while light gray was picked for the street picture. During the post-hoc interview, the designer plainly mentioned the influence of object-semantics: *"I think.. it relates to impressions of each object. I recognized the similarity in color features, but it was hard to associate the tenderness with a car, I mean a taxi. But I can sense soft and warm feelings from fruits."*

The evidence of object-semantics was observed frequently and commonly among designers throughout diverse stimuli. Its influence was less strong in comparison with contextual-semantics, but it broadly interacted with the given keywords and colors of the object during the creation process of designers. In qualitative analysis, the view of object-semantics was mainly identified in concordance with the code G (Figure 3.6) which encompasses the holistic view regarding image, style, and color. This result suggests that object-semantics have supported the integration of image, style, and color. By doing so, it contributes to a semantic structure among them which provides a persuasive rationale for designers' selection.

Figure 3.11 Personalized interpretation of object-semantics regarding a style keyword.
To generate a key color delivering 'enjoyable' mood, each participant associated distinctive objects of the image with the enjoyable feeling. In left case, the designer associated the enjoyable mood with a pleasant tea time and the right case of designer reminded the joy of book reading.

In addition to the role of object-semantics, we identified another interesting trait originated from individual designers. Even with the same image and keyword, sometimes the perceived semantic upon an object was highly personal and idiosyncratic. Figure 3.11 highlights the outcomes of two designers who made distinctive interpretations on meanings and relationships between objects and the given keyword. As shown, the mood of the presented picture is quite distant from the desired style *Enjoyable*. The perceptual distance made the task fastidious, and all designers commented its difficulty. As a result, three designers did not deploy any of semantic-focused perspectives, but D7 and D10 brought their personal impressions into the design process. For instance, D7 mentioned about a warm and delectable tea time in order to support his color choice from the golden teacup. On the other hand, D10 related the *Enjoyable* feeling with books: *"I wanted to convey the pleasures of reading since there are books in the image."*

As mentioned previously, the researcher did not make a minute observation on the results of the code A (Figure 3.6) which is solely related to given style keywords. A preliminary analysis suggested characteristic differences of designers in the perceiving and interpreting the style keywords. This indicates the possibility of other factors that encourage designers to disclose their distinguishable characteristics. Hence it is difficult to argue that object-semantics is a major factor that enforces the expression of personal identities during the design process. Considering the role of object-semantics, however, the researcher believes that understanding the view of object-semantics has a significant relationship with the understanding of the way that designers express their identity. Designers constantly endeavor to provide meanings and values toward their design. Throughout the endeavoring, object-semantics offer opportunities to build compelling narratives behind the design by integrating multiple design components. Although there have been attempts to utilize the outcomes of designers (Lin & Hanrahan, 2013; O'Donovan et al., 2014a), the tactics and strategies embodied in the color generation process are still veiled. As an initial step, investigating the utilization and implication of object-semantics could contribute to understanding a hidden facet of designers' tacit knowledge.

Furthermore, the view of object-semantics also implies design-oriented potential of advanced techniques in other disciplines, for instance, an object detection technology which identifies objects in images. Due to the continuous efforts made in computer vision domain, the technology is now capable of detecting objects rapidly with a high detection rate (Felzenszwalb, Girshick, McAllester, & Ramanan, 2010; Tian, Wan, & Yue, 2010; Viola & Jones, 2001). However, the technology has yet been applied to construct a meaningful narrative that delivers a sentiment and an intent. By incorporating these techniques in further studies, we expect novel insights that trigger prospective applications are suggested and demonstrated.

To summarize, examining the color features of images seems the prior and major perspective of designers to perceive an image (color-focused perspective). Specifically, designers selectively focus on either of the dominant colors or salient colors depending on the color distribution of an image. In addition to color features, designers also perceive semantics from the image (semantic-focused perspective). In general, object-semantics broadly engages in the interpretation and configuration of the entire design components – image, color and a keyword.

3.4.2 Crafting Colors

In the earlier stage of color design, designers exhibited a tendency to discover colors that represent given images. Once a satisfactory color is identified, designers moved to craft the color to make it aesthetically and purposefully proper for design usage. In such crafting activities, we identified two distinctive factors that designers considered. The first factor is the style keyword we suggested in the experiment, and the second one is a design component designers assumed that the color would be applied.

3.4.2.1 Influence of Style Keywords to Craft Colors

In general, designers identified multiple representative colors. Thus they had to select one among them as we asked them single color as a solution. We found that the style keywords are frequently used to prioritize the representative colors according to their perceptual congruity with the given style. Figure 3.12 shows two sets of a design outcome along with representative colors that have been discovered during the design process. The left set of Figure 3.12 derived from outcomes and verbal protocols of D11, the participant of experiment 3. He said, *"This image is quite complicated. There are several salient colors - yellow, red, and purple... Among them, I think, yellow fits to the Fresh feeling."* His description explicitly displays the role of style keyword to select the most suitable color from the representatives.

Through prioritization, designers were able to narrow down their choices into a single color feature. Thus it was one of the most significant decision-making activities throughout the color generation process. In addition to the selection, the style keywords were also highly engaged in the articulating process. D8 who designed the right set Figure 3.12 said, *"Ugh... this was a truly knotty case. For me, this image is something opposite to Chic mood. Among yellow, red and green, I looked for a color that is likely to be Chic. Green was chosen, and I deliberately change its tone to the dark one."* This partial protocol clearly demonstrates the act of color generation and the further elaboration of the selected color according to the style keyword.

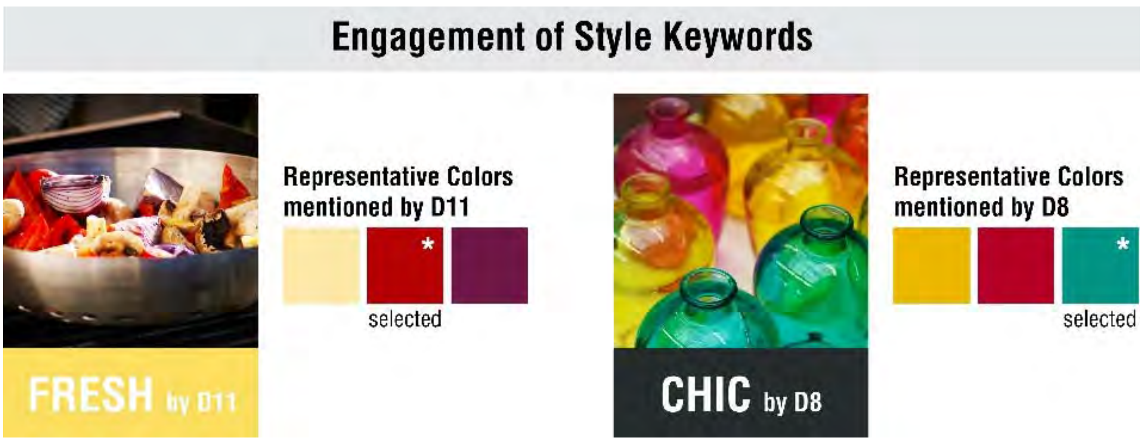


Figure 3.12 Engagement of style keywords in selecting and crafting colors.
The left example demonstrates the role of the style keyword in the selection of colors and the right one demonstrates both selection and crafting of a color.

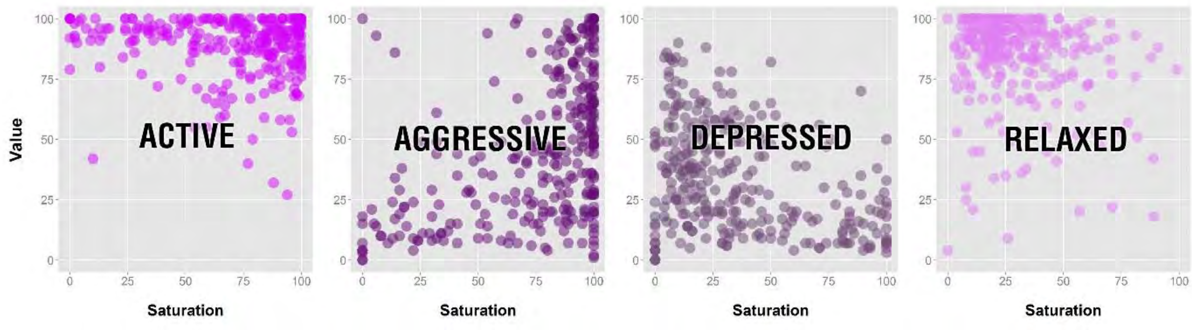


Figure 3.13 Saturation and value of designers' colors for four style keywords.
The distributions of saturations and values of designers' key colors show a stronger coherence within a style. In the case of Active, higher saturation and value were preferred, and lower saturation and value were preferred for a depressed style.

In particular, repetitive and explicit mentions were found regarding the association of style keywords and the tone of a color.

"For me, relaxed colors are not too dull, not too vivid... Something light and pale."(D8)

"To deliver depressed feelings, colors should be less saturated, and near to achromatic." (D7)

"For active colors, I intentionally maintained the value and saturation at a high level." (D10)

The association was supported by the quantitative analysis of designers' colors as well. In Figure 3.13, the saturation and value of designers' stylized colors are plotted across the four style keywords – active, aggressive, depressed and relaxed – from the experiment 2. Since the perception of keywords from Color Image Scale (Kobayashi, 1991) varied, the outcomes of experiment 2 were only used due to its conceptual framework that helped designers to interpret the style keywords more coherently. Although the given images were distributed in a wide range of value and saturation, the stylized colors show a coherent pattern for each emotion. Vivid colors with higher value were preferred for *active* emotion. Pale colors were frequently chosen to appeal to *relaxed* emotions, while dark-grayish colors were selected to express *depressed* emotions. This result indicates that designers tend to articulate the tone of color in consideration with emotions rather than the image itself.

In summary, designers began their color generation process by picking a dominant or salient color of a given image. They had a tendency to pick a color from the main object or the central part of the image by reflecting upon the contextual and regional information. Once a satisfactory color was identified, the designers began adjusting the color through minor changes in its hue and tone. In particular, the tone of the color was mainly adjusted and decided according to the target emotion. Such tendency of designers seems to align with the findings of previous color studies that showed emotional responses to colors are varied more by the tone rather than the hue (Gao & Xin, 2006; L. C. Ou et al., 2004; Suk & Irtel, 2010; Valdez & Mehrabian, 1994).

3.4.2.2 Influence of Uses of the Selected Colors

The other factor that designers considered in the articulation stage is the component that the color will be used. Even the researcher did not specify the usage of the color selected, designers frequently assume or imagine its usage by themselves to assist their decision making. The most notable consideration is whether the color will be used for text or not. Seven designers have considered the text component when they are designing the color, and articulate the color in order to make it more proper to be used for a text color. It is highly related to the functional aspect of the design outcome that determines its readability and clarity. Additionally, there were instances that a color is considered as a background or a dominant color of the design. Since we asked designers to fill in a rectangle, it is somehow natural to assume a background color to present an image or texts. In this case, designers often exhibit their prior knowledge about the area effect, which means that a larger area makes the color looks more saturated (Moon & Spencer, 1944b).

3.4.3 Creating Integrated Aesthetics of an Image and a Color

At last, we observed two viewpoints that help us to envisage the designers' perception upon image-color pairs. The findings were mainly extracted from the segments belong to the code F (Figure 3.6) which signify the interaction between an image and a color. In terms of their properties, the viewpoints are not compatible with each other, but each provides valuable insights and implications towards potential applications.

The first viewpoint is considering the image-color pair as a two-color combination. We observed multiple cases that designers devised their prior knowledge of the color harmony and emotion. Words such as *'contrast' 'rhythm'* and *'balance'* frequently appeared in their descriptions. They also referred to the general emotion and perception they had obtained from various color combinations. For instance, D6 commented, "For me, a strong contrast between complementary colors looks dynamic and active." D7 also mentioned that the use of analogous colors looks not only harmonious but also calm and *Peaceful*. In relation to this viewpoint, we identified that designers considered the color as a liberal design component that is not subsidiary, but equivalent to the image. Especially when designers had a clear intention or design direction, the color often became a leverage to steer the look and feel of the entire image-color pair. They strived for unified and synergetic visual impressions by manipulating the color.

The second finding covers a more comprehensive and practical view of designers. Although the use of image-color pair was not prescribed purposely, nine out of 15 designers mentioned a specific use of the image-color pair more than once. For example, D11 said, *"If I'm gonna use this for a perfume package…"* The comments of D12 indicates a possibility of different color generation criteria depending on the purpose: *"If this is for a calendar, I think this color can be a good alternative, but for a book… I'd rather use a heavier color."* Throughout the protocols, *a book cover, a calendar, a package* and *a poster* were mentioned, and *a perfume package* and *a travel guide* were specific cases with the detailed application.

3.5 Results: Image Recoloring of Designers

As mentioned, the formative study had a concrete goal to understand designers' tactics regarding harmonious image adjustment. A focused and exclusive analysis of both verbal protocols and design outcomes was made with the following two aspects:

- Color features that designers mainly manipulate to achieve harmony with a target color
- Approaches used to adjust color features for harmonious outcomes

To identify important color features, the frequencies of color-related terms were counted based on the coding results. If a word or an expression was repeatedly mentioned to illustrate the same process, such cases were counted as a single occurrence. Note that the expressions of designers often disagreed with the approved term of the feature that designers wanted to indicate. Hence every term was classified on the basis of the contexts the term has been used. In this study, semantic features, as well as spatial information, were not considered.

3.5.1 Color Features Manipulated for Harmony with a Target Color

The results showed designers' intense and delicate interests on the hue rather than the value or saturation of an image. Table 3.3 shows representative color-related terms that have frequently been mentioned by designers to describe their adjustment process. Some of the terms were used to indicate a combined concept of saturation and value. The researcher categorized such terms (e.g. tone, dull, heavy) separately with the specific terms used for saturation or value. Hence every color-related terms were classified into one of the four categories – 1) hue-related, 2) saturation-related, 3) value-related and 4) tone-related terms. As shown in Table 3.3, hue-related terms take a relatively large proportion compared to other three categories. This indicates the frequent and significant engagement of hue features on the image recoloring process.

To identify which color features were manipulated, each of the adjusted images was compared with the

Table 3.3 Representative color-related terms used to describe image recoloring process.

<table>
<tr><th></th><th>Hue-related Expressions</th><th>Saturation-related Expressions</th><th>Value-related Expressions</th></tr>
<tr><td rowspan="2">Representative Examples</td><td rowspan="2">Color Names (Yellow, Red, Blue, Magenta...), Bluish, Greenish, Warm, Cool, Nuance</td><td>Saturation, Colorful, Vivid, Neon, Greyish</td><td>Dark, Lightness, Brightness, Contrast</td></tr>
<tr><td colspan="2">Tone, Dull, Pale, Pastel, Heavy</td></tr>
<tr><td rowspan="2">Proportion (%)</td><td rowspan="2">45.95 %</td><td>18.92 %</td><td>21.62 %</td></tr>
<tr><td colspan="2">13.51 %</td></tr>
</table>

original one to quantitatively estimate the color differences resulted from the image adjustments. For the comparison, we utilized three different color spaces including sRGB, HSV, and CIELAB. In all calculations, we assumed that the original images are saved in sRGB color space. For sRGB to HSV transformation, the formula given by Smith(Smith, 1978) was used, and CIELAB values were calculated using the formulas for illuminant D65 stated in the study by Connolly and Fleiss. (Connolly & Fleiss, 1997)

Among 360,000 pixels of an image (600 by 600), average 92.14 % of pixels have been adjusted in at least a channel of sRGB space. This indicates that the color adjustment was applied widely throughout an image regardless of the amount of color changes. Table 3.4 shows the color changes after the adjustment in terms of color differences in three different color spaces – sRGB, HSV, and CIELAB. Each of the color difference was measured as the Euclidean distance on the designated color space. In the case of hue difference in CIELAB space, it is usually calculated as a color difference after accounting for lightness and chroma differences. In this study, however, the hue-angle difference was used to compare the original and adjusted images in order to observe each color feature independently. The quantitative comparison described in Table 3.4 indicates that the color differences calculated on sRGB space offer no discrete explanation about the image adjustment performed by designers. In contrast, color differences on HSV and CIELAB spaces suggest that hue changes are relatively large and significant in comparison with the value (HSV) or lightness (CIELAB) changes. The saturation change in HSV space and the chroma change in CIELAB space are also noticeable. Overall, the color adjustments cause approximately ten differences in ΔE_{ab} distance.

Figure 3.14 shows an exemplary case which compares an original image and the one adjusted by a designer. The grayscale images indicate the relative color changes in each feature. They clearly demonstrate the significant changes in hue dimension in comparison with others.

To investigate how the adjustments influence the color similarity of images and target colors, we compared the color differences between images and target colors in two conditions; before and after adjustments. In this comparison, the sRGB color space is excluded since it did not provide a relevant description of color

Table 3.4 Average color differences between the original and adjusted images.

Color space	sRGB			HSV			CIELAB					
Feature	**ΔR**	**ΔG**	**ΔB**	**ΔH**	**ΔS**	**ΔV**	**ΔL***	**Δa***	**Δb***	**ΔC**	**Δh**	**ΔE_{ab}**
Average color differences after adjustment	14.62	12.16	14.68	**27.58**	**9.12**	4.80	3.95	5.23	6.63	**7.81**	**26.90**	10.49
SD	14.95	11.92	13.06	25.72	8.42	4.26	4.29	6.32	8.40	8.14	23.48	10.68

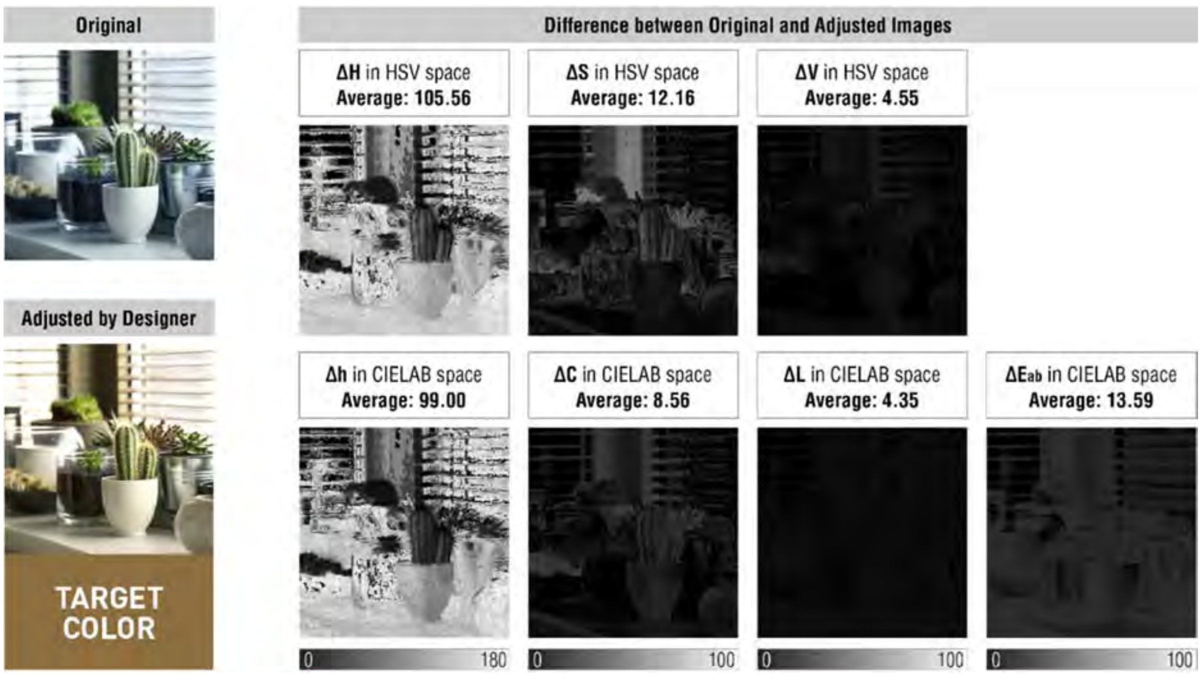


Figure 3.14 Color differences between original and adjusted images by a designer.
The level of whiteness indicates the average amount of color adjustment by designers. Compared to saturation, value (HSV), chroma and lightness (CIELAB), designers' adjustment is highly concentrated on hue dimensions.

adjustments by designers. As shown in Table 3.5, the color adjustments of designers reduce the average color difference between images and target colors from 64.08 to 59.08 in the ΔE_{ab} distance. This indicates, in general, designers tended to reduce the color differences between images and target colors to achieve harmony of an image and a target color.

Furthermore, the color differences in individual color features suggest an interesting explanation about designers' intent to achieve harmony between them. Although the color adjustments made significant differences in both saturation/chroma and particularly hue dimension (Table 1), the color difference between images and target colors exhibited significant changes in hue dimension only after adjustments. To be specific, hue has been reduced approximately 20 degrees in both HSV and CIELAB spaces, and these changes comprise the great portion of the entire color differences (Table 1: 27.58 in HSV, 26.90 in CIELAB) made by the color adjustments. In contrast, the saturation and chroma differences between images and target colors were less influenced by the color adjustments. The result implies that hue is the key feature that designers intentionally manipulate throughout the color adjustment process, and its manipulation is a primary solution to achieve harmony with a target color.

Table 3.5 Average color differences between images and target colors before/after adjustments

Color space	**HSV**			**CIELAB**					
Feature	**ΔH**	**ΔS**	**ΔV**	**ΔL***	**Δa***	**Δb***	**ΔC**	**Δh**	**ΔE_{ab}**
Before adjustment: Average difference between original images and target colors	**71.28**	**33.44**	20.07	18.78	31.46	36.14	**40.55**	**80.23**	**64.08**
SD	46.76	22.03	13.00	12.98	20.14	25.18	28.88	49.64	20.25
After adjustment: Average difference between adjusted images and target colors	**51.96**	**30.42**	18.69	17.59	30.65	34.77	**38.84**	**62.55**	**59.08**
SD	48.07	21.18	12.73	12.56	20.68	26.04	27.40	50.21	21.25

3.5.2 Approaches for Harmony with a Target Color

As described in the previous section, changes in the hue feature play a critical role which alters the color difference between an image and a target color. Although the average color distance shows that the differences between images and target colors are reduced in general, a more minute analysis was made by comparing the verbal protocol of designers with the quantitative analysis results. By doing so, we were able to identify three distinctive approaches taken by designers to generate a harmonious image with a target color. One approach is adjusting the colors of an image to increase the similarity with the target color. The other approach goes in the opposite direction. It increases the color difference between an image and a target color to promote the contrast between them. The last approach is an extreme case in which image colors are adjusted exhaustively to have a great resemblance to a given target color. Thus, the image loses its original color features.

Table 3.6 shows the representative cases of each approach with the frequency data. As suggested by its dominant frequency, the approach of promoting similarity with the target color was far more preferred than the other approaches.

There were no enough cases to estimate critical features that elicit two supplementary approaches instead of the primary solution which increases the color similarity between an image and a target color. Though

Table 3.6 Frequencies of adjustment approaches and related examples by designers

Adjustment Approach	Increase Similarity with a Target Color	Promote Contrast with a Target Color	Discard Original Features
Examples	 Left (original) / Right (adjusted)	 Left (original) / Right (adjusted)	 Left (original) / Right (adjusted)
Frequency	190 cases	7 cases	13 cases

it is not confirmatory, the results imply that the color difference between an image and a target color is relevant to the choice of approaches rather than the absolute color features of a target color. To be specific, designers generally prefer to devise supplementary approaches when an image and a target color exhibit an apparent color dissimilarity. This tendency was firstly discovered in the verbal protocols of designers. The quantitative analysis somehow supported the finding since the average color differences between original images and target colors of 20 supplementary cases (ΔH_{HSV} = 98.46 ± 53.32, ΔE_{ab} = 67.28 ± 26.64) was slightly larger than the rest of the cases (ΔH_{HSV} = 58.12 ± 45.82, ΔE_{ab} = 58.22 ± 20.41). However, there were few cases that violate the tendency, which means, designers devised the supplementary approaches even enough amount of color similarity is already ensured. Additionally, it was difficult to identify the factors engaged in the choice between two supplementary approaches. In the future study, a more elaborate and refined study could be performed in order to understand the role of predefined color features and designers' responses toward them.

3.6 Discussion

3.6.1 Insights from Designers' Color Generation Process

The experiment with designers revealed a general flow of designers' color generation process and the factors related to their decision making. To select a color in relation to a given image, designers usually start from exploring colors of the image. In this stage, the dominant or salient colors were extracted from the image while considering the semantics of the objects shown in the photograph. The findings related to this stage are parallel with the previous studies in which dominance or saliency has been suggested as a key feature in the perception of images. For instance, the study of Wang (P. Wang, Zhang, Zeng, & Wang, 2012) used the name of the dominant color to search and index image within a web database. Saliency has been used in several studies to identify regions of interest (Ma, Qing, Miao, & Chen, 2009; M. Saad & A. C. Bovik, 2009), to detect significant objects (Tian et al., 2010; Walther & Koch, 2006), and to extract meaningful colors from images (Achanta, Estrada, Wils, & Süsstrunk, 2008; Jahanian et al., 2015). In such perception, the colorfulness and the hue of a color were important. Contrary to the perception of image colors, our understanding of the semantics of images is not mature enough to formulate a concrete concept or a model. A growing number of studies are introduced to detect objects and related semantics from images (Borji, Cheng, Jiang, & Li, 2015; Q. Chen et al., 2015; Girshick, Donahue, Darrell, & Malik, 2014), few studies has been done on how the semantics of images are related to aesthetics and how it involves in creative design activities. It is expected that a more profound explanation would be possible as the number of the studies is increased in this area.

The second step of color generation is elaborating the initial color. The way that designers associate the image colors with a certain affective properties also corresponds to the basis of computer vision studies which have utilized image colors to identify semantics of the image (Shin & Kim, 2010; Solli & Lenz, 2010, 2011). The strong association of color tone and affective quality also resonates with the conventional color theory that color tone has a stronger influence on emotion than hue (Suk & Irtel, 2010; Valdez & Mehrabian, 1994).

To summarize, the color generation process was quite similar to the color extraction from an image. A dominant or salient color was often prioritized, and hue features were considered more often than the tone of the color. An interesting finding that distinguishes the color generation process with color extraction is the intentional color craft that makes the color distant from the image colors in order to steer the look and feel of the image. In this step, designers' prior knowledge about the color emotion or color theory was highly engaged. Based on these findings, a conceptual framework of the automatic color generation process was established. The details of the framework will be described in the following chapter.

3.6.2 Insights from Designers' Image Recoloring Process

The image recoloring experiment reveals two distinctive aspects of designers' image adjustment process. First, hue feature predominantly engages in the adjustment process, and its manipulation provides distinguishable results in comparison with the manipulation of tone features. Designers' intense interest in hue also agrees with the results of several studies that have proven the significance of hue relationships to harmony (Lenclos & Lenclos, 2004; L.-C. Ou & Luo, 2006; L. C. Ou et al., 2004). This implies that the hue feature should be mainly considered in developing our adjustment method.

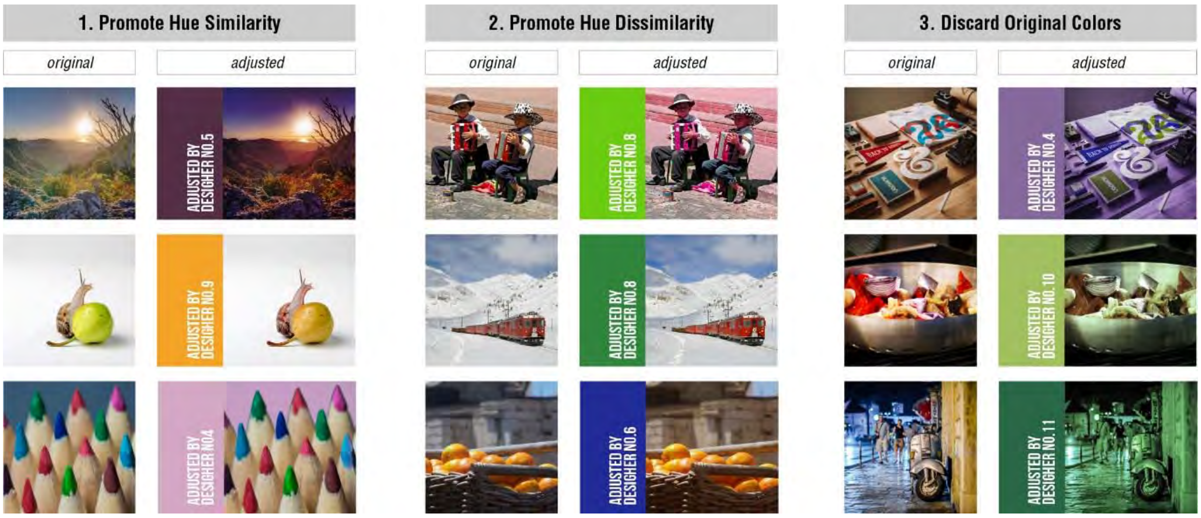


Figure 3.15 Examples of designers' outcomes that represent three distinctive strategies.
The first strategy shows cases that images are adjusted to be similar with the corresponding target color. The second strategy shows the opposite cases that images are adjusted in the way of promoting hue contrast. The last cases show that original colors of images are exhaustively adjusted.

Second, designers used one of three distinctive strategies to adjust an image for harmonious outcomes. Figure 3.15 illustrates the three strategies with examples. The first strategy was the most frequently used one that alters an image to increase the similarity with the target color. Contrary to the first strategy, the second one rather alters the image toward the opposite direction of the target color in order to construct a complementary relationship. The last strategy attempts to reduce the cognitive gap between the target color and the image by discarding the colorfulness of the image. The second and third strategies were rarely found compared to the first one but often used effectively when the target color and the image show an apparent dissonance.

The strategies of designers imply the influence of color theory on designers' perception and judgment upon the harmony between an image and a color. In a majority of the adjustment tasks, designers preferred to increase the color similarity for a harmonious outcome (G. Hu et al., 2014; L.-C. Ou & Luo, 2006; L. C. Ou et al., 2004; Schloss & Palmer, 2011). It corresponds to the conventional theory of color harmony that colors with shared attributes are easier to be harmonized (G. Hu et al., 2014; Lenclos & Lenclos, 2004).

To summarize, hue features have received more attention than saturation or value, and a strategy to increase the color similarity between an image and a target color has frequently been applied among three strategies. Designers also devise two alternative strategies to compromise the limitation of the primary solution. We formulated the adjustment methods of the proposed method based on the strategies identified in the formative study. Hence the proposed method has three adjustment methods. The details of the methods will be explained in the next chapter.

3.7 Summary

In this chapter, firstly, the color generation process of designers was investigated in consideration of a given image and a desired style. A series of experiments were conducted with a total of 30 designers, and the protocols from concurrent verbalization and the selected colors were analyzed using qualitative and quantitative approaches. The results revealed that designers mainly consider the hue feature in order to extract harmonious color from images, and the tone of a color is often associated with desired styles or emotions. It was observed that designers viewed an image-color pair similar to a color combination as an integrated piece of design. The findings lead to the framework of the color generation method developed in the following chapter.

The image recoloring process of designers was investigated based on an experiment with 17 designers. The designers were asked to adjust image colors to achieve a harmony with a given color. Verbal protocols and adjustment results were collected and analyzed using both qualitative and quantitative approaches. The analysis results showed that hue features of images colors received more attention throughout adjustment process. When adjusting image colors, designers preferred to local adjustment rather than change the colors of the entire images. Lastly, three strategies to achieve harmony with a color were identified which follow the principles of color theory. Within the entire research framework, the content of this chapter fulfills the objective to understand the principles of designers to create image-color harmony through the color generation and image recoloring. ■

4 KEY COLOR GENERATION & IMAGE RECOLORING

4.1 Overview
4.2 Technical Approaches
4.3 Method to Generate a Key Color
4.4 Method to Recolor Images
4.5 Discussion
4.6 Summary

4. KEY COLOR GENERATION AND IMAGE RECOLORING

4.1 Overview

This chapter proposes a set of automatic methods to create image-color harmony. The method includes **key color generation** to generate a color which is harmonious with a given image, and an **image recoloring** method that adjusts image colors to achieve harmony with a given color. Before describing the technical details of each method, this chapter provides how the insights from designer link to the method development by revealing the technical approaches we have adopted. The details of each method will be followed. Figure 4.1 illustrates the research activity of this chapter within the comprehensive research framework.

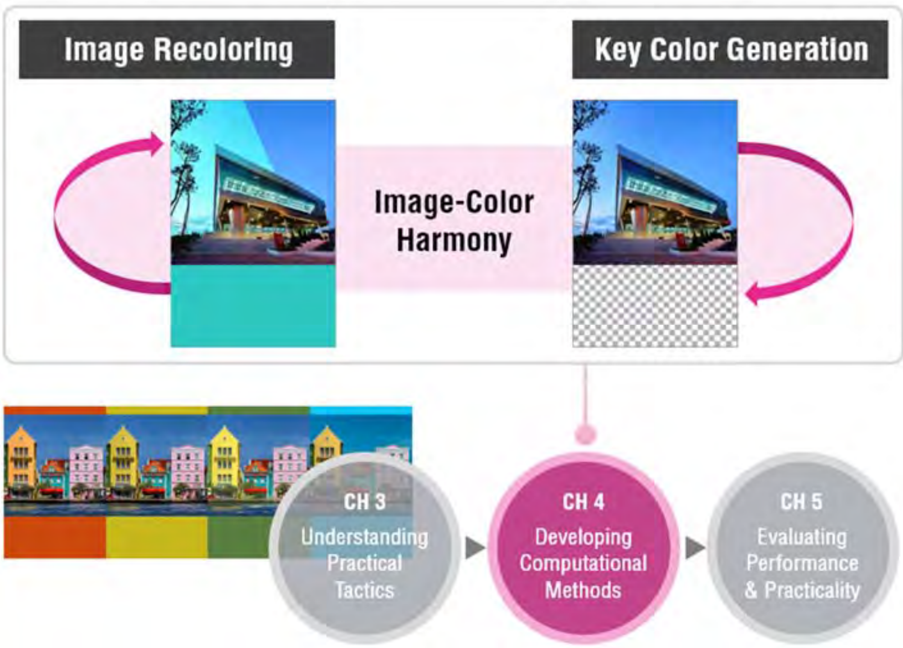


Figure 4.1 Research framework: Developing a color-bound image recoloring method
This chapter describes the process of developing methods and technical details to achieve image-color harmony based on the insights of the previous chapter.

4.2 Technical Approaches

4.2.1 Palette-based Image Abstraction

Whether it is a color generation context or an image recoloring context, the perception of an image plays a significant role in designers' practice. We found that designers tended to summarize the complex and dynamic color features into a limited number of representative features and take one of the features to adjust. This behavior is significantly different with an approach to resemble a statistical color distribution of a reference. Thus we used a color palette as a color descriptor of an image to identify the viability of our method and to validate the adjustment results.

4.2.2 Hue Manipulation for Harmony

In both color generation and image recoloring, designers have shown a more intensive interest in hue features rather than tone. In particular, they viewed that hue feature is much more important to achieve harmony between an image and a color. Thus it was decided to mainly manipulate hue feature for the proposed method instead of manipulating saturation or lightness together with the hue. As appeared in the experiment, manipulating hue was regarded as a primary solution to achieve harmony, while changes in saturation or lightness have a minimal influence on the harmony between images and target colors. It was viewed that the benefits of altering saturation or lightness are less significant than the increased complexity. In addition, designers' intense interest in hue agrees with the results of several studies that have proven the significance of hue relationships to harmony.(Lenclos & Lenclos, 2004; L.-C. Ou & Luo, 2006; L. C. Ou et al., 2004)

To manipulate hue of image colors, hue notations of both HSV and CIELAB spaces were considered. In the quantitative analysis of designers' results, there was no evident indication that one of the spaces is better than the other in illustrating designers' color adjustment process. As mentioned previously, average and standard deviations values of both hue notations are almost equivalent, and the correlation between two hue values of individual cases was strong and significant as well (Pearson's $r = 0.94$, $p < 0.05$, $n = 630$). Theoretically, HSV space is derived from RGB space, and CIELAB space is based on the CIE1931 XYZ color space. Considering the origin and their characteristic, it is expected that the use of CIELAB space provides a closer representation of human perception while preserving a greater degree of uniformity throughout the color manipulation. Considering this aspect, CIELAB space was utilized in this study to manipulate image colors in the proposed method.

4.2.3 Alternative Suggestion

One of the distinctive characteristics of the design problem is that there is no optimal or best solution. Although we identified a macroscopic and general principle of image-color harmony among designers, the outcomes were quite diverse. To embrace this diversity, we made the proposed methods to produce not a single solution but multiple solutions as alternatives. In addition, we have ordered the alternatives in a certain manner in order to help users to properly select the output they need.

4.2.4 Local Recoloring

Throughout the experiment, designers were interested in altering color of a specific region or a specific color range to the desired color. Except for several contrast changes or luminosity changes to enhance the overall quality of images, designers hesitated to alter hue globally since it impairs the original colors. We thus determined to take a local transfer approach instead of a global transfer. Lastly, the proposed method comprises three adjustment functions that produce distinctive outcomes with the same input. The adjustment strategies of designers clearly demonstrate that the principles of color harmony are largely engaged in the process of image adjustment. Like designers' strategies, the proposed method suggests three adjustments following the principle of analogous, complementary, and monochromatic schemes (Burchett, 2002; Matsuda, 1995; Whelan, 1994).

4.2.5 Framework of the Proposed Method

Overall, the proposed methods – key color generation and image recoloring – undergo the same preprocessing steps with the input image. The principal goal of the preprocessing steps (A-C) is segmenting the input image and extract a color palette from the segments. These steps reduce the overall computational cost of the proposed methods and also provide essential data sets for further processing. Key color generation utilizes the color palette from the pre-processing. Through hue prioritization (Step D), the palette colors are re-arranged in order of their visual importance. The first ranked color becomes a key

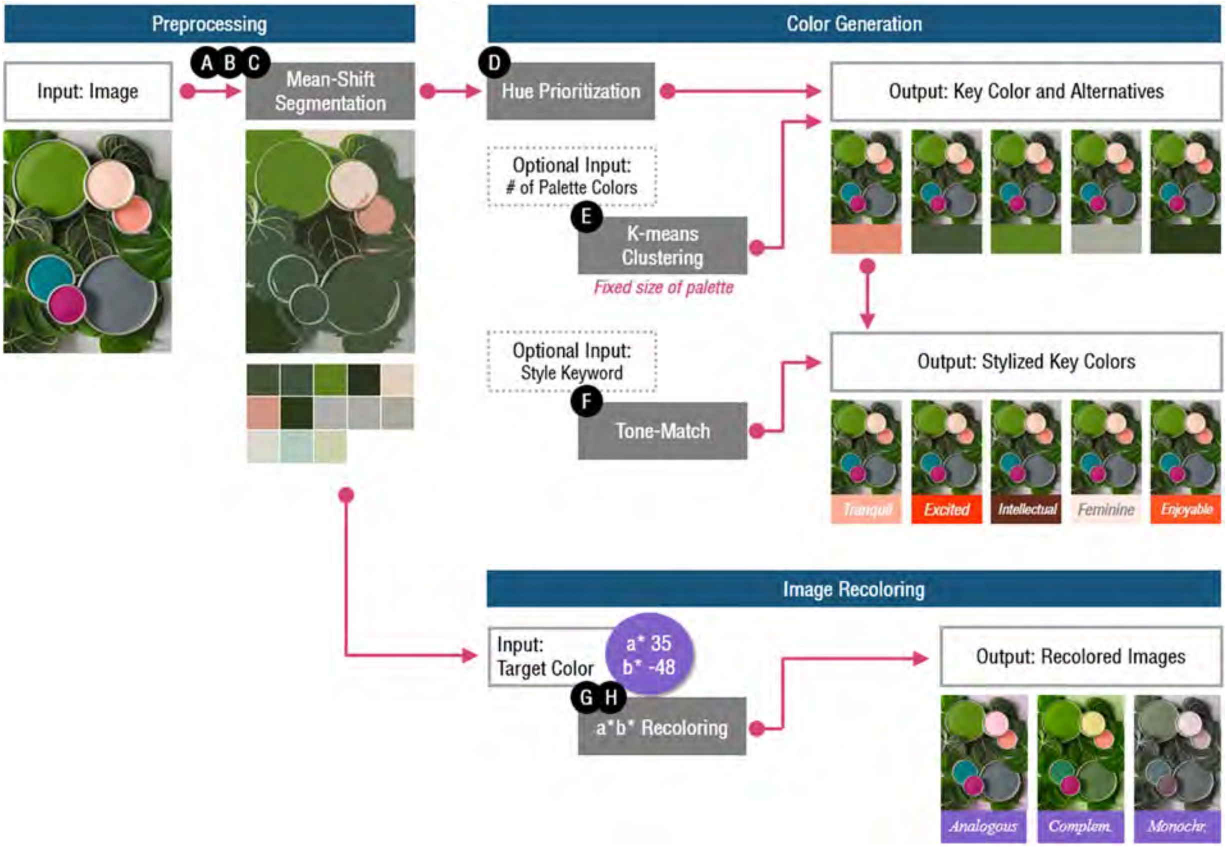


Figure 4.2 Overall framework of the proposed methods to create image-color harmony
The method developed in this study comprises a shared preprocessing steps (A~C) and two independent methods to satisfy distinctive design contexts. The first method is color generation to generate colors from an input image, and the second one is image recoloring with an input image and a target color.

color of the input image. If a fixed number of palette colors is required, the method additionally runs k-means clustering (Step E) with the original color palette to extract a certain number of colors. Image recoloring utilizes all outputs of pre-pre-processing - color palette and the segments. The palette colors are utilized to identify whether a certain color is within the chroma threshold from a target color. If so, the segment that the color represents undergoes a*b* recoloring (Steps G and H).

4.3 Preprocessing of Input Image

Step A. RGB to CIELAB conversion: First, we transform the input data – an image and a target color if it exists – into CIELAB color. In RGB to CIELAB color conversion, the formula described in Connolly ad Fleiss (1997) was utilized with a white point of D65. In all calculation, we assumed that the original images are saved in sRGB color space. The specific formula used in color conversion is as follow. Here, X_0, Y_0, and Z_0 are the tristimulus values of the illuminant, in this case, illuminant D65;

$$\begin{aligned} \mathrm{X} &= 0.4303\mathrm{R} + 0.3416\mathrm{G} + 0.1784\mathrm{B} \\ \mathrm{Y} &= 0.2219\mathrm{R} + 0.7068\mathrm{G} + 0.0713\mathrm{B} \\ \mathrm{Z} &= 0.0202\mathrm{R} + 0.1296\mathrm{G} + 0.9393\mathrm{B} \end{aligned}$$

$$L^* = 116 f\left(\frac{Y}{Y_0}\right) - 16$$

$$a^* = 500\left[f\left(\frac{X}{X_0}\right) - f\left(\frac{Y}{Y_0}\right)\right] \qquad \text{where} \qquad \begin{aligned} f(q) &= \sqrt[3]{q} && q > 0.008856 \\ f(q) &= 7.787q + \frac{16}{116} && q \leq 0.008856. \end{aligned}$$

$$b^* = 200\left[f\left(\frac{Y}{Y_0}\right) - f\left(\frac{Z}{Z_0}\right)\right]$$

Step B. Color Quantization: Once the image was converted, we quantized the image in 8×16×16 units for LAB components respectively. Previous color quantization studies have usually utilized a larger unit to quantize images, and they proved its sufficient performance to index or abstract image color information (Chou & Wu, 2001; Palus, 2004; Siang Tan & Mat Isa, 2011). For instance, the study by Lee et al. (2005) showed that the performance of comparing image color similarity reaches to saturation in 8×8×8 quantization. In this study, however, we decided to use a denser unit for both of lightness and chroma dimensions in order to preserve the original colors as much as possible while reducing the computational cost. In particular, we have focused on the minute discrimination of hue – a* and b* dimensions since the human visual system is much more sensitive to hue features when quantizing the image colors (Swain & Ballard, 1991; Weeks & Hague, 1997).

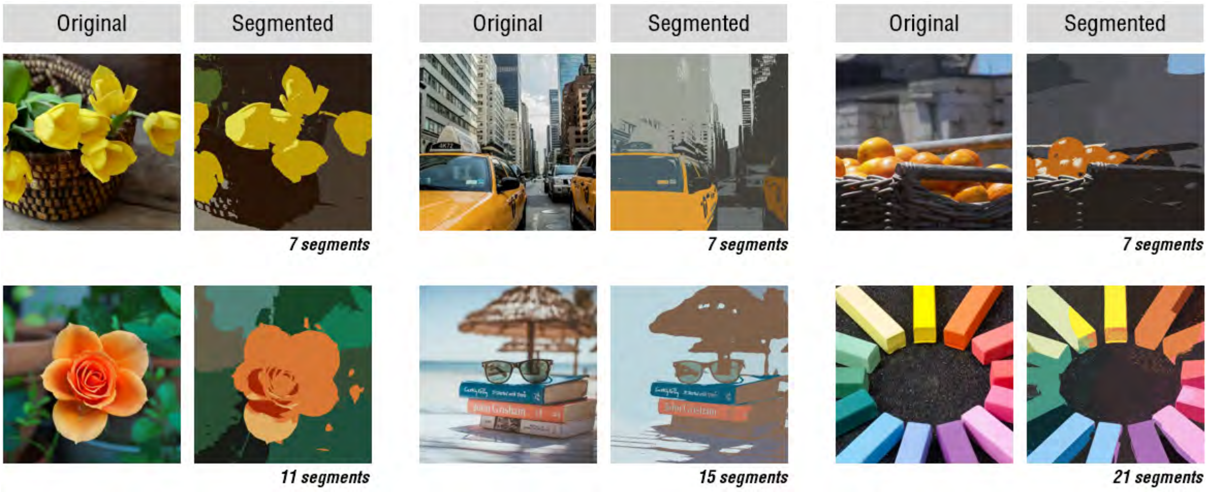


Figure 4.3 Mean-shift segmentation results with bandwidth 0.3 and Epanechnikov kernel. The number of segments is diverse across the input images, since the Mean-shift segmentation distinctively determines the number of segments according to the color distribution of the image.

4.3.1 Segmenting the Input Image

As mentioned previously, we took a local adjustment approach in order to selectively recolor regions of an image. To do so, it is needed to segment the image in prior to recoloring. Thus we utilized mean-shift segmentation to segment an image into several regions according to the color and spatial features of pixels. The segmentation produces two types of data, in general. First data is the segmented regions of an input image, and the second is the representative color (mode) of each region. These two outputs are utilized for the subsequent processes – key color generation and image recoloring. Figure 4.3 previews the results of the mean-shift segmentation algorithm described in subsequent sections.

Step C. Mean-Shift Segmentation: With the quantized image, a mean-shift segmentation was performed to segment the image into multiple regions. Mean shift is a technique for findings the modes of given data points based on a kernel density estimation. The mean-shift algorithm used in this study as built based on the formula described in Fukunaga and Hosetetler (1975) and Comaniciu and Meer (Comaniciu & Meer, 2002). In calculating the modes of the image pixels, we used their CIELAB values (3 features) and also the spatial features (x and y) of each pixel. Thus each pixel is a data point in a 5-dimensional Euclidian space. Using these five features, the mean-shift algorithm was performed.

Contrary to k-means clustering, mean-shift clustering does not require a pre-defined number of clusters. It instead calculates the final number of clusters based on the underlying probability density function. Due to this advantage, we decided to adopt mean-shift clustering to segment and identify the initial number of the color palette of an image. When a user or a system does not specify the required number of color palette from the input image, the proposed method suggest a specific size of color palette calculated by mean-shift clustering.

4.3.1.1 Bandwidth Selection

Figure 4.4 shows the segment results when different bandwidth values are applied. As shown, as the bandwidth value increases, the segments become smaller and denser. It also indicates the increase of a computational time. There is no optimal or best answer for the bandwidth value. Considering both computational time and the granularity of the segments, we have utilized bandwidth 0.2 throughout this study.

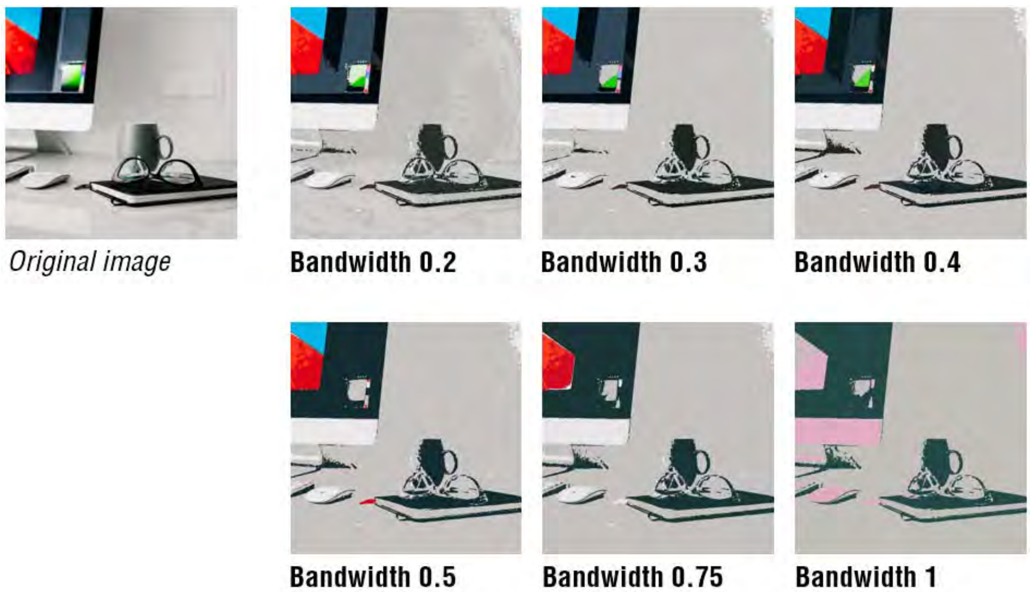


Figure 4.4 Mean-shift segmentation results with different bandwidth values.
As the bandwidth increases, the number of color segments decreases since the window size to estimate color and spatial distribution becomes larger. For the demonstration, Epanechnikov kernel was adopted to estimate the distribution of image colors and the spatial distribution.

4.3.1.2 Kernel Estimation

Since mean-shift segmentation estimates the distribution data points based on the given kernel density function, the selection of kernel also has a significant influence on the result of segmentation. Figure 4.5 shows several kernel distributions. Among these, the Flat (also known as Tophat), Gaussian (also known as Normal) and Epanechnikov kernel was often utilized in image segmentation. Considering the ambiguity of edges and color changes in an image, the flat kernel may not be a proper representation to estimate image colors. In cases of normal and Epanechnikov kernels, there is no apparent consensus among their performance in segmentation. However, few studies have suggested that Epanechnikov kernel provides a robust but concise results in segmenting color regions (Cabria & Gondra, 2012; Comaniciu & Meer, 2002). Figure 4.6, which illustrates the segmented images by three different kernel-based mean-shift, also shows that Epanechnikov kernel segments the input image in a discrete and meaningful regions. Thus we decided to devise Epanechnikov in our method.

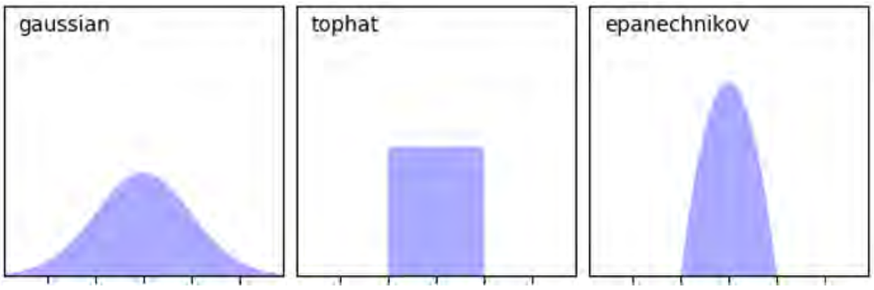


Figure 4.5 Various kernel density functions. Reprinted from scikit-learn.org.

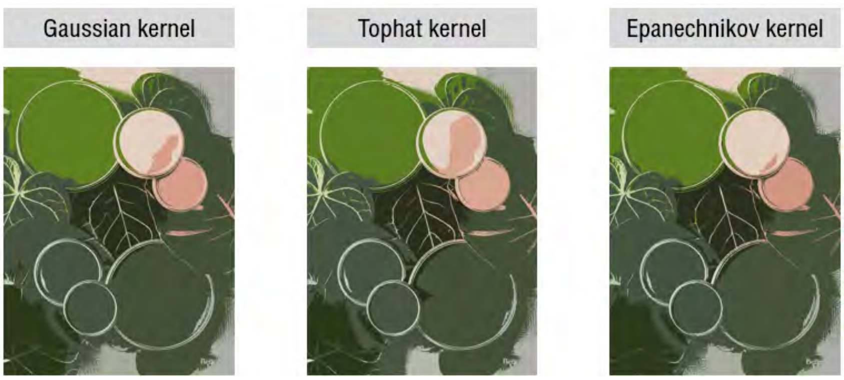


Figure 4.6 Mean-shift results using different kernel density estimation with bandwidth 0.2
Depending on the kernel used, the segmentation results are different. The segmentation result by Epanechnikov kernel shows the most discrete and condensed results among three outcomes.

4.4 Method to Generate a Key Color

If a user or system requires a key color which is harmonious with the input image, the algorithm proceeds to step D with the segmented image. In this study, we used the term ‘key color’ since our color generation method focuses on suggesting a single color that achieves a solid harmony with the input image while dominating the overall atmosphere of a visual outcome. Figure 4.7 shows the framework of the key color generation method proposed in this stud.

4.4.1 Ranking the Palette Colors in order of Perceptual Importance

In general, mean-shift segmentation produces multiple color palettes that represent the mode of each segment of the input image in CIELAB color space with spatial consideration.

Step D. Hue Prioritization: To prioritize the multiple palette colors in order of perceived visual importance, hue prioritization was performed. To do that, firstly the hue value of each palette color was calculated based on the following formula (H. C. Lee, 2009);

$$h_{ab} = \arctan\left(\frac{b^*}{a^*}\right).$$

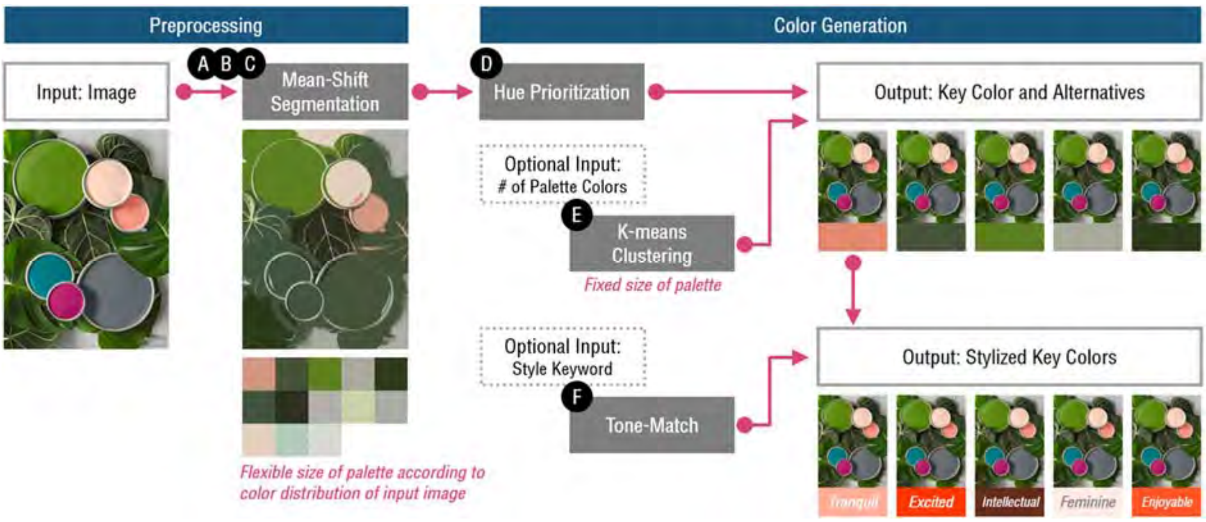


Figure 4.7 Framework of key color generation

With an input image, the proposed method provides a key color which is ranked as the first by the hue prioritization (Step D). IF a number of required palette color is specified, the method optionally performs k-means clustering to produces the fixed number of color palettes (Step E). Additionally, the method offers an elaborated way of suggesting alternatives by stylizing the key color through tone-match (Step F).

As the name implies, in this prioritization process, we exclusively consider the hue feature of the palette colors is reflecting designers' acute sense of hue in color manipulation.

In hue prioritization, to be specific, following two factors were considered. The first one is the dominance of the palette colors which is usually described by the size of the segment that each palette color represents. The second one is saliency of the palette colors. Since designers often choose a contrasting color to catch more attraction, it is also important to account the saliency factor in prioritizing the palette colors.

4.4.1.1 Dominance of the Palette Colors

It is obvious that a larger segment has a greater impact on perception. It also takes a significant role in achieving harmony with a target color. To take account the effect of the dominance of a segment, we utilized the area factor which is merely the ratio of the segment size to the size of the input image (Tian et al., 2010). It is computed as;

$$D_i = \frac{S_i}{S_{img}}.$$

Here, D_i indicates the dominance score of a segment i, S_i indicates the size of a segment i, and S_{img} indicates the size of the entire input image. In this notation, the size refers to the number of pixels belong to a segment or an image.

4.4.1.2 Saliency of the Palette Colors

In describing the saliency of color, the both of contrast-based and dominance-based features are important (Tian et al., 2010). In this study, however, the dominance-based saliency is largely accounted while considering the size of the palette. Thus, we only considered the contrast-based saliency of color particularly in the hue dimension. To calculate the hue saliency of an individual segment i, we utilized 1-dimensional sigmoid function (C. Huang, Liu, & Yu, 2011; M. A. Saad & A. C. Bovik, 2009; Tian et al., 2010; Zhou, Ma, Celenk, & Chelberg, 2005). Here, S_i indicates the hue saliency score of the segment i, h_i is the representative hue value of the segment i, and h_m indicates the mean hue value of the segmented image I_s. After calculating the saliency of all segments, the values were normalized in the range of [0, 1] (Tian et al., 2010);

$$S_i = \frac{1}{1 + exp\left(-\frac{h_i}{h_m}\right)}.$$

Both of dominance and saliency scores are ranging from 0 to 1. As a segment takes a larger region, the dominance value becomes closer to 1. In a similar manner, as a palette color of a segment is more contrasting and salient, it has a larger salient value. To encounter the effects of both dominance and saliency, the hue priority score of a palette color of a segment was described as the multiplication of dominance ratio and saliency values. Figure 4.8 shows the influence of hue-prioritization in ordering the palette colors;

$$P_i = D_i \times S_i.$$

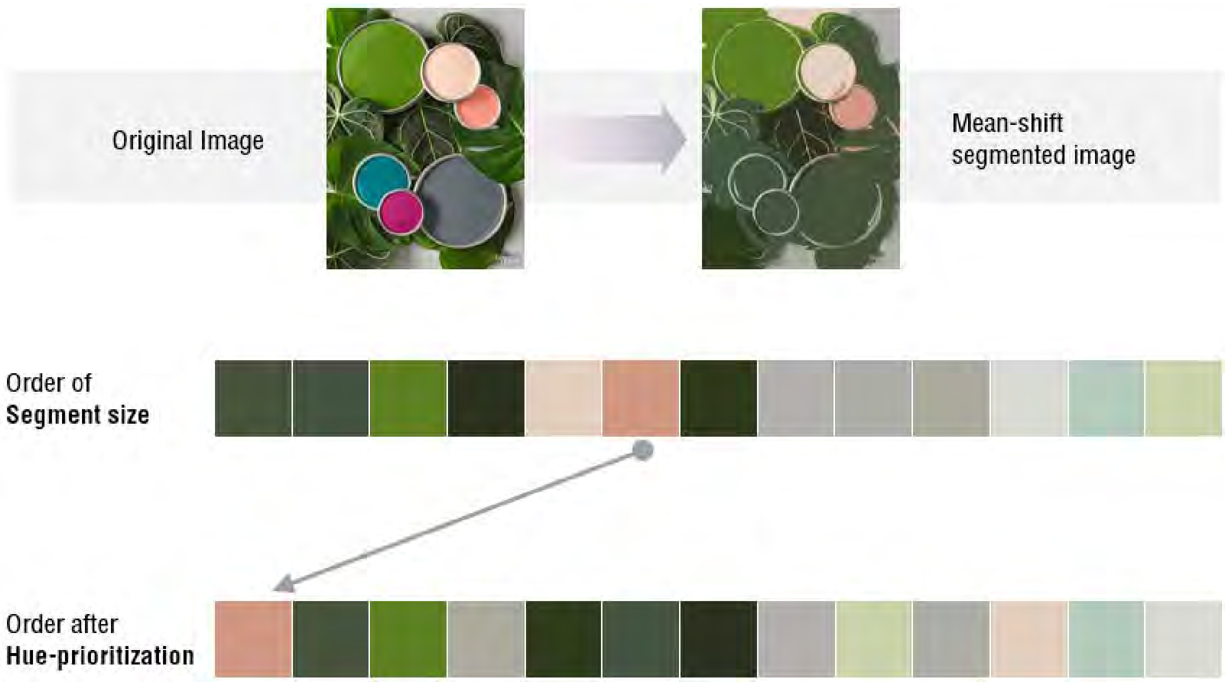


Figure 4.8 Influence of hue-prioritization in palette color ordering
When ordering the palette in order of segment size, the greenish colors take higher ranks than orange and gray colors. When the saliency is counted, the bright orange color comes first because of its saliency.

4.4.2 Creating a Specific Size of Color Palette (Optional)

The size of a color palette generated through mean-shift clustering is varying depending on the color and spatial distribution of the given input image. Sometimes, however, a user or a system may require a fixed size of color palette depending on its purpose. To respond to this issue, the proposed method also support a generation of fixed size of color palette while its main objective is still generating a single key color. We adopted k-means clustering to extract a pre-defined number of colors from an image. Similar to mean-shift clustering, the pixels which have L value lower than 12.5 were removed during the clustering. The initial cluster centroids were selected using k-means++ algorithm (Arthur & Vassilvitskii, 2007).

4.4.3 Generating Alternatives: Stylization of a Key Color

One of the distinctive character of the proposed method is providing alternative outputs with a single input. In case of key color generation algorithm, a user or a system may use the first ranked color among palette colors suggested by the mean-shift segmentation k-means clustering. However, if they have a more elaborated need particularly in emotional or affective quality, the alternatives produced by stylization process could be a solution.

For stylization of a key color, the hue extracted from the palette color is matched to a specific tone composed of a saturation and value. The core of the tone-match step is a manifestation of the emotional characteristic by matching a certain tone with a specific emotion. To identify an appropriate tone for a given style keyword, two databased were utilized; one is Kobayashi Color Image Scale developed by Kobayashi (1991), and the other is Adobe Color CC dataset (2017b), a large-scale database created by the crowd and crawled by O'Donovan et al. (2011).

4.4.3.1 Tone-match using Color Image Scale dataset

Step F1. Color Image Scale presents the images associated with color combinations by using 130 basic colors and 180 style words. In addition, the engagement between a color and a style word is described as a score between 0 (least) and 5 (best engagement). For instance, the color Gold is graded as five, the highest score, to appeal to luxurious and hot styles (Figure 4.9). We integrated the entire engagement scores and identified the top three colors that are highly engaged with a style keyword. By averaging the saturation and value of three colors, the researcher was able to define the absolute tone to be matched with a specific keyword. By combining the hue extracted from an image and the tone defined by Color Image Scale, a stylized color is generated. Figure 4.10 shows the examples of stylized colors of an image with various style keywords.

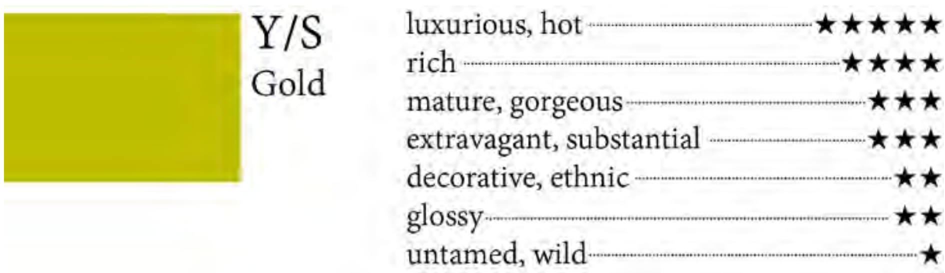


Figure 4.9 Associated keywords with Gold, from an excerpt of Color Image Scale (Kobayashi, 1991).
The number of stars indicates the strength of the association between the color and the given keyword.

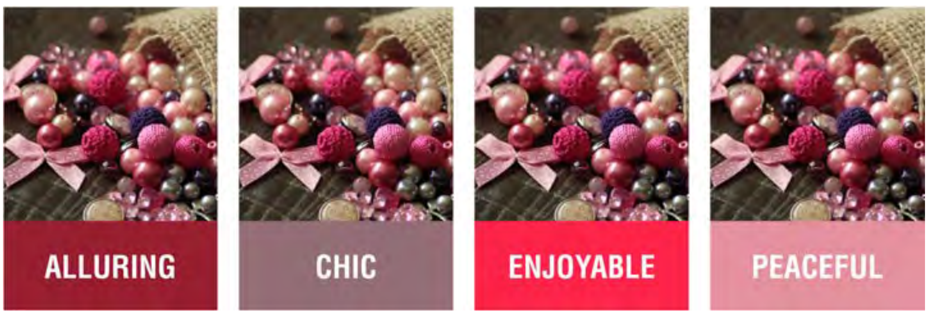


Figure 4.10 Stylized colors generated based on the Color Image Scale database.
A distinctive tone – saturation and value – is matched to each style keyword according to the association between a style keyword and colors suggested by Color Image Scale.

4.4.3.2 Tone-match using a Large-scale Database: Adobe Color CC

Step F2. Adobe Color CC® (Adobe Kuler) is a well-known crowd-sourced color database, which enables users to create, rate and modify the themes with five colors. Over 45,000 themes have been created on this platform, and each theme has a name and a rating score by users. Its richness has provided a reliable resource to infer color emotion in several studies (S. Liu & Luo, 2015; B. Wang et al., 2010; X. Wang et al., 2013). Like these studies, the researcher tried to derive a solid and latest knowledge about color emotion by associating color features and the name of each theme.

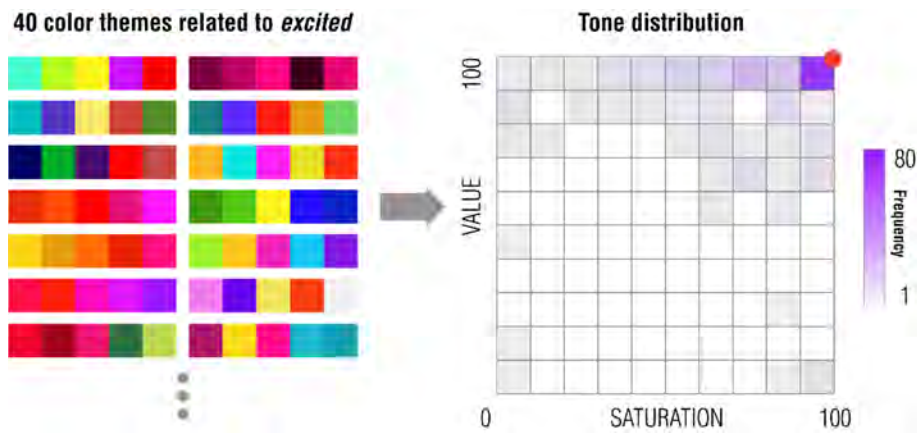


Figure 4.11 Identifying popular tones for Excited style from Adobe Color CC database.
The saturation and value dimensions were quantized into ten levels to identify the most popular range of saturation or value among 200 colors related to the *excited* keyword.

Figure 4.11 demonstrates the process of matching a tone with a certain style keyword. To define the tone for style keyword '*excited*', up to 40 color themes were crawled from the searching results in order of their ratings. Since each color theme has five colors, a total of 200 colors is obtained. Each color mapped on the saturation-value matrix according to its values.

Then, we quantized the matrix into ten by ten cells and counted the frequency of colors belong to each cell. By utilizing the histogram, we have tried to avoid the limitation of average that can be compromised by outliers. We identified the most popular tone range among 100 cells and defined the tone of a style keyword as the highest saturation and value of the cell. In the case of *excited*, the tone range with the highest

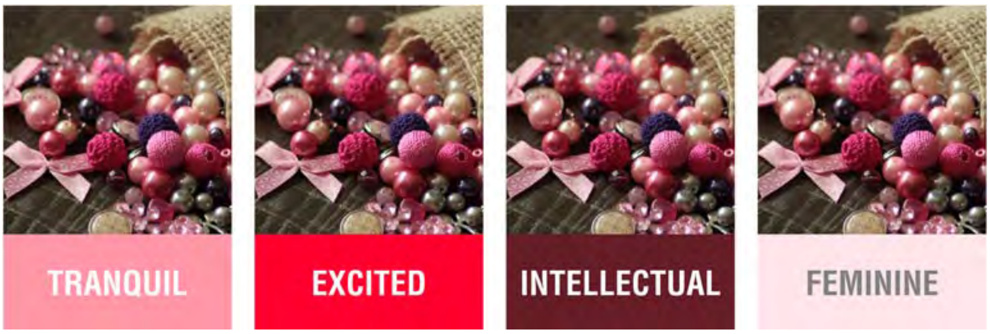


Figure 4.12 Stylized colors generated based on the Adobe Color CC database.
A distinctive tone – saturation and value – is matched to each style keyword according to the association between a style keyword and colors suggested by Adobe Kuler.

frequency was saturation 90~100% and value 90~100%. Among 200 colors, 76 colors were located in the cell. As a result, the tone of *excited* was defined as the combination of 100% saturation and 100% value.

By combining the hue extracted from an image and the tone defined by color themes from Adobe Color CC, a stylized color is generated. In Figure 4.12, examples of stylized colors with four style keywords are presented. Since the hue of a stylized color is inherited from the given image, all stylized colors have the same hue but are differentiated by the tones matched with style keywords.

4.5 Method to Recolor Images

For image recoloring, the segmentation results were utilized to identify the segments to be recolored for harmony with a target color. Since the hue features have a stronger impact on the perceived harmony between the image and the target color, we utilized a* and b* values only to compare the color difference between the target color and palette colors. In other words, Chroma threshold was utilized to discrete the segments to be adjusted and the segments not to be adjusted. Moreover, also the adjustment was applied to a* and b* dimensions only. For calculation of chroma, following formula was utilized (H. C. Lee, 2009);

$$C_{ab}^{*} = \sqrt{a^{*2} + b^{*2}}.$$

In general, the analogous and monochromatic recoloring follow the principle to increase the hue similarity between the target color and image colors. The complementary recoloring takes the opposite approach in order to construct a complementary relationship between them.

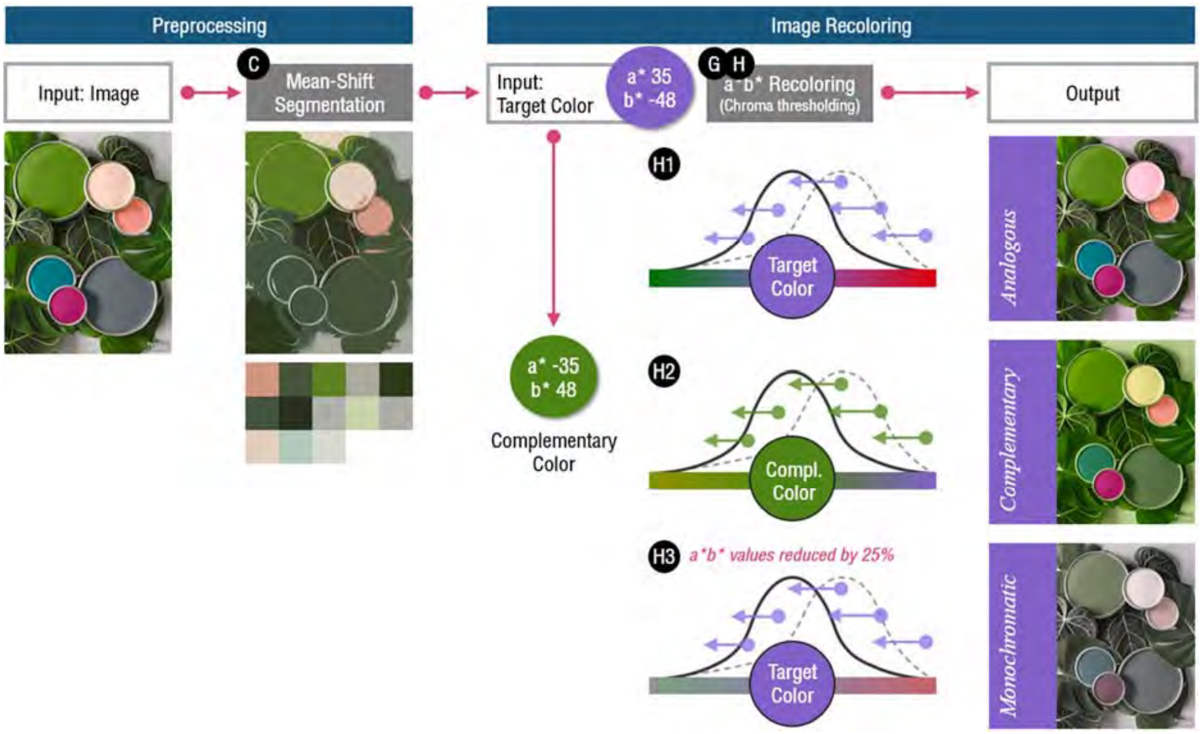
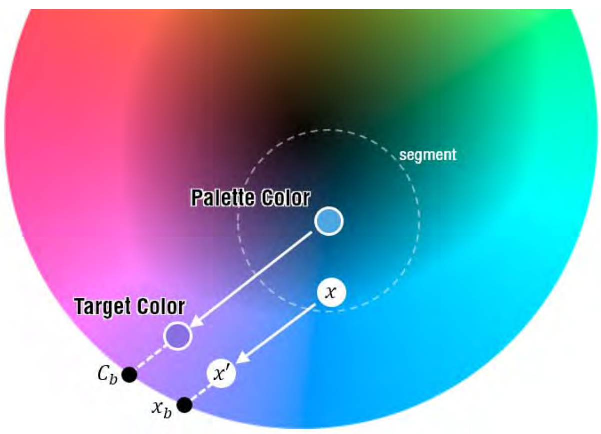


Figure 4.13 Framework of image recoloring to achieve harmony with a target color.
With an input image and a target color, the method provides maximum three alternatives depending on the availability of each of three recoloring methods: analogous, complementary and monochromatic recolorings.

Step G. Identifying Adjustable Segments using Palette Colors If at least a palette color lies within the chroma difference (50 in this study) with the input target color, the segment represented by the palette color was defined as an adjustable segment.

Step H. a*b* Recoloring to Achieve Harmony with a Target Color In order to recolor a certain segment toward the given target color, a recoloring function was proposed based on the color transfer methods by Chang et al. (2015). As shown in the Figure 4.14, for any color x within the palette segment, we would like to calculate x'. In general, the adjustment direction is same with the direction of palette to target recoloring. Thus a simple and naïve approach is applying the same offset vector $(Target - Palette)$ to the all colors of the segment. However, due to the chroma threshold we defined, or due to the limited range of gamut, the simple offset is not always applicable to all colors. To compensate this issue, we devised a scheme that squeezes the recoloring values as a color is close to the boundary. Within a segment, the colors that are closer to the recoloring boundary are clamped while the rest of the colors are adjusted as much as the offset vector of Target and Palette colors.



$$\frac{||x' - x||}{||Target - Palette||} = min\,(1, \frac{||x_b - x||}{||C_b - Palette||})$$

Figure 4.14 Conceptual illustration of a*b* recoloring.

4.5.1 Analogous Recoloring

Step H1. If at least a palette color locates within the chroma threshold from the target color, an analogous recoloring method is performed. As the name 'analogous' implies, this recoloring approach aims to increase the color similarity between a segment and the target color. To do so, it alters the image colors by shifting the mode of the adjustable segments toward the target color in a*b* dimension. In this alteration, the L* value was not considered. Figure 4.15 illustrates the conceptual framework of the analogous recoloring method with an exemplary outcome.

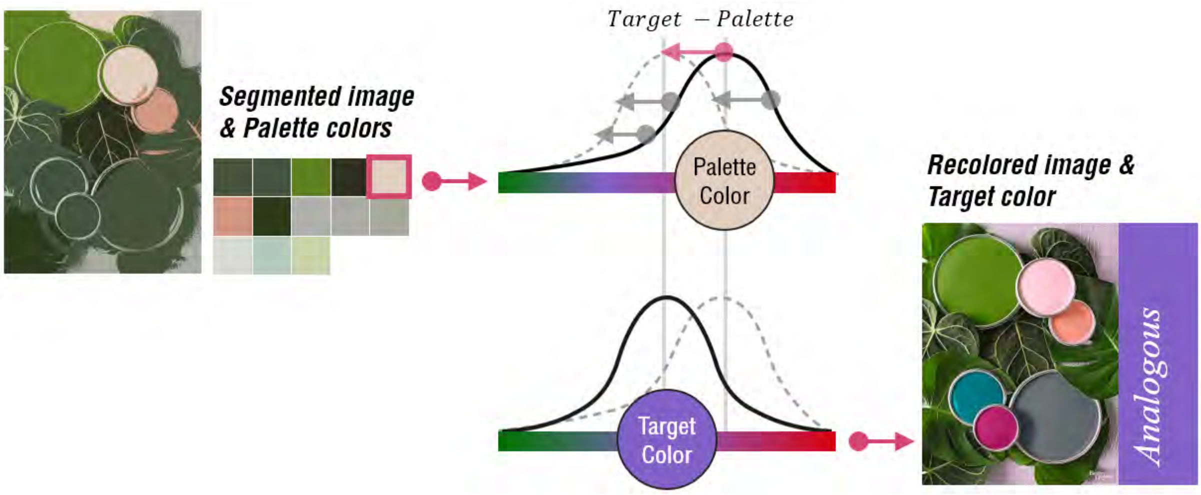


Figure 4.15 Conceptual framework and exemplary outcome of analogous recoloring.
After identifying the adjustable segments using Chroma thresholding, analogous recoloring alters the image colors by shifting the mode of the adjustable segments toward the target color in a*b* dimension.

The maximum adjustment value is defined by the hue distance between the target color and the nearest palette color as calculated in Step H. To maintain the hue monotonicity and to avoid artifacts, the maximum value is assigned to the palette color and the colors who locate further from the recoloring boundary. The rest of the colors closer to the recoloring boundary have smaller adjustment value in proportion to their distance from the boundary.

4.5.2 Complementary Recoloring

Step G. As the name implies, the complementary recoloring aims to construct a complementary harmony between the image and the target color. To do so, the method firstly calculates the complementary color by taking the opposite of a*b* values of the target color. Then the method identifies whether any of the palette colors lie within the chroma difference (50) with the complementary of the target color. If so, the method proceeds to the next step – a*b* recoloring.

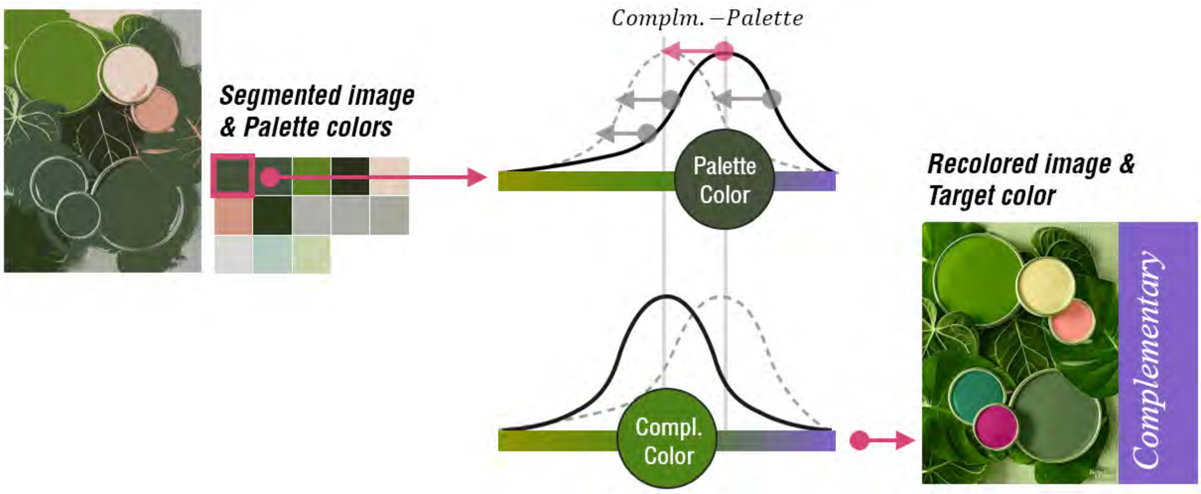


Figure 4.16 Conceptual framework and exemplary outcome of complementary recoloring.
Contrary to analogous recoloring, complementary recoloring utilize the complementary color of the target color to identify adjustable segments and to calculate the amount to be adjusted.

Step H2. The conceptual framework of the complementary recoloring is as same as the analogous recoloring. The only difference is that the direction of recoloring is changed from target to complementary color. Figure 4.16 shows the conceptual framework of the complementary recoloring and its exemplary outcome.

4.5.3 Monochromatic Recoloring

Step H3. The last solution is a monochromatic recoloring that drastically reduce the chromaticity of the output image. After performing the same process of analogous recoloring, monochromatic recoloring additionally reduce a* and b* values of the entire image by 25%. Figure 4.17 shows the conceptual framework of monochromatic recoloring with an exemplary outcome.

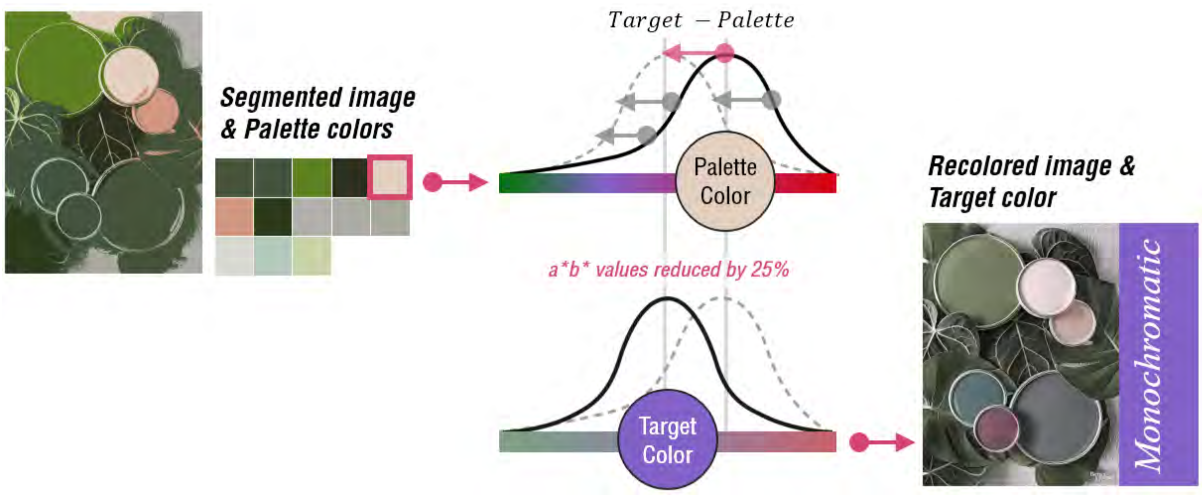


Figure 4.17 Conceptual framework and exemplary outcome of monochromatic recoloring.
After performing the same process of analogous recoloring, monochromatic recoloring additionally reduce a* and b* values of the entire image by 25% in order to reduce the chromaticity of the output image.

4.6 Summary

In this chapter, two automatic methods – key color generation and image recoloring - were proposed to automate the creation image-color harmony. The methods share the same pre-processing steps to minimize the computational cost. Based on the findings from designers' color generation process, hue-prioritization and tone-match steps were devised. By entering an image and a style keyword, palette colors were selected from an image, and the tone of the colors was articulated to deliver the desired style properly. The tone-match step was supported by external databases that define the relationship between colors and emotion. Image recoloring method starts from the pre-processed outcome – segmented images and color palettes – and identifies the availability of three recoloring approaches using Chroma threshold. The content of this chapter is related to the research aim 2 and its related objectives. ■

5 EVALUATION AND APPLICATION

5.1 Overview
5.2 Evaluation: Image-Color Context
5.3 Evaluation: Color Generation Method
5.4 Evaluation: Image Recoloring Method
5.5 Applications and Evaluation
5.6 Discussion
5.7 Summary

5. EVALUATION AND APPLICATION

5.1 Overview

This chapter proposes an image-bound color generation method to create aesthetic and affective image-color pairs. To construct a framework of the proposed method, the findings and insights from the previous chapter were utilized. Together with Chapter 5, this chapter constitutes a set of research activities to suggest a color generation method for aesthetic and affective image-color pairs. In the following sections, the details of the method are described, and the results of user tests are revealed in order to evaluate the performance of the method and to discuss its pitfalls and issues to be investigated further.

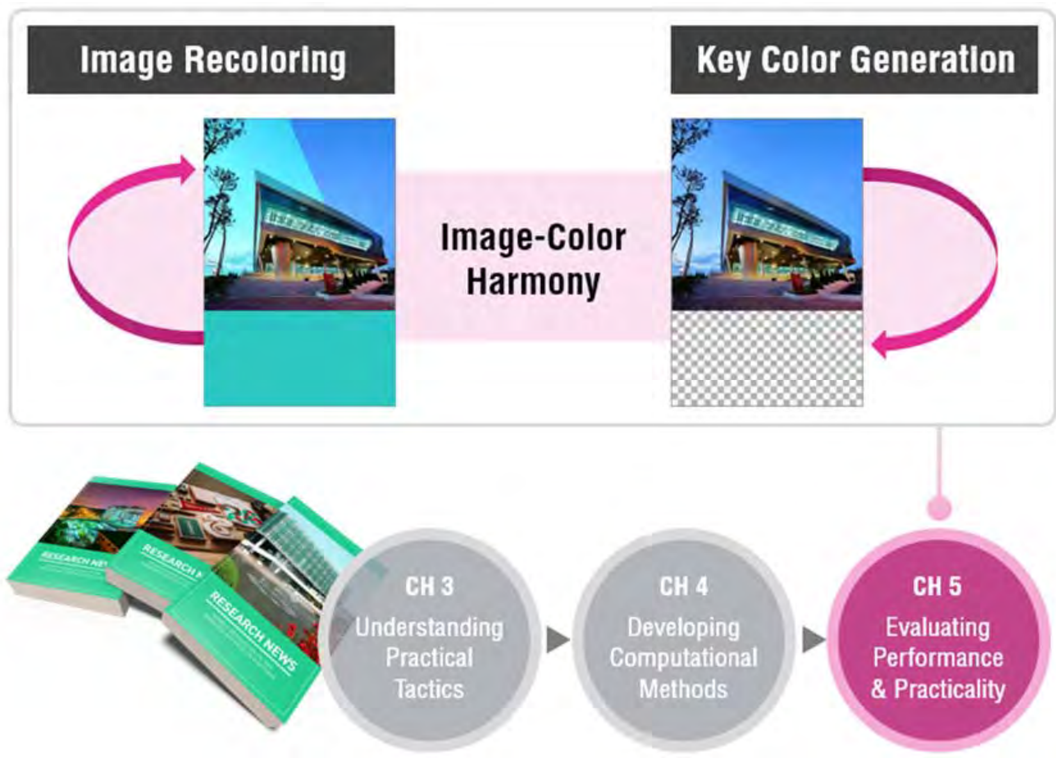


Figure 5.1 Research framework: Evaluation of developed methods and their application
This chapter describes a series of user test to evaluate the performance of the proposed methods.

5.2 Evaluation: Image-Color Context

As mentioned, recoloring techniques to improve the 'aesthetic quality' of images have been studied with various aims in mind. Then, is the requirements of *harmonious image recoloring* really different from the one of *aesthetic recoloring*? In consideration of this question, an experiment with designers and a survey was conducted. Through these experiments, the characteristics of image-color harmony were investigated.

5.2.1 How Designers Deal with Image-Color Context Differently

To understand the differences between harmonious and aesthetic recoloring, we firstly take a qualitative approach to investigate the designers' recoloring process in both contexts. In more detail, we tried to examine whether the recoloring methods and latent thoughts are changed depending on the objectives of recoloring – aesthetic or harmonious – given to them.

5.2.1.1 Participants and Materials

We have experimented with five designers (four males and one female) who have at least five years of professional experience in the visual-design field. Their mean age was 31.20 with the standard deviation of 1.72. The experiment was composed of two parts to perform *aesthetic* and *harmonious* image recoloring respectively.

Figure 5.2 briefly shows the tasks and stimuli given to the designer for each part. To capture a wide range of insights from a limited number of participants, we provided each designer with a distinctive set of images and image-color pairs. For a direct comparison between aesthetic and harmonious recoloring, the half of the images used in aesthetic recoloring (part 1) were reused in harmonious recoloring tasks. All of the images were copyright-free photographs from Pixabay.com (2016), and the target colors were chosen among uniformly distributed colors in the CIELAB color space with ΔE^*ab = 30 by devising the sampling method of Thomas et al. (2013).

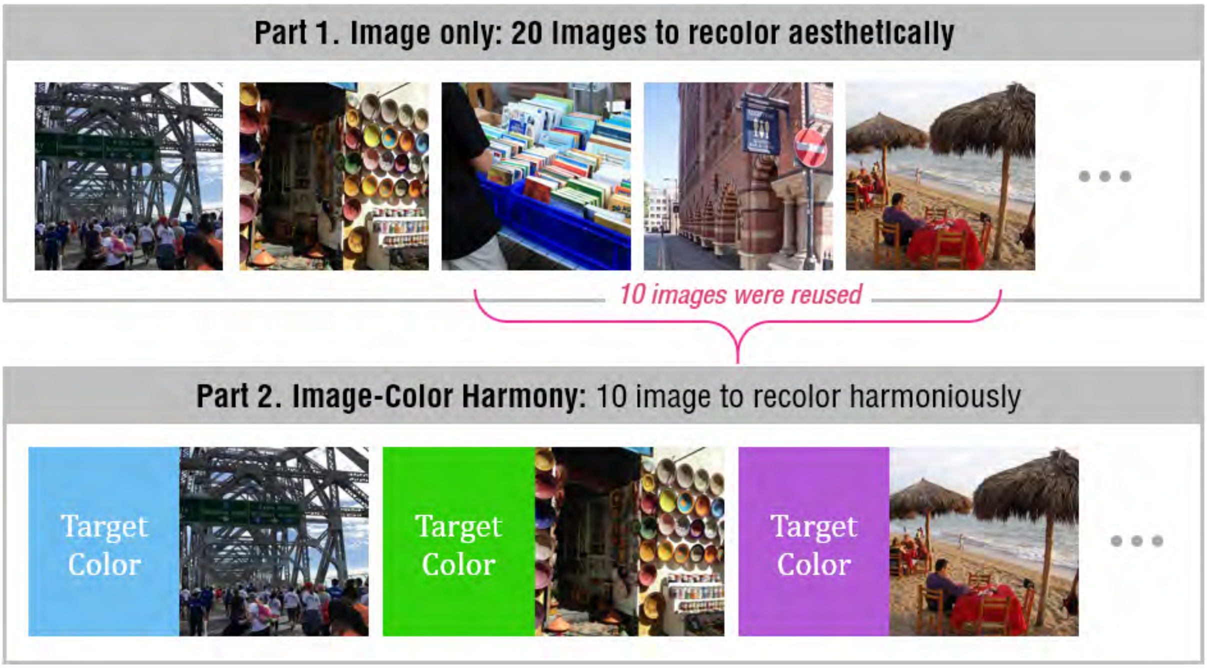


Figure 5.2 Examples of recoloring stimuli given to designers
In Part 1, the designers were asked to recolor given images to make them aesthetically pleasing. In Part 2, designers again recolored the half of the images from Part 1 to make them harmonious with a given color.

5.2.1.2 Procedure

In Part 1, designers were asked to recolor twenty images to improve their aesthetic qualities. In Part 2, ten image-color pairs were given, and unlike the first part, the designers performed harmonious recoloring to make each image harmonious with the target color. In order to capture the rich and profound practical knowledge designers have, we have described the target color as an identity color of a specific brand, and ask designers to suppose that the given image is used with the target color to design a poster, a brochure, and a website of the brand. After completing the tasks of both Part 1 and 2, a retrospective interview was conducted while reviewing the recoloring outcomes.

5.2.1.3 Data Analysis

Through this experiment, we were able to collect two types of data. One type of data is the image recoloring outcomes by designers, comprising 100 recolored images in Part 1 and 50 recolored image-color pairs in

Table 5.1 Coding scheme devised to analyze designers' verbal protocols

Code	Category	Sub-category
A	Image features adjusted to recolor images	A1. Hue A2. Brightness / Lightness A3. Saturation / Colorfulness A4. Contrast A5. Style / Texture
B	Ranges of the region adjusted	B1. Entire image (= global recoloring) B2. A certain color range B3. A certain region or object
C	Purpose of adjustment	C1. To preserve the original colors as much as possible C2. To correct the color balance of an image C3. To restore the memory colors C4. To make an image looks vivid and impressive C5. To give a certain mood or touch to an image C6. To emphasize the semantic features of an image

Part 2. The other one is the voice data collected from the post interviews, which portrays how and why the designers recolor the images in a certain way. To analyze these data, we took a qualitative approach to characterize the distinction between *harmonious* and *aesthetic* image recoloring. A thematic coding was conducted for the verbal protocols of designers, and the findings of the protocol were confirmed by analyzing the recolored images quantitatively. Table 5.1 shows the final coding scheme used in the analysis.

5.2.1.4 Results and Findings

Overall, the objective of aesthetic recoloring was highly associated with enhancing the naturalness and vividness of an image while preserving its original colors as much as possible. In other words, designers refrained from adjusting the colors of an image to a great extent, and showed an apparent congruity between the perceived level of aesthetics and naturalness. On the other hand, in cases of *harmonious* recoloring, designers exhibited a tendency to pursue a visual balance between the image and the target color in an integrated perspective. If necessary, they discarded the original colors of images or preferred to add artistic and artificial effects even compromising the naturalness of the picture. Figure 5.3 shows examples demonstrating the differences between *aesthetic* and *harmonious* recoloring.

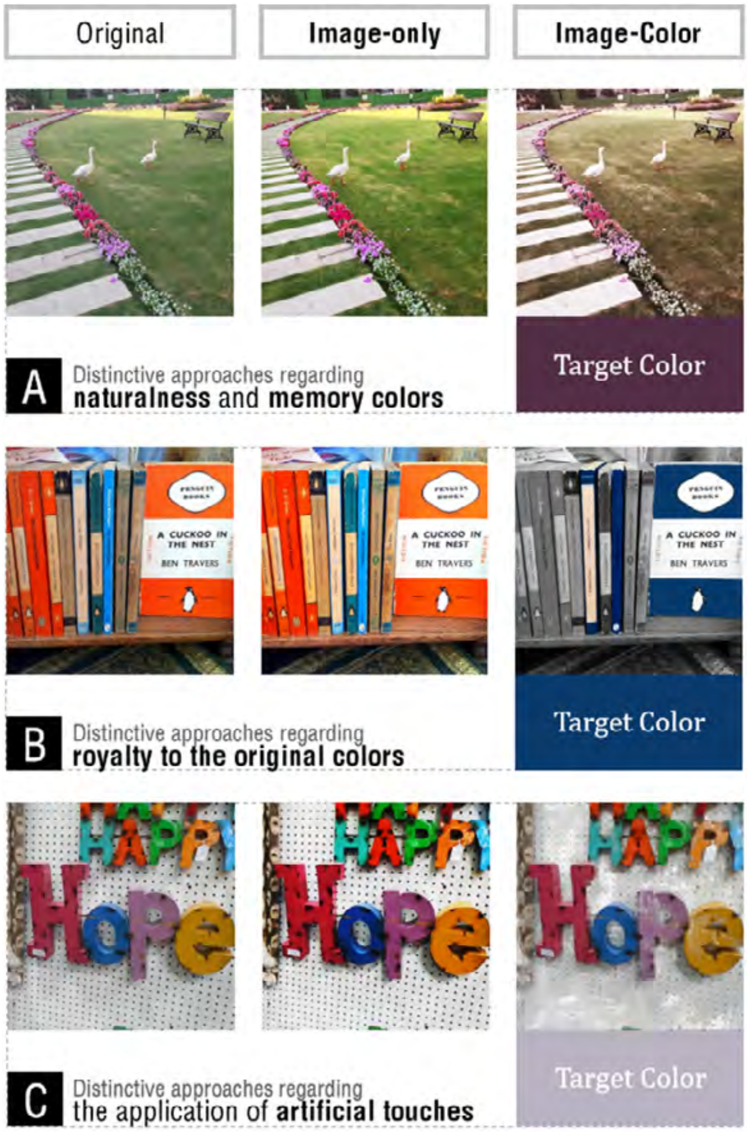


Figure 5.3 Differences between image-only and image-color context in terms of image recoloring
Depending on the context the recoloring task was given, the outcomes look different. Moreover, there were three distinctive approaches regarding memory colors (A), original colors (B) and artificial touches (C).

Differences in perceptions on naturalness: The differences regarding naturalness of an image were mainly found in the transcripts encoded in C2 and C3 categories of the coding scheme (Table 5.1). In relation to the color balance of an image (code C2), most of aesthetic recolorings were aimed to make an image neutral, like a white balancing of a photograph. In addition, we have frequently found that the aesthetic recoloring is performed in the way of restoring the memory color of natural objects such as sky, grass, and ocean.

In contrast, designers became less sensitive to the naturalness or restoration of memory colors when they perform harmonious image recoloring. Figure 5.3A shows the difference between *aesthetic* and *harmonious* recoloring in terms of naturalness. In aesthetic recoloring, the designer made the lawn greener, so the color of the lawn shifted near to the memory color he remembered. However, when the same image was presented with a deep purple, the target color, the designer completely abandoned the memory color of the lawn and proceeded to recolor the lawn in purple to increase color similarity with the target color.

Differences in royalty to the original image and the level of vividness: Figure 5.3B shows the difference between *aesthetic* and *harmonious* recoloring regarding the tendency to retain the original color of the image (code C1) and the tendency to make the image more vivid (code C4). When an image was aesthetically recolored, the designer wanted to make it more vivid by adjusting the brightness and contrast while minimizing the changes of the original colors particularly in hue dimension. However, when indigo color was presented together as a target, the designer decided to discard the original colors of the image. Designer 18 (D18) described his recoloring process as following:

> *"It was a tricky case… If I retain the original colors of the image, it seems impossible to achieve harmony between the image and the target color. I mean, the colors of the image were so bright compared to the target color. So I chose to completely kill the original colors of the image…."*

This explanation clearly illustrates the characteristics of harmonious recoloring – a reduced tendency to retain the original colors and an elaborated sense of balance and integrated aesthetics between an image and a target color.

Differences in the scope of acceptable recoloring techniques: In relation to code C5 – styles and textures, a distinctive approach was found especially in *harmonious* image recoloring. The approach aims to provide an artistic mood or feeling to the image by applying artificial editing techniques. Although only three cases belong to this category, these are important examples which demonstrate the increased

Table 5.2 The average color differences between original and recolored images in HSV color space. The color difference also corresponds to the amount of the color adjusted.

Color Feature	Average difference between Original and Image-only Recolored Images	Average difference between Original and Image-Color Recolored Images
Hue	71.95 (±46.85)	53.44 (±46.62)
Saturation	33.19 (±23.78)	30.47 (±20.49)
Value	20.73 (±12.98)	18.88 (±13.05)

variability of techniques that designers devise for harmonious recoloring. Figure 5.3C shows one of the three cases, and the verbal description of D20 was:

> *"Unexpectedly the target color was too calm and even gloomy. So I thought, maybe it is better to depict a mood of fainted 'hope', so I added some worn marks to give it fainted and old feeling."*

Differences in color features mainly adjusted: Aesthetic and harmonious recoloring also showed a significant difference in the color features (code A) adjusted during the recoloring process. The designer's verbal description and the colorimetric values of the actual image were used together to determine which color features were mainly adjusted. In this comparison, we have used 50 sets of aesthetic and harmonious recoloring cases that utilized the same original images for one-to-one comparison. In the verbal protocol of the designers, the number of vocabulary describing a specific color feature was counted, and the results suggested that, unlike other features, a much higher number of hue-related expressions (146 times) were found in the case of harmonious recoloring in comparison with aesthetic recoloring (36 times).

This tendency was prominent in the colorimetric analysis as well. Table 5.2 summarizes the average color differences calculated in HSV color space to compare aesthetic and harmonious recoloring. As shown, the hue feature exhibits a huge difference that demonstrates a more considerable amount of hue adjustment in harmonious recoloring than an aesthetic one. These findings support the importance of hue feature in evaluating and manipulating the degree of image-color harmony.

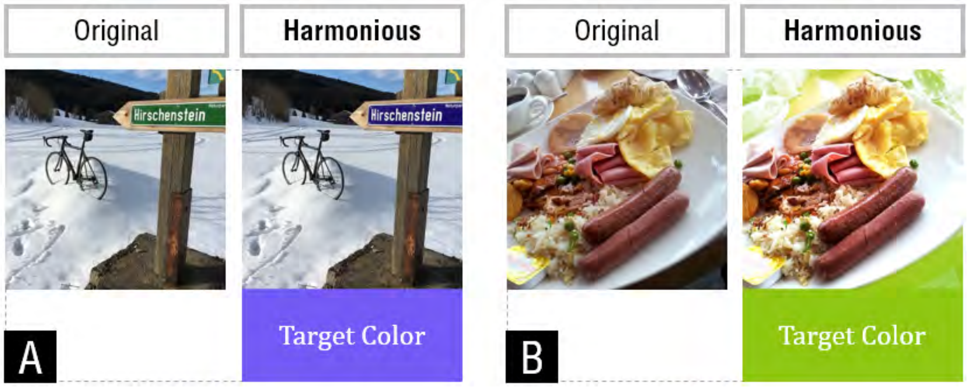


Figure 5.4 Examples of local recoloring approaches to achieve harmony with a target color.
Both cases demonstrate designers' preference to change the colors of an image locally. As shown, local recoloring is applied to an object (A) or a certain region (B).

Differences in the area-of-interest to apply recoloring: In the case of the aesthetic recoloring, the areas that color adjustment was applied were either the entire image (code B1) or a certain range of colors (code B2). Although it is limited to 100 cases only, we were not able to find approaches to adjust colors of a certain region or an object (code B3) to improve the aesthetic quality of an image. In the case of harmonious recoloring, however, nine out of fifty cases demonstrated a sophisticated local recoloring that colors of a certain region or an object were selectively changed. Figure 5.4 shows two of these examples. The left example shows a local recoloring applied to an object, of which color is the accent color of the image. The right example is a case that recoloring is applied to a certain region to harmonize the image and the target color. This result suggests that a local color change is a distinctive strategy of harmonious recoloring, and often a bold and brave color change is attempted in local approaches to maximize the impact of recoloring.

5.2.2 How People Perceive the Image Recoloring in Different Contexts

The findings from designers support differentiability between aesthetic and harmonious image recoloring. If so, will general users perceive the two recoloring contexts differently? To explore the perception of general users, we conducted an online survey with people who have no prior experience in design education.

5.2.2.1 Participants and Materials

Twenty males and twenty females participated in the survey, and their mean age was 21.73 years with the standard deviation of 3.63. The online survey consisted of two parts that each contains thirty sets of stimuli. Figure 5.5 shows an example of the stimuli used in Part 1 and Part 2. In Part 1, the participants were asked to rank three images including an original, an aesthetically recolored, and a harmoniously recolored one. In Part 2, we utilized the same images as Part 1 but presented them as design cases like book covers in combination with a target color. Participants were asked to rank the visual aesthetics of three design cases in the perspective of an integrated quality of an image-color combination.

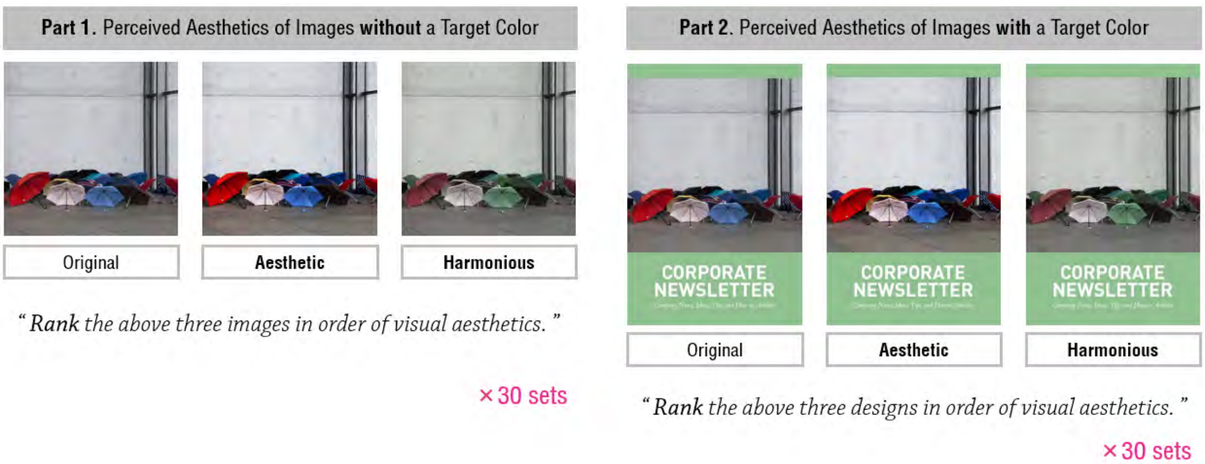


Figure 5.5 Examples of stimuli used in the online survey
In Part 1, three images were displayed without any other components. On the contrary, in Part 2, each of the images was provided with an adjacent color component.

5.2.2.2 Results and Analysis

In order to investigate whether the presence of a target color affected the preference of images, we performed a Wilcoxon signed rank test to compare the rankings of Part 1 and Part 2. The test was performed for each of three image conditions – original, aesthetically recolored and harmoniously recolored. The results showed that the presence of a target color elicits statistically significant changes in the preference ranks of all three conditions at an alpha level of 0.05 (original: $Z = 6.31$, aesthetic: $Z = 6.73$, harmonious: $Z = 13.43$).

Figure 5.6 shows the changes in ranks in three conditions. As shown, in cases of original and aesthetically recolored images, a greater portion of preference ranks was decreased when images were presented with a target color. In contrast, in cases of harmoniously recolored images, a greater portion of preference ranks was increased when the images were presented with a target color. The result indicates that the evaluation of visual aesthetics could change significantly depending on the context in which the image is presented, and thus shows that image recoloring techniques suitable for specific design contexts are required.

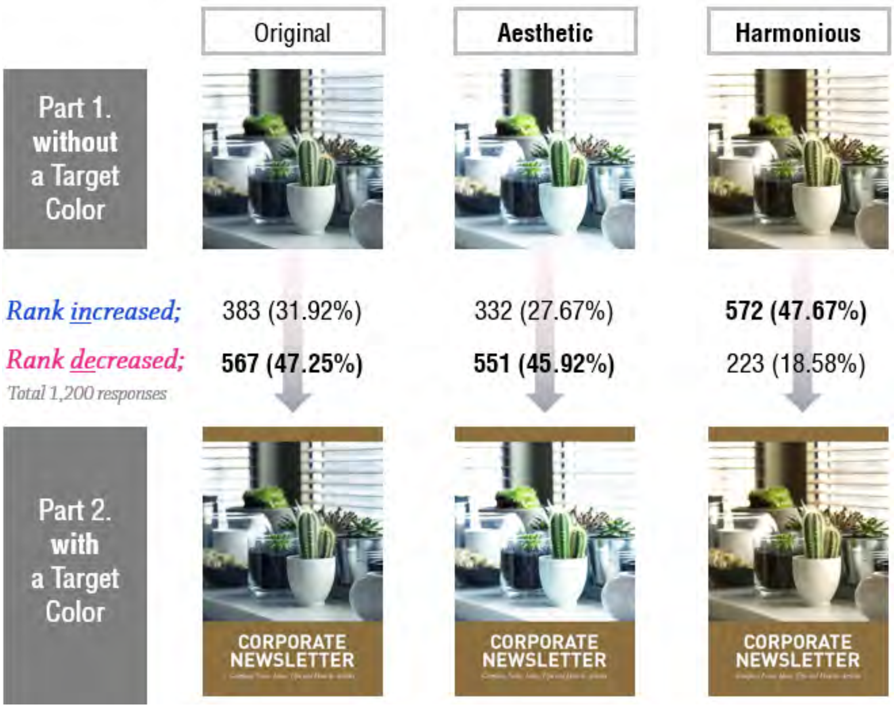


Figure 5.6 Frequencies of rank changed depending on the presentation context
Total 1,200 responses were collected for each recoloring condition – original, aesthetic and harmonious.

5.3 Evaluation: Key Color Generation Method

This section describes a set of activities to evaluate the performance of the developed method. Section 5.3.1 provides a source for evaluating the performance of the palette extraction and hue-prioritization of the proposed method. The subsequent two sections offer the procedures and results of systematic experiments to assess the performance of the entire method with an interest of its tone-match feature.

5.3.1 Validation of Palette Extraction and Hue-prioritization Features

Figure 5.7 shows the palette colors extracted by different methods. Since the method proposed in this dissertation does not contain any new or unique feature in comparison with previous studies, it is not appropriate to argue its superiority in comparison with previous studies. Instead, it demonstrates that a fixed size of palette extracted by the proposed method produces satisfactory colors as previous methods do and the extracted colors are well-harmonized with the given image as a piece of visual design.

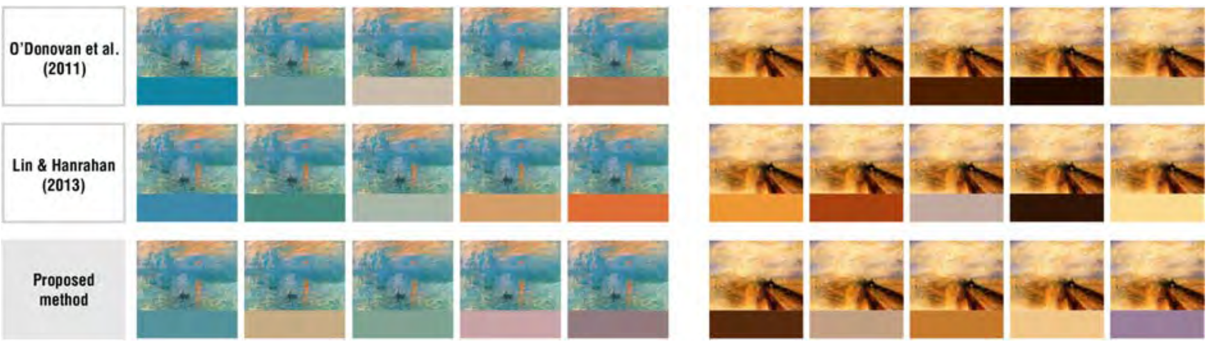


Figure 5.7 Comparison of palette extraction methods
When a desired number of colors is specified, the proposed method performs k-means clustering using the preprocessed image. Moreover, the result shows that the proposed method is good at capturing salient and distinctive colors while identifying the appropriate dominant colors as well.

Figure 5.8 compares the order of palette colors before and after applying hue prioritization rule. As shown, the hue-prioritization feature picks the color that dominates the image but also salient among palette colors. By doing so, the hue of the rose is selected instead of the leaves, and the hue similar to the teacup is selected for the next step – *tone-match*.

Figure 5.8 Comparison before and after applying hue-prioritization rule
A more salient but also enough dominant colors move to the front by considering the hue saliency in hue-prioritization of palette colors.

5.3.2 User Test 1: Evaluation of Key Color Stylization using Color Image Scale

A user test was conducted in order to assess the performance of the key color stylization using Color Image Scale database (Kobayashi, 1991). Since the proposed method is composed of two separate steps, we evaluated the stylization method in two aspects. In more details, the performance of hue-prioritization step was assessed by rating the aesthetic harmony between a color and an image, and the performance of tone-match step was assessed by rating the affective quality of each color-image combination.

5.3.2.1 Method

As stimuli, we utilized ten affective keywords and five images for each word. The keywords were selected from among 30 words that were rated as highly liked styles in Color Image Scale suggested by Kobayashi (Kobayashi, 1991). They were *Chic, Clean, Enjoyable, Intellectual, Modern, Pastoral, Peaceful, Placid, Sporty,* and *Youthful*. For each keyword, five images were randomly chosen out of 25 images in a size of 1000 pixels by 1000 pixels. Accordingly, a total of 50 image-keyword sets were prepared. For these 50 sets, we prepared five variations of stylized colors; four of the variations were made by four experienced designers, and the fifth one was generated by the proposed method.

Thirty college students participated in the test and were exposed to the 50 sets. When one set is displayed, the subjects ranked five color-image combinations in terms of two aspects: affective quality and the aesthetic harmony. From each participant, each color-image combination got two ranking scores ranging from 1 to 5 depending on its ranking order (1: best – 5: worst). One score represents the rank of affective quality, and the other represents one of aesthetics.

5.3.2.2 Results and Analysis

The ranking data were analyzed by performing a Friedman test. The result showed a statistically significant difference among stylized colors generated by four designers and the proposed method in their aesthetic harmony ($\chi^2(4) = 354.86$, $p < 0.05$) and affective quality($\chi^2(4) = 56.67$, $p < 0.05$). Post hoc analysis using Wilcoxon signed rank tests with a Bonferroni correction was conducted for pairwise comparisons in a significance level at $p < 0.0125$.

In the case of aesthetic quality, the stylized colors generated by Designer 2 (Z= -10.562, p<.01) and Designer 3 (Z = -11.988, p <.01) ranked significantly higher than the colors generated by the proposed method. There were no significant differences among Designer 1, 4, and the proposed method. This indicates that the proposed method performed as satisfactory as some designers in generating stylized colors that are harmonious with given images regardless of target emotions.

In the case of affective quality, there was a significant difference between stylized colors generated by Designer 2 and the proposed method (Z = -4.190, p< 0.01) and between colors generated by Designer 4 and the proposed method (Z = -6.096, p< 0.01). However, there was no significant difference among Designer 1, 3, and the proposed method. This result suggests that stylized colors generated by the proposed method deliver emotions as some designers do, while other designers perform better.

Although the proposed method does not perform significantly better than all the designers, the ranks of the proposed method seem to fluctuate less than the ones of four designers in perspectives of both aesthetic and affective quality. For instance, designer 3 outperformed in generating aesthetic stylized colors but was less competitive in selecting stylized colors. On the other hand, designer 4 produced stylized colors that are good at representing affective terms but are less harmonious with images. Compared to these designers and the distributions of rank that they received, the proposed method showed a balanced performance in generating aesthetic and stylized colors with stable ranks.

In addition to the general assessment, we investigated the performance of the proposed method for each of ten emotions. For both of aesthetic and affective quality, a Friedman test and post hoc Wilcoxon signed rank tests were performed to compare five stylized colors of each emotion. Based on the analysis, we classified ten emotions into three categories: the emotion that the proposed method showed superior results, the emotions for which the proposed method showed intermediate performance, and the emotions for which the proposed method performed poorly. Table 5.3 summarizes the results.

The results of affective and aesthetic quality showed discrepancy to some degree. The stylized colors for *Pastoral* emotion received high ranks on aesthetics but poor ranks on affective quality. On the contrary, the method was good at generating *Placid* colors with superior affective quality while the aesthetic quality was poor. Except for the keywords *Sporty* and *Youthful*, there were disagreements between the aesthetic and affective qualities of stylized colors. It may imply the independent performance of two steps of the color generation method and indicate the need to improve both *hue-prioritization* and *tone-match* steps in consideration of holistic quality of image-color pairs.

Table 5.3 Classification of style keywords according to the performance of the proposed method

	Aesthetic Quality	Affective Quality
Superior Outcomes	*Chic*, ***Pastoral***	*Clean*, *Enjoyable*, ***Placid***
Intermediate Outcomes	*Clean*, *Enjoyable*, *Peaceful*, *Sporty*, *Youthful*	*Chic*, *Intellectual*, *Sporty*, *Youthful*
Poor Outcomes	*Modern*, *Intellectual*, ***Placid***	*Modern*, ***Pastoral,*** *Peaceful*

5.3.3 User Test 2: Evaluation of Stylized color generation using Adobe Color CC

The goal of this user test was to assess the performance of the proposed method in relation to the utilization of Adobe Color CC. Although the Adobe Color CC database only affects the tone-match process of the proposed method, both of aesthetic and affective qualities were evaluated in comparison with the designers' selection.

5.3.3.1 Method

As stimuli for the test, we used 30 images from the previous designers' workshop and prepared six variations of stylized colors for each of the images. Five of the variations were made by five experienced designers, and the sixth one was generated by the proposed method. Moreover, an image-color pair had one of the four affective terms – excited, afraid, depressed and relaxed – as the theme. As a result, we had a total of 120 image-color pair sets for the experiment.

A total of 30 subjects (15 male, 15 female) participated in the test and exposed to the 120 sets. When one set is displayed, the subjects rated each of the six variations regarding aesthetic harmony and affective quality using a 7-point-Likert scale.

5.3.3.2 Results and Analysis

The average ratings on designers' stylized colors and the proposed method are presented in Table 5.4 Average ratings on 120 image-color pairs created by five designers and the proposed method. A repeated measures one-way ANOVA was conducted twice to compare the aesthetic harmony and overall affective quality of stylized colors generated by designers and the proposed method. In addition, a one-way ANOVA was performed four times in order to compare the affective quality of stylized colors for each of four affective terms.

For the ratings on **aesthetic harmony**, there was a significant difference among stylized colors generated by designers and by the proposed method (F (5,7194) = 70.68, p < 0.05). The post hoc comparison with

Table 5.4 Average ratings on 120 image-color pairs created by five designers and the proposed method

	Mean(SD) 1: very poor ~ 7: excellent	
	5 designers	the proposed method
Aesthetic quality	4.17 (1.61)	3.63 (1.55)
Affective quality	4.27 (1.54)	4.56 (1.45)
Excited	4.28 (1.54)	4.73 (1.49)
Afraid	3.88 (1.58)	3.66 (1.37)
Sad	4.52 (1.55)	4.85 (1.15)
Relaxed	4.40 (1.41)	5.00 (1.39)

Tukey's HSD indicated that the ratings on colors by the proposed method were significantly lower (M = 3.63, SD = 1.55) than the ones on colors by four designers. Only one designer showed a non-significant difference with the proposed method in the perspective of aesthetic harmony.

In the case of **overall affective quality**, stylized colors by the proposed method have received the highest mean ratings, and the ratings were significantly higher (M = 4.56, SD = 1.45) than colors by four designers ($F(5,7194) = 13.88$, $p < 0.05$). We also performed a one-way ANOVA test and post hoc test for each emotion. The results confirmed significant differences in six variations for all four affective terms. In cases of *excited* and *relaxed*, the proposed method received the highest mean score, and significantly better than four designers ($p < 0.01$ with Bonferroni correction). The proposed method also received a significantly better score for *depressed* stylized colors than three designers ($p < 0.01$). In the case of the *afraid* state, there were no significant differences among the proposed method and four designers ($p < 0.01$). Only one designer showed a significantly better performance than the proposed method ($p < 0.01$).

5.4 Evaluation of Image Recoloring Method

In order to assess the performance of the proposed method, we first compare the proposed method directly to the existing methods in previous studies. We then performed two user tests. Section 5.4.2 presents one user test that compares our results with the unadjusted one, and section 5.4.3 describes the other user test to investigate the practical application of the proposed method in the perspective of expert designers.

5.4.1 Comparison with the Existing Method

To our best knowledge, no directly comparable method works automatically with a given image and a target color to perform an image adjustment. Among palette-based image recoloring methods (Chang et al., 2015; Greenfield & House, 2003; Nagai et al., 2013; B. Wang et al., 2010; Yoo et al., 2013), the method proposed by Chang et al. (2015) exclusively supports the manipulation of each palette color. With the difference in mind, we present a brief comparison result of the method by Chang et al. and ours (Figure 5.9). For the method of Chang et al., we arbitrarily selected one color from the palette and changed it into the target color.

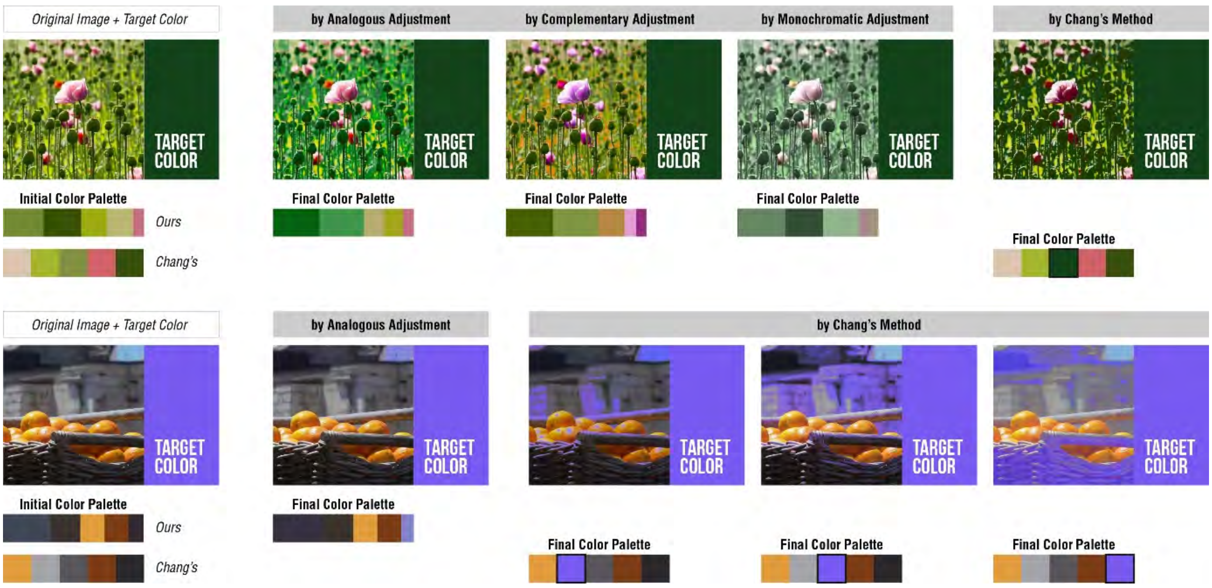


Figure 5.9 Comparison to the method of Chang et al. (2015).
The upper case shows three outcomes by the proposed method and the result by Chang's method. It shows the proposed method automatically suggests various alternatives while their method can suffer from the poor user input. The lower case shows that the proposed method provides a harmonious outcome without significantly impairing the original colors.

The upper case of Figure 5.9 shows that the proposed method produces relatively satisfactory outcomes that deliver distinctive visual characteristics while a poor palette selection may produce an undesired outcome in Chang's method. The lower example shows that the current method may not be able to produce desirable outcomes regardless of the palette selection. On the contrary, our analogous recoloring moderately alters the background colors to be harmonious with the target color while remaining faithful to the original image. These examples demonstrate that the proposed method provides faithful results to achieve harmony with a target color, even without user input. In addition to its full automation, the proposed method is distinguished from others in that we provide three distinctive solutions based on color harmony (G. Hu et al., 2014; Itten & Birren, 1970; Westland, Laycock, Cheung, Henry, & Mahyar, 2007).

5.4.2 User Test 1: Comparison with Designers' Recoloring

5.4.2.1 Method

The first user test was conducted to identify whether the proposed recoloring method provides satisfactory outcomes that can enhance the visual quality of image-color pairs. For the survey, 40 sets of stimuli were prepared. Each set consists of five design cases using an original image, an image harmoniously recolored by designers, and three images recolored by analogous, complementary and monochromatic method respectively. Figure 5.10 shows a set of stimuli used in the survey. A total of 40 people composed of 20 females and 20 males participated in the online survey and asked to rank the design cases in order of visual aesthetics. As a result, a total of 1,600 ranking scores was collected for each recoloring conditions.

5.4.2.2 Results and Analysis

A Friedman test was performed in order to compare the ranks of five recoloring conditions - original, by designer, by *Analogous,* by *Complementary*, and by *Monochromatic* – and, there was a statistically significant difference in their ranks, $\chi^2(4) = 770.64$, $p < 0.05$.

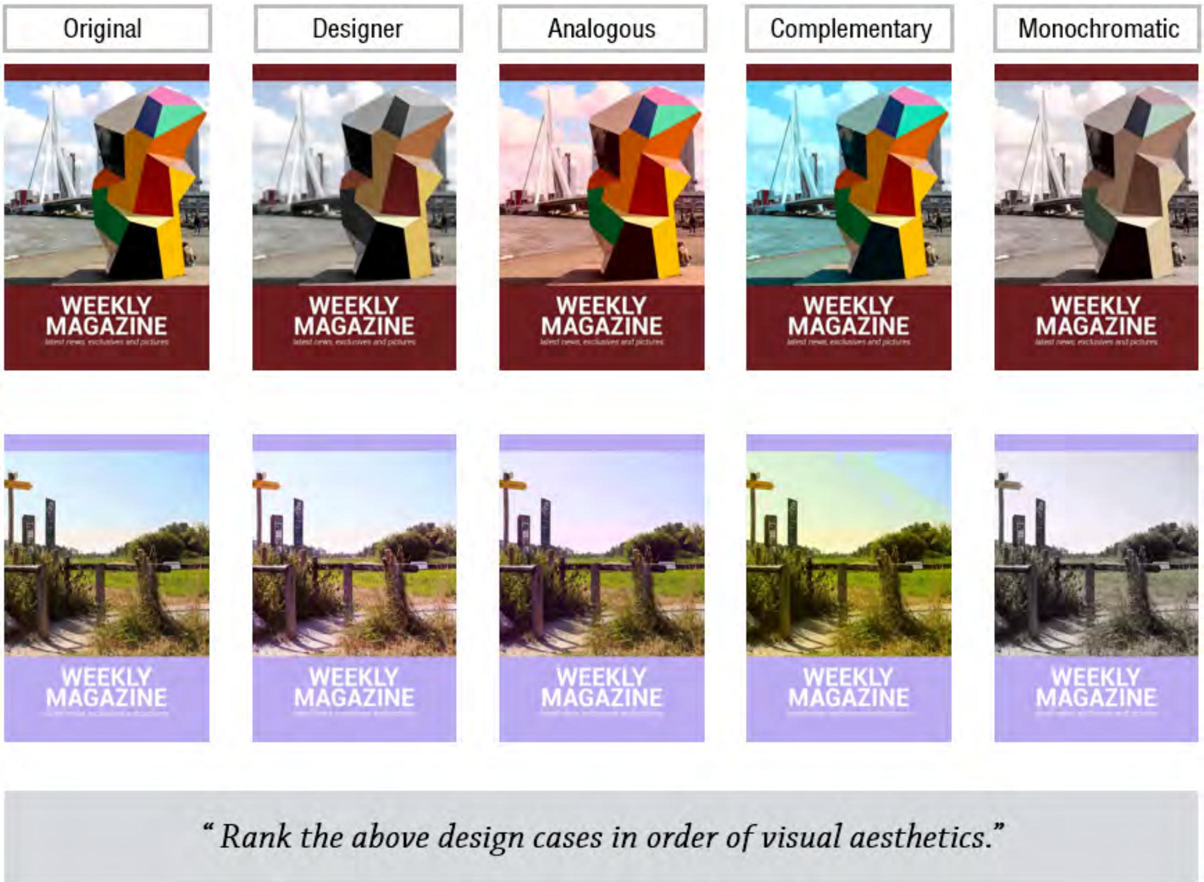


Figure 5.10 An example of stimuli used in user test 1
A set of stimuli consists of five design cases using an original image, an image harmoniously recolored by designers, and three images recolored by analogous, complementary and monochromatic method respectively.

Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni correction applied, resulting in a significance level set at $p < 0.01$. The results showed that recoloring outcomes by *Analogous* and *Monochromatic* have no significant difference (Z = 1.76, p = 0.08) while the ranks of *Monochromatic* was significantly higher than the ranks of designers' outcomes (Z = 3.75, p <.01). The ranks of designers' outcomes had no significant difference in comparison with the ranks of design cases using original images (Z = 2.27, p = 0.2). The least preferred recoloring method was complementary one, and there was a statistically significant difference between the original images and the complementarily recolored cases (Z = 18.96, p < 0.01).

Overall, the proposed recoloring methods, particularly *Analogous* and *Monochromatic* methods were preferred throughout a variety of image-color pairs. This indicates that the two recoloring approaches of the proposed method provide satisfactory outcomes that achieve robust and fair image-color harmony. Despite the statistical significance, the median ranks of four conditions except complementary one are considerably similar to each other. Thus, it is hard to argue that our two methods provide better solutions than designers. Instead, it suggests that an automatic method could improve the perceived quality of image-color combinations by implementing the practical knowledge of designers.

5.4.3 User Test 2: Comparison of Three Alternatives

5.4.3.1 Method

The user test was conducted to compare the preference among three alternatives generated by our recoloring methods and original image without recoloring. Similar to the previous experiment, the researcher gathered copyright-free 35 images (600 by 600) from pixabay.com and prepared 100 sets of stimuli by matching each image with two to three colors. Each set of stimuli consists of graphic works using an original image, an image adjusted by analogous, complementary and monochromatic recoloring. The order of four graphic works was randomized throughout the entire stimuli. Figure 5.11 three exemplary sets of stimuli.

A total of 37 people participated in the online survey and exposed to the 100 stimuli. They asked to select an example among four that looks more harmonious and aesthetic. As a result, a total of 3,700 responses was collected.

5.4.3.2 Results and Analysis

Among 3,700 responses, 1,902 responses (51.41%) preferred the analogous recoloring results most, and the monochromatic recoloring (21.46%), original images (15.84%) and the complementary recoloring (11.30%) were followed. This indicates our result is preferred in approximately one-tenth of total cases regardless of the approaches used. Among three approaches, the analogous recoloring dominated the preference, whereas the complementary recoloring scores are less than the unadjusted images.

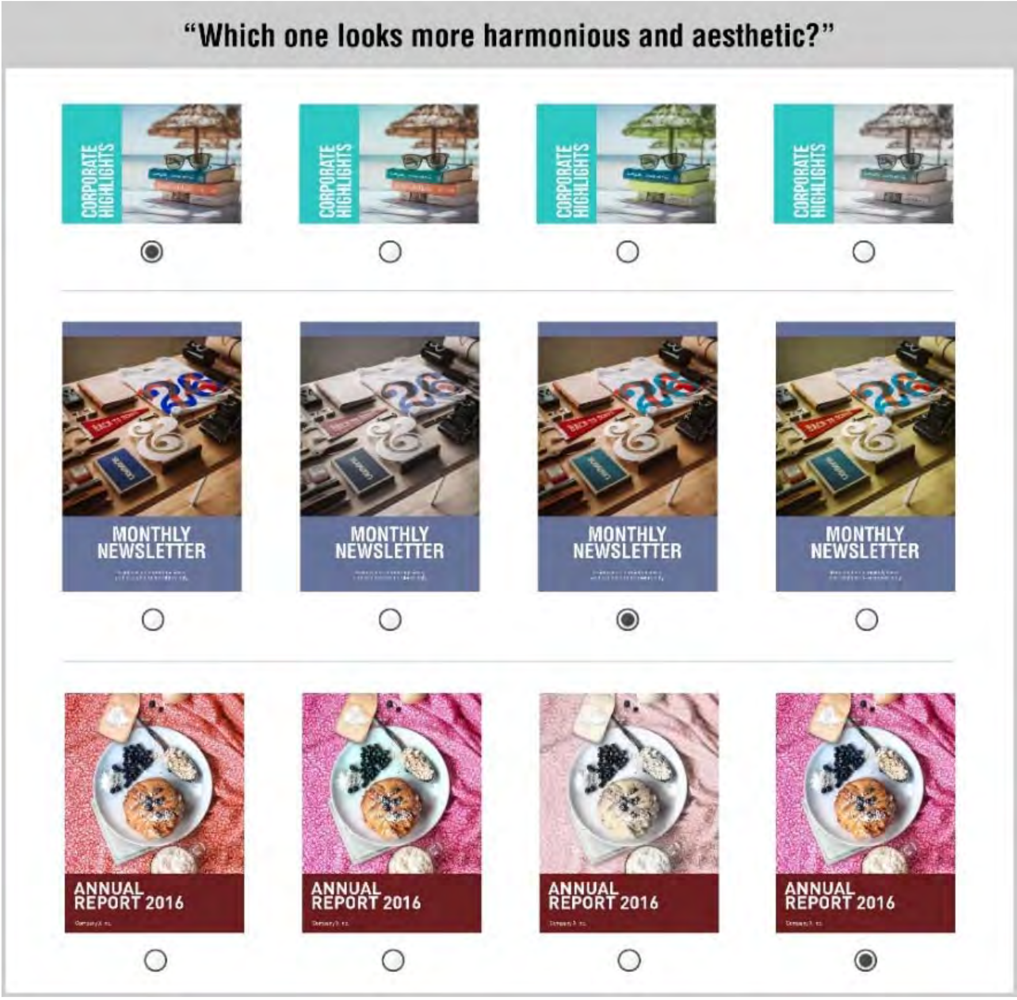


Figure 5.11 Exemplary sets of stimuli used for the user test 2.
For each set, the marked one (marked radio button) is the original image without any adjustment.

We found that, in general, users are much less tolerant of color changes of organic things such as human skin, food, and animals which have innate colors. Although the image editing has increased the hue similarity between the color and the image, the color change was perceived as a color distortion and had a negative influence on the harmony and aesthetic judgment. Contrary to the worst cases, color changes of objects were often appreciated and good at delivering a harmony and aesthetics.

5.4.4 User Test 3: Interview with designers

The second user test was conducted in order to investigate the advantages and limitations of each method more profoundly and to discover practical usability that the first user test did not reveal.

5.4.4.1 Method

For the second user test, we recruited five participants who hold at least a bachelor's degree in the design field. The test was carried out individually in a closed room equipped with two monitors. Similar to the first user test, a total of 120 sets of stimuli were prepared. The participants reviewed each set of graphic works one by one and verbally described their impressions and evaluations upon the stimuli. Since the test aims at exploring the overall potential of each approach, participants were allowed to revisit previous cases as many time as they want. Their verbal description was recorded and transcribed for analysis.

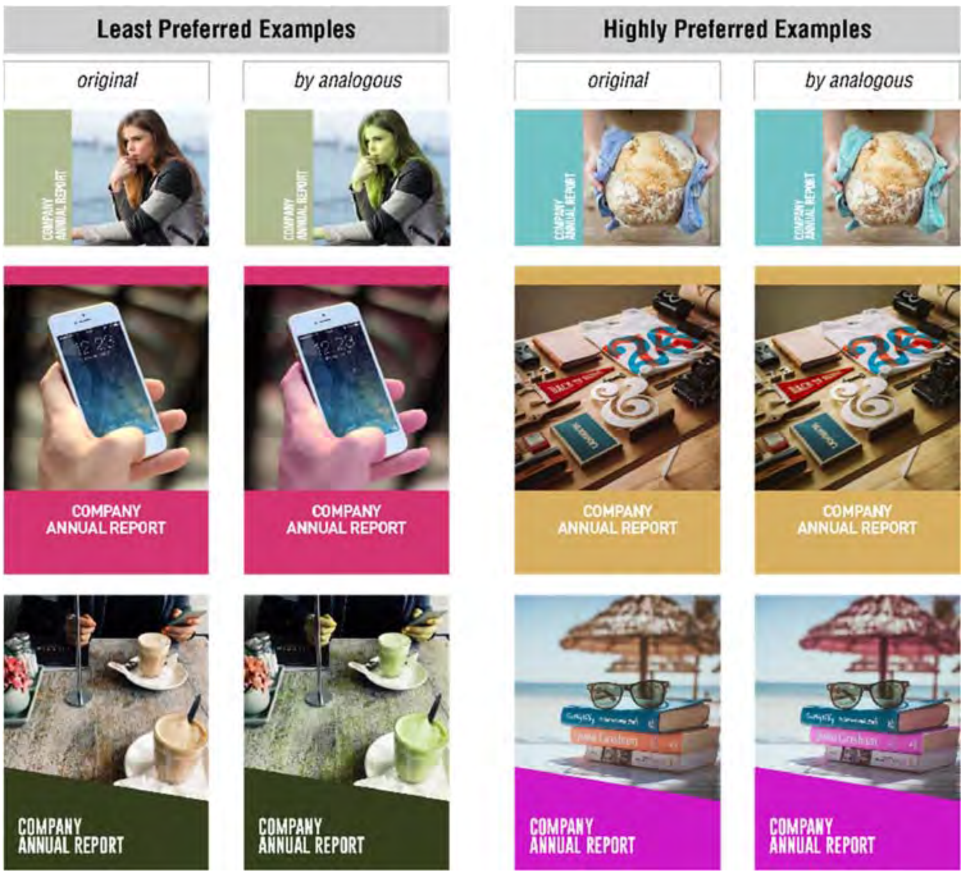


Figure 5.12 Least preferred and highly preferred outcomes by analogous recoloring
When the recoloring is applied to human skin or food, the recolored images received a poor score by users.

5.4.4.2 Results and Analysis

The verbal protocol of participants confirmed the strengths and pitfalls of the analogous recoloring and revealed the potential usages and application of two alternatives. They generally agreed that the analogous recoloring provides desirable outcomes for non-organic objects such as books, clothing, and ornaments. In contrast, images with human skin, animal, and foods were indicated as risky cases that the method may fail. For such risky cases, participants frequently viewed the monochromatic recoloring as a better solution. In addition, two of the designers commented that monochromatic recoloring could be useful when the corporate identity itself should attract more attention than the visual contents. Figure 5.12 shows the representative outcomes that demonstrate the characteristics of least or best-preferred examples.

The application of the complementary recoloring has evoked both critics and appreciation. Except for several incidental cases, the outcomes of complementary recoloring rarely assist the deficiency of analogous recoloring. Regarding its practical usage, participants viewed the complementary recoloring not as an alternative for the analogous recoloring, but as a stand-alone method that provides artistic and creative results. If the user has an evident intent of a certain graphic style, the complementary outcomes can be adapted to enhance the saliency and dynamic impression of graphic works. Notably, three of designers reported its positive function that provides unexpected visual effects and excitement.

5.5 Application of Key Color Generation Method

5.5.1 Prototype of an Automatic Video Editing System

As a prospective application, we adopted our color generation method into a prototype of an automatic video editing system. The system aims at creating a commercial film or a promotional video for local retail stores, which are mainly operated by individual owners. Unlike stores from franchised chains, it is difficult for local retail store owners to manage and update their promotional materials continuously. The video editing prototype allows users to quickly make a promotional video of their retail stores with a video taken by themselves and a keyword of an affective style they want to express (E. Kim & Suk, 2016).

Among various application alternatives, a video editing prototype was chosen for three reasons. First, a video can be viewed as a series of images. In this manner, video is a type of media that an image-based method can be easily extended. Second, the quality of user-generated videos is poor in general. Hence, the performance of the proposed method in enhancing the aesthetic quality of multimedia outcomes can be examined effectively. At last, unlike home videos, commercial films usually have target emotions or styles to express. In this sense, we thought that it is an appropriate application to verify the affective tone-match of the proposed method.

5.5.1.1 Framework of the Video Editing System

Figure 5.13 illustrates the overall flow of the automatic video editing system. It has two pre-constructed databases; one is a shape database of various graphical elements, and the other is an image database regarding diverse themes. Moreover, three types of algorithms or computational methods are embedded as core functions of the system; the first one is a video summarization algorithm, the second one is a color generation method and the last is a set of motion graphic algorithms to combine multiple footages. In this paper, we will only discuss the role and advantages of the color generation method, where the main focus of this study is laid on.

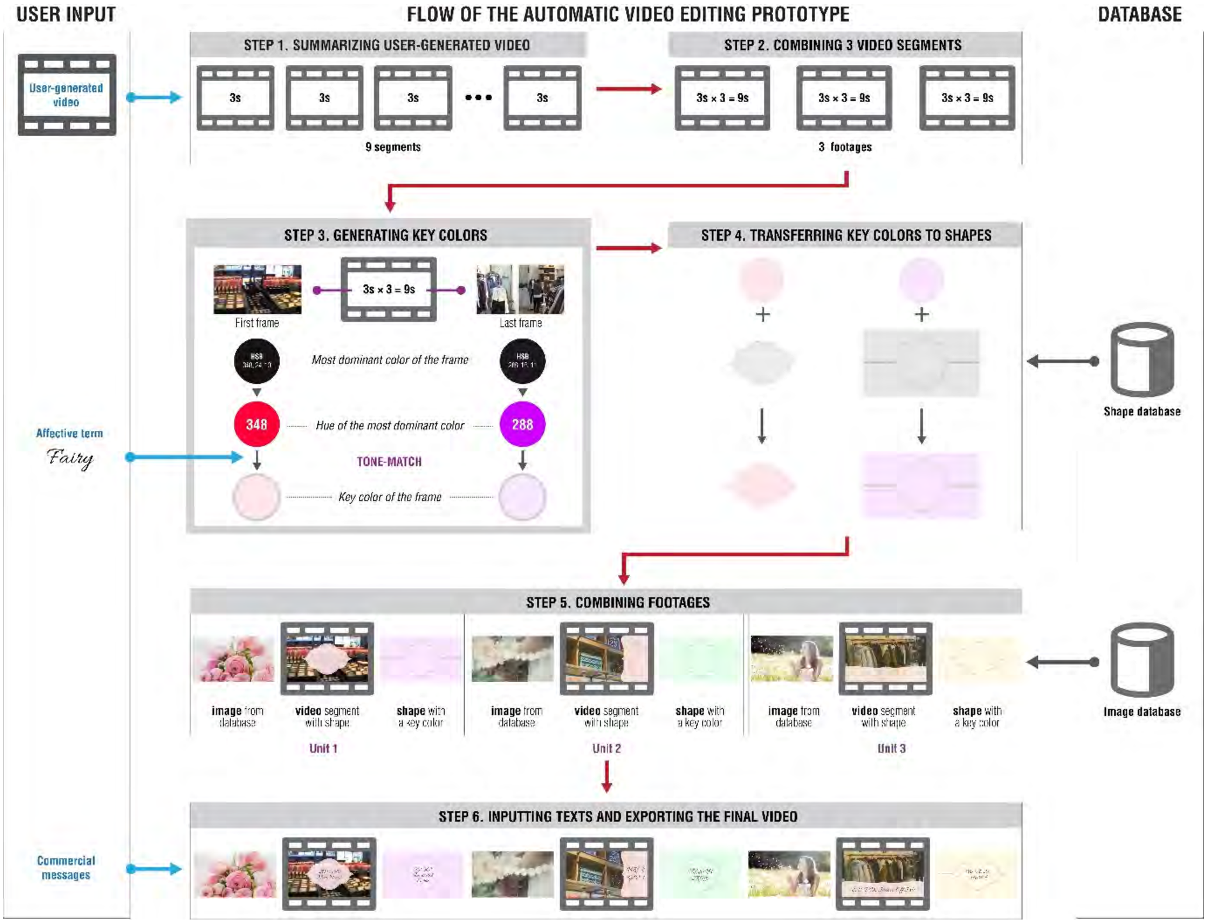


Figure 5.13 Framework of the automatic video editing prototype.
The system requires two types of input – user-generated videos and an affective term – and with this input, it generates a promotional video of which color components are generated by key color generation.

By utilizing the two databases and three algorithms, the prototype generates a video from three types of user input including a user-generated video, an affective term and commercial messages to be presented in the final video. In step 1, the system summarizes the user-generated video into nine segments of three seconds long. Previous studies about the qualities of videos have suggested that the shot length is one of the most crucial aspects that enables people to distinguish the work of professionals and amateurs (Choi & Lee, 2015; Niu & Liu, 2012). Majority of professional video shots are shorter than six seconds, and a shot of three to four second length was appeared most frequently (Niu & Liu, 2012). Base on this finding, we decided to summarize a user-generated video into multiple segments of three-second footage. Then, three segments are combined into a footage of 9 seconds in step 2. This process enables us to construct longer video footages while improving the perceived quality.

Step 3 is the core part that our color generation method contributes. The system captured the first and the last frame from each of 9s footages. For each frame, the proposed method generates a stylized color by extracting the most dominant hue of the frame and matching the tone defined by the affective term. Since two stylized colors are generated for footage, total six stylized colors are generated during this process. In step 4, the system retrieves three partial elements and three full elements from the shape database, and change the color of each shape into a stylized color. For each footage, a stylized color from the first frame is transferred to a partial element, and the one from the last frame is used for a full element. The shape database was constructed by three industrial designers, and the system randomly retrieves six among approximately 100 shapes. In step 5, the system combines all footages including images from the database, video footages, and shapes with the full element. As shown in Figure 5.13, each video footage constructs a unit with a preceding image and a followed full shape. The partial element is overlaid on the video with 10% reduced opacity. Finally, in step 6, a commercial film is created by entering the commercial messages that a user wants to deliver. A motion graphics algorithm plays a pivotal role in these step 5 and 6 to combine each footage into a smooth narrative.

The system involves a variety of techniques, algorithms, and decision making protocols that did not fully described in this paper. The details of them are beyond the scope of this paper. Instead, we tried to provide a brief but holistic view in order to locate the proposed method in the overall system.

5.5.2 Evaluation of the Video Editing System using Key Color Generation

A user test was carried out to examine the benefits of key color generation within the automatic video editing system. The test was composed of two experiments. For the first experiment, we focused on assessing the overall performance of the system in comparison with other automatic video editing systems. The aesthetic benefits of the proposed method were examined in this experiment. The second experiment measured the extent to which the proposed method delivers the desired affective state. Both experiments conducted in a room with a 40-inch display and a supplementary 27-inch display (Figure 5.14). In total, thirty subjects (fifteen males and fifteen females) participated in both experiments, and they were 21.33(± 3.20) old on average.

5.5.2.1 Experiment 1: Comparing Overall Quality of Edited Videos with Others

To assess the overall performance of the system, we searched for comparable services or systems that help users to create a video with few steps. As a result, we identified three alternative systems. The first one is *magisto*, an automatic online video editor that turns videos and images into an edited film. Although the solution of *magisto* does not perfectly fit the commercial film, it was selected due to its popularity with more than 70M users. The second one is *Shakr*, which provides hundreds of video design templates specialized for a business purpose. Up to our best knowledge, *Shakr* showed the highest similarity with our system in the aspects of considering target emotions for a promotional purpose. The last one is *MagicInfo*, a bundle software of a digital signage display manufactured and sold by a well-known global company. Unlike prior two systems, it offers a set of images that represent diverse retails. Using these images, the user can create a promotional video without taking any footage of themselves.

Figure 5.14 Display setting of experiment 1.
In 40-inch display, one of the four promotional videos was played while the 27-inch display was showing the entire four variations.

Stimuli

Utilizing these three systems and ours, we prepared four variations of commercial films for each of seven retails. Table 5.5 shows the seven pairs of a retail and a target affective state. We used the same images, user-generated videos and commercial messages for retail. However, commercial messages were not included in *magisto,* and videos were not utilized for *MagicInfo* due to their functional limitation.

Table 5.5 Comparison of four video editing tools including the proposed prototype.
The underlined ranks indicate ties.

Video Editing Tool	Suggested Prototype	Shakr	magisto	Magic-info
Aesthetic Quality	2nd rank	1st rank	2nd rank	4th rank
Attention Capturing	1st rank	2nd rank	3rd rank	4th rank
Message Deliverability	1st rank	2nd rank	4th rank	3rd rank
Preference	1st rank	1st rank	4th rank	3rd rank

Procedure

Each participant saw one of the commercial films presented in a 40inch display. For each retail, four variations of commercial films were presented in a random order. A supplementary 27inch display was used to play four variations together on a screen (Figure 5.14). After watching four variations, participants asked to rank them in four aspects; aesthetic quality, attention capturing, message deliverability and preference as a commercial film. The researcher has devised these four criteria based on several studies that have investigated the quality and effectiveness of advertisements with diverse perspectives (Ma et al., 2009; Moorthy, Obrador, & Oliver, 2010; Pawlowski, Badzinski, & Mitchell, 1998).

Results and Analysis

The ranking data of each evaluation criteria was analyzed with a Friedman test, and multiple Wilcoxon signed rank tests for post hoc analysis. Table 5.5 summarizes the results of the analysis.

For **aesthetic quality**, a Friedman test showed a significant difference among four types of commercial films ($\chi^2(3) = 106.68$, $p < 0.05$). Wilcoxon signed rank tests showed that *Shakr* ranked as significantly better than our system ($Z = 2.50$, $p < 0.05$). There was a significant difference between ours and *MagicInfo* ($Z = 6.69$, $p < 0.05$), while there was no significant difference between ours and *magisto*. There was a statistically significant difference in **attention capturing** among four variations (χ^2 (3)= 150.15, $p < 0.05$). Our system received significantly better ranks compared to the second-ranked *Shakr* ($Z = 3.50$, $p < 0.05$).

For **message deliverability**, a Friedman test showed a significant difference (χ^2 (3) = 273.41, $p < 0.05$). Our system ranked significantly better than any other services, especially in comparison with the second-ranked *Shakr* ($Z = 5.50$, $p < 0.05$). Finally, for the **preference as a commercial film**, a significant difference was confirmed (χ^2 (3) = 121.96, $p < 0.05$). Our system ranked significantly better than *MagicInfo* ($Z = 6.65$, $p < 0.05$), but was not significantly different with *Shakr*.

In general, the performance of our system and *Shakr* were quite comparable, while *Shakr* has a competency in aesthetics and ours has strengths in message deliverability and promotional preference. Although it is hard to discriminate the effect of the color generation method in the entire system, stylized colors may have a strong influence on the aesthetic quality and attention capturing rather than the message deliverability. In this regard, it seems like that the color generation method requires an improvement in constructing an aesthetic harmony with a given visual content.

5.5.2.2 Experiment 2: Assessing Affective Quality of Edited Videos

The goal of the second experiment was to assess the performance of the video editing prototype in delivering a desired affective state. As shown in Table 5.6, seven retails were targeted same as the first experiment and three different affective terms were tested for each retail. Accordingly, a total of 21 films was prepared using the video editing prototype. Figure 5.15 shows the exemplary scenes of fashion retail films. Although each film has used the same user-generated videos, stylized colors with different tones provide distinctive and satisfactory visuals for all three cases.

Procedure

Each participant watched one of the 21 commercial films and asked to mark two to four keywords that describe the affective state or the style of the film. For each film, we provided a list of eight affective/style terms including a term that the film initially targeted. The affective terms were derived from the word set of Color Image Scale developed by Kobayashi (Kobayashi, 1991). This process was repeated for all 21 films.

Table 5.6 Retail categories and three style keywords for each retail.
Highlighted cells indicate films that have expressed the target emotion successfully according to the assessment results.

Retail Category	Style Keywords for Each Retail		
Fashion	Feminine	Flamboyant	Sporty
Leisure	Enjoyable	Noble	Natural
Medical	Gentle	Trustworthy	*Modern*
Living	Classic	Dynamic	Tranquil
Restaurant	Traditional	*Modern*	Fresh
Performance	Elegant	Fiery	Progressive
Education	Cheerful	Free	Intellectual

Results and Analysis

We compared the participants' selection with the affective terms which were targeted originally. Among 630 trials (30 participants × 21 films), 553 were correct matches with the target emotions, which indicate 87.78% of agreement. We analyzed the responses for individual films as well. The frequency of selected words was calculated in order to identify the most frequently chosen word for each film. The results showed that 15 films successfully delivered the target emotion as the most appealed one. These films are highlighted in Table 5.6. Among them, seven retails were targeted same as the first experiment, and three different affective terms were tested for each retail. Accordingly, a total of 21 films was prepared using the video editing prototype. Figure 5.15 shows the exemplary scenes of fashion retail films. Although each film has used the same user-generated videos, stylized colors with different tones provide distinctive and satisfactory visuals for all three cases. In cases of four films, the target term was ranked as the second, and the remaining two films were better described by two other terms than the original one.

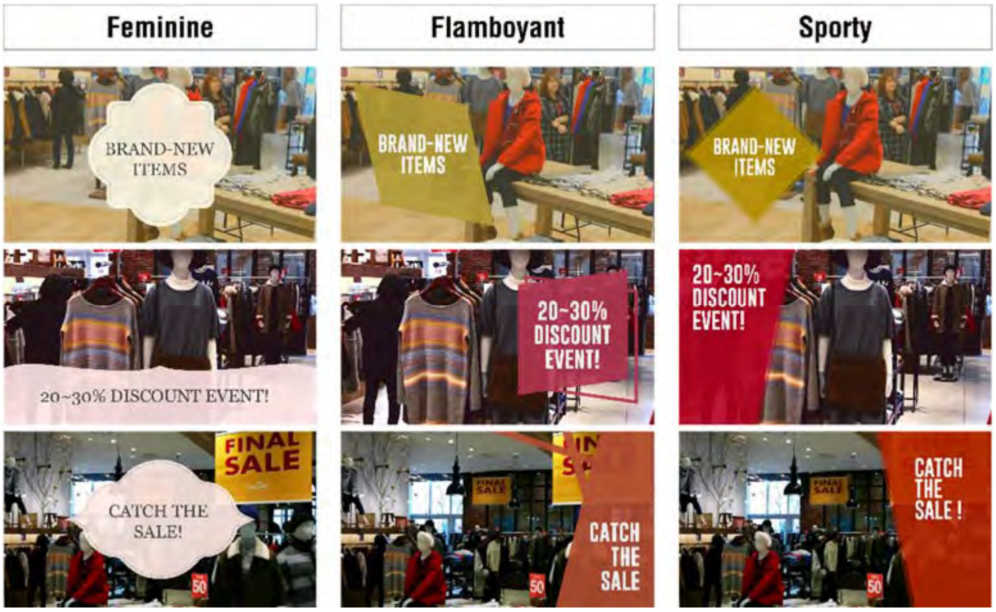


Figure 5.15 Exemplary scenes of videos generated by the prototype.
The key color generation produces different colors with the same source video depending on the style keywords.

According to the results, it seems like that the prototype performs well in creating commercial films to deliver the desired emotion in general. However, the detailed analysis shows a possibility of confusions and misleading about the affective state the film wants to express. In particular, two films – *sporty* in fashion retail, *trustworthy* in medical retail – were not successful enough to deliver the target emotion.

There could be several reasons for this. First, certain contents may have a higher variability due to the subjectivity of people's perception of films and interpretation of keywords. In the perspective of color generation, it implies a limitation of the tone-match process. The method now uses colors crawled from Adobe Color CC, and the collected dataset reflects the characteristics of a given affective term but does not the context of retails. Hence, the tone of a stylized color defined by the dataset may not be suitable to the context of a specific retail. In fact, the affective state *modern* was fully expressed in medical retail while it was not fully delivered in restaurant retail (Table 5.6). In addition, the amount of colors we used was quite limited, and they were constrained in the Adobe Color CC database. To improve the performance of the tone-match process, more diverse data sources can be incorporated. It is expected that a context-specific tone match with a larger database might suggest a more persuasive tone of a stylized color.

5.6 Application of Image Recoloring Method

Throughout this study, the researcher has investigated image-color harmony when both of image and color are presented together in a scene. As described, studies regarding the performance and practicality of image-color harmony shown that well-harmonized image-color pairs could improve the perceived aesthetics and attractiveness. Then, do harmonized image and color still have association even if they are presented separately? To respond this question, we have explored a probable situation that harmonized images are presented independently. Moreover, the researcher surveyed to investigate whether harmonious image-recoloring could improve association of a certain brand with its indirect promotional pictures.

5.6.1 Embedded Marketing: Implicit Promotion

Nowadays, we are quite familiar with embedded marketing, also known and product placement, which is a promotion technique to advertise specific brands or products by incorporating them in a wide range of media such as a film or a television program. Not only the product placement, but companies and brands also sponsor a sports team or host a big social event to advertise their names. The entire promotional activities of a company are solely about promoting their items and evoking positive responses from the target customers. Although a company spent a huge amount of budget, however, if they failed to associate the company identity with the promotional materials clearly, the promotion might bring nothing.

For instance, Figure 5.16 show promotional pictures distributed by ETIHAD Airways, UK Labour Party, and Petronas AMG, the F1 racing team. Even though they distributed these photographs to announce an award-winning, a voluntary event or a company news, it is challenging to recognize their brand or party from the pictures without further information. In general, the public relation managers distribute press messages in relation to these pictures, but people often skip text messages and sometimes refuse to read the full length of the article. In this regard, we have investigated whether harmonious image recoloring could enhance a brand recognition even images are independently presented with the brand identity or not.

Figure 5.16 Promotional pictures distributed by each brand that brand identity is not revealed explicitly.

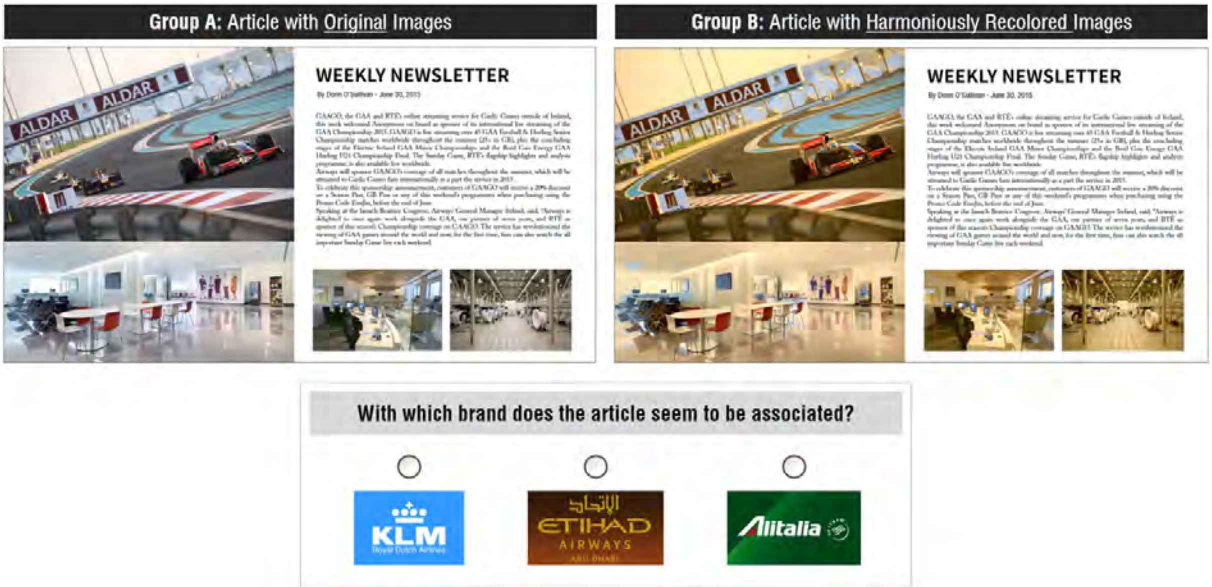


Figure 5.17 An example of stimuli used in survey - article type

The left side example is a mock article using original images while the images of the right one are recolored one to be coherent with the brand color (ETIHAD AIRWAYS). The entire contents of the article were anonymized.

5.6.2 Method

5.6.2.1 Participants

In the experiments, a total of 52 people (32 males, 20 females) participated. The average age of the participants was 22.11, and the standard deviation was 4.54.

5.6.2.2 Materials

From a variety of brand or media websites, promotional photographs were collected. To avoid recognition or association by text or brand logo, we only collected photographs that include implicit contents about a brand. As a result, a total of ten brands-related photographs was collected. Then, analogous recoloring was applied to the collected photographs to make them harmonious with the brand identity color that each picture is related. By doing so, we obtained two types of photographs for each brand – one is an original image set, and the other is a harmonious recolored image set. Using the image set, we make a mock article (Figure 5.17) or a photo stream (Figure 5.18) for each brand.

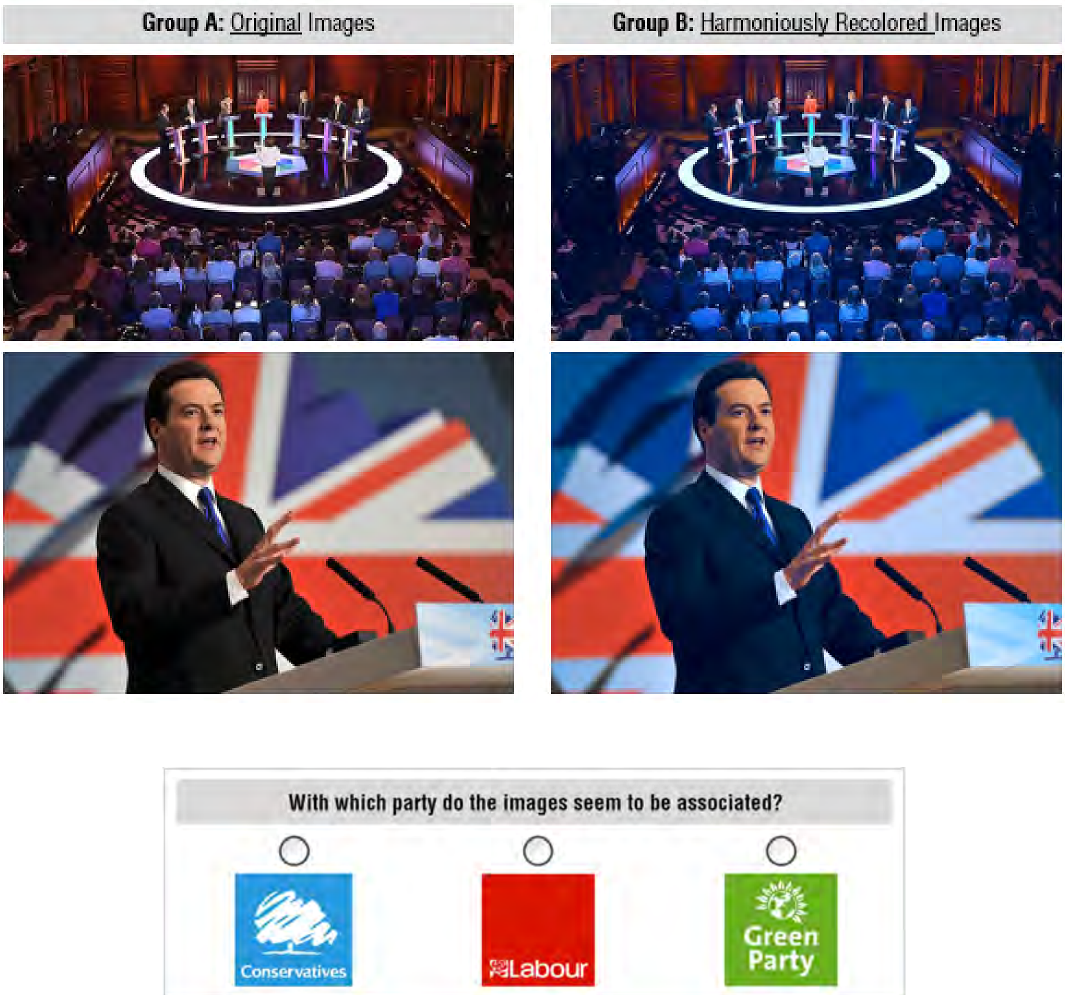


Figure 5.18 An example of stimuli used in survey – image type
The images of the left side are original images while the right-side images are recolored one to be coherent with the identity color of the UK Conservative party.

As similar to photo collecting criteria, the contents of all articles were anonymized not to provide any clue to guess the brand. To summarize, the stimuli were composed of two different types – original type and recolored type, and each type includes five articles and five photo streams that implicitly promote a brand.

5.6.2.3 Procedure

The experiments were conducted as an online survey. For each of 10 brands, each participant viewed one of original or recolored type of promotional contents. After reviewing the contents, they were asked to choose a brand that seems to be associated with the contents they watched in prior. For every question, three brands were presented with their logo, and participants had to select one of them. If a participant has recognized a person or a context in the photograph, we asked them to report it since his/her judgment could be highly biased by prior-knowledge.

5.6.3 Results and Analysis

From 52 participants, total 512 responses were collected. Among them, 248 responses were based on original type stimuli, and the rest of responses – 264 answers – was based on the recolored type stimuli. Since the number of responses for each brand is not equalized, we calculated the proportions of correct responses that successfully associate the photographs with the proper brand. Then, a two-sample t-test between proportions was performed to determine whether there was a significant difference between original and harmoniously recolored images with respect to the percent of correct association with the brand. The result suggests that the association rate using harmoniously recolored images (46.21%) is significantly larger than the rate of original images (20.56%), t (510) = 6.13, $p < 0.05$). This indicates that making images harmonious with a brand identity can positively contribute to the brand recognition even without an explicit manifestation.

Due to the increase of obtrusive product placements, there are several studies that report the adverse effects of extrinsic promotion of a brand or a product (Cowley & Barron, 2008; d'Astous & Chartier, 2000). Considering the ambient effect of the harmonious recoloring, it is expected that this could be an alternative solution to communicate brand identity without evoking negative responses.

5.7 Discussion

5.7.1 Performance of Key Color Generation Method

Regardless of the database used for tone-match, the results of user tests showed that the proposed method is good at selecting stylized colors but relatively poor at selecting aesthetic colors in comparison with designer' colors. To be specific, regarding the aesthetic quality, the designers' choices were more appreciated than the colors generated by the proposed method. In the present study, we devised a simple k-means clustering to extract the most dominant hue of an image. Although the method provided us simple and acceptable solutions, it does not consider the spatial information and saliency of each pixel that has been highlighted in designers' color generation process. A more elaborated method will be explored further using a knowledge base of computer vision studies. In particular, studies related to saliency (C. Huang et al., 2011; Z. Liu, Le Meur, Luo, & Shen, 2013) and human perception (Lin & Hanrahan, 2013) could be employed in the process of improving hue-prioritization method.

In the case of affective quality, the proposed method has a strength in expressing desired affective states in comparison with designers. It indicates that exclusive engagement of tone and affective term could have practical benefits and potential. Compared to previous color extraction methods, the proposed method can generate a wider range of colors by assigning a tone regardless of the color features of images. This could provide more creative and insightful alternatives for color generation of multimedia production. For future study, an extension of this method will be explored by refining the tone identification process and utilizing a wider range of resources. In particular, prior knowledge of color emotion could be used to process and filter possible noise of crowd-sourced data (Kobayashi, 1991; Plutchik, 1980).

5.7.2 Performance of Harmonious Image Recoloring

Figure 5.19 shows representative cases that illustrate the key advantages of each adjustment method. As indicated by the results of two user tests, the analogous recoloring generates widely acceptable results that satisfy both aesthetic quality and harmony with the target color. In particular, color adjustment of nonliving

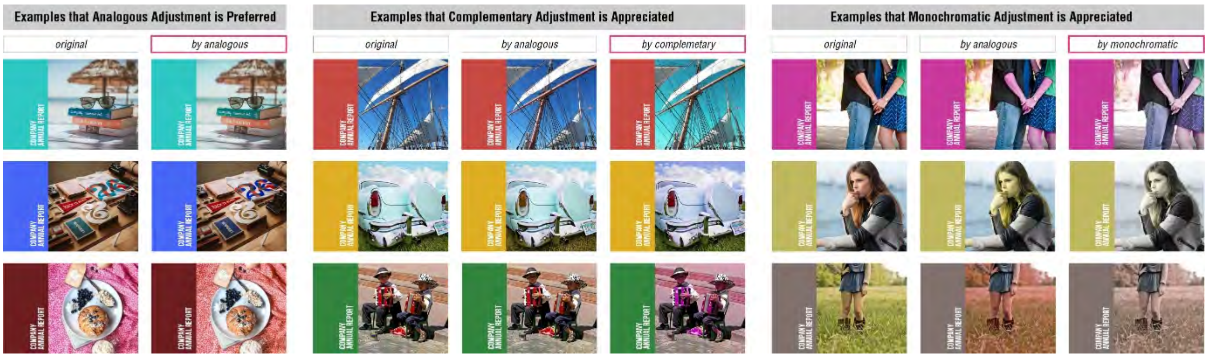


Figure 5.19 Representative outcomes of three aesthetic image recoloring methods.
From left: examples that analogous recoloring is preferred; examples that complementary recoloring is appreciated; examples that monochromatic recoloring is appreciated.

objects such as books, clothing, and vehicles were acclaimed for its faithful and smooth local color transformation. Contrary to nonliving objects, objects involving the human skin, foods, and animals exhibit a resistance even to minimal hue changes because of their rigid memory colors. When a recoloring is applied to human skin or food, the analogous recoloring has received negative responses. Restraining the color adjustment of certain colors could be a possible solution to this problem. However, it can increase the probability of color discontinuity as well as artifacts across the regions. To provide a robust and faithful solution, we expect that a semantic analysis or a user-assisted method is embodied in the future study.

The complementary recoloring was least preferred in comparison with other approaches. The result of the first user test showed that the complementary recoloring is generally preferred when it has the least influence on the original colors because of the minimal amount of color adjustment. On the other hand, the second user test revealed practical benefits of the method. Due to the high contrast between an image and a target color, the results of complementary recoloring produce color discord that can be visually disturbing and disharmonious. Several participants of the second user test pointed out this aspect as a unique property of the complementary recoloring. They mentioned that such color discord could bring an excitement and visual saliency to design, which are significant factors to be notable among numerous visual contents. Furthermore, it provides opportunities to explore unexpected visual effects that designers rarely try voluntarily. In this manner, the researcher believes that the compliment adjustment can be used to support designers' ideation process to inspire a new and interesting graphics style.

The results of user tests imply that the monochromatic recoloring functions can be a good alternative to the analogous recoloring. By reducing the saturation of the entire image, the monochromatic recoloring has an apparent benefit to moderate the negative impression by color changes of human skin and natural things. It generates gentle and subdued outcomes throughout cases. Thus it has received least amount of negative responses in comparison with other adjustments. Additionally, the monochromatic outcomes were suggested for a distinctive design purpose, for instance, when a company wants to highlight its brand identity rather than the image itself. Table 5.7 summarizes the key characteristics of three recoloring mentioned in this paper.

By providing maximum three results with the same input, the proposed method supplements the limitation of a single solution, and more significantly, it contributes to the expansion of design capability of both novice and expert users. For novice users, it is expected that the proposed method can provide satisfactory outcomes that can be utilized in their graphic design in harmony with their identity color. In the case of experts, our solution can be an insightful starting point to proceed to additional editing.

Table 5.7 Characteristics of three adjustments with its representative examples.

Adjustment	Analogous recoloring	Complementary recoloring	Monochromatic recoloring
Characteristics	 Providing harmonious outcomes in general with the minimum amount of color changes of the image.	 Deriving an excitement and tension to graphic outcomes from the color discord.	 Providing gentle and stable harmony while making the target color more significant and salient.
Strength	Providing satisfactory and generally acceptable outcomes that enhance the aesthetic harmony of a wide range of image-color pairs.	Providing impressive and distinguished appearance. Good inspiration sources to explore novel and exotic styles.	Reducing the perceptive resistance of the color change of skin and foods. Providing a coherent look that emphasizes the target color.

5.7.3 Practicality of the Proposed Methods and Their Broader Applications

5.7.3.1 Utility of the Proposed Methods in Design Practice

In this dissertation, a set of methods was proposed to achieve image-color harmony. The first method generates a key color according to a given input image, and the second method recolors an image to achieve harmony with a target color. Figure 5.20 shows screenshots of a stand-alone application of the proposed methods. Since the entire algorithm was built on Matlab environment, the application was created using Matlab compiler and Matlab GUI builder. As shown, the application offers two algorithms on the main page. If key color generation is chosen, the application requires an image input and displays top five colors which are generated by the method. In the case of image recoloring, the application requires two inputs – an image and a target color – and offers download of three recolored outcomes.

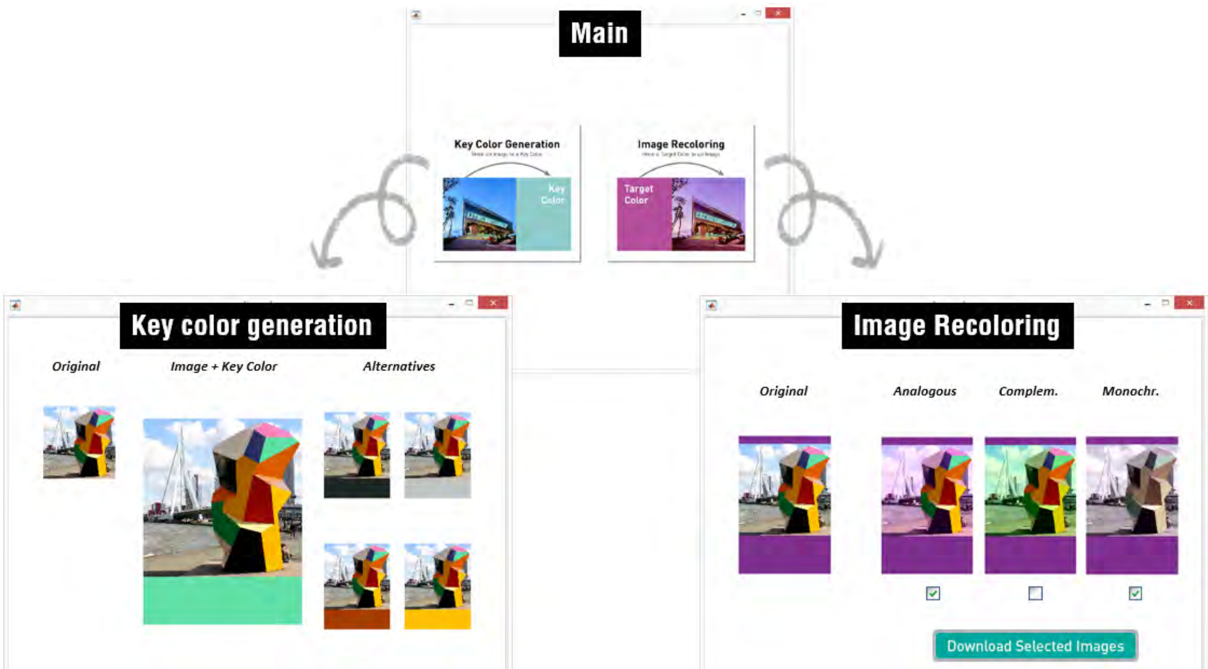


Figure 5.20 Screenshots of a stand-alone application of the proposed methods.
The proposed methods were built on Matlab environment. Using a Matlab compiler and GUI builder, a stand-alone application was made to demonstrate key color generation (left) and image recoloring (right).

In order to assess the practicality of the proposed methods, a semi-structured interview was conducted with a total of ten users of the platform. Each user was asked to utilize the application at least ten times, and then participated in the face-to-face interview while reviewing the features of the platform. The average age of the participants was 23.45 with a standard deviation of 2.71, and the half of them had received design education for at least two years.

In the case of users who have not received design education, they appreciated outcomes from both methods. They mentioned that the application highly reduces their burden in selecting a proper color or in adjusting an image by providing a set of reliable alternatives. These responses indicate that general users could use the outcomes of the proposed method as a design solution without further editing. Contrary to the general users, design students who have received more than three years of design education viewed the application as a tool that provides inspiration sources or a starting point for additional editing. Although they generally agreed or satisfied with the outcomes of the application, they manifested their desire to elaborate the outcomes by themselves to achieve a more personally preferred or a more stylish outcome.

For instance, in the case of key color generation, the users said that the application provides a good summary of the probable key colors by displaying top five colors with the image. It highly reduced the cumbersome tasks of designers to explore and compare alternatives at the early stage of color selection. Instead of using the colors directly, however, designers wanted to elaborate them in order to improve the aesthetic harmony or to reflect their personal taste on the result. This implies that the proposed method and the associated application can be used as a tool which provides fundamental resources for design tasks. In a more advanced perspective, the application can be a platform that provides a large body of alternatives on the paradigm of generative design.

Designers showed a more interest in the image recoloring outcomes than the outcomes of key color generation. Since the image recoloring jobs usually require more time and efforts than a color generation, they viewed that the automation of recoloring has a great benefit for designers. Due to the time and efforts, a single recoloring requires, in practice, it is almost impossible to try more than two recoloring jobs and compare them. By producing three outcomes based on the proposed method, it is expected that the tool can greatly enhance the utility and practicality of the advanced recoloring method. Despite its great utility, designers still had a desire to manipulate the outcomes further. One of the probable function suggested by two users was a function that adjusts the degree of recoloriung amount for each strategy. By doing so, designers wanted to elaborate the outcome to reflect their intention and personal preference better. Thus, in future, additional features such as a controller that alters the amount of adjustment or a region selector to include or exclude a certain region of an image in adjustment could be supplemented.

At current, the application and also the methods yet have been tested in a wild. A series of user tests conducted inside of a lab has revealed limitations of the proposed methods that should be resolved in the advanced study. It is expected that the methods and the application can be improved further based on the findings from the lab-base studies. Addition to the improvement, longitudinal and contextual user studies are required beyond the boundary of the laboratory in order to properly assess its practicality and usability in design education and practice.

5.7.3.2 Future Research Issues for Technical Improvements

In computer vision and image processing discipline, a variety of color extraction methods have been developed and verified. By utilizing established knowledge of the field, we will fully considered the various color features that images possess. In addition to color features, contextual information will be considered in the future study. We noticed that similar colors could evoke distant feelings depending on the objects that each color represents. For instance, yellow from fruits was regarded as warm and tender, while the yellow from a New York taxi was rarely associated with warm and tender images. By incorporating the meanings and contexts of a given content, hue-prioritization method could be strengthened in order to produce persuasive results for various contents. In addition, other types of images such as drawings and illustrations could be used for further investigation.

For each keyword, the current method utilizes 200 colors from the searching results of Adobe Color CC® database. Although we selected these colors based on their ratings in the most recent database, several pitfalls should be handled in the future study. First of all, 200 colors may not be enough to gratify the comprehensive needs and wants of users considering the diversity of colors and emotions that people pursue. Increasing the number of colors used can be a possible solution, but it also increases the amount of possible noises that crowd-sourced data innately has. Especially the data from Adobe Color CC has possibilities of an internal dissonance, since there could be a discrepancy between the emotion of a color theme and the one of an individual color belongs to the theme. In order to maximize the benefits of a crowd-sourced data, we will firstly filter the database by employing acknowledged color emotion theories and increase the number of colors that to be used for the tone-match step. In addition, real-time data crawling could leverage the advantages of a crowd-sourced database, which is susceptible to changes and adjustments. Moreover, each affective term can be interpreted differently depending on the contexts, retails and events the term is used for. The context-specific color searching process can enhance the congruency between desired emotion and retrieved colors.

5.7.3.3 Implications for Multimedia Production

Contrary to previous color extraction studies, the proposed color generation method can generate colors beyond the color features of a given images due to the tone-match. This feature makes the proposed method novel and be capable of generating creative color solutions. We believe that this feature could bring not only a wider range of alternatives but also unexpected insights to designers in the multimedia discipline. Our color generation method also showed a possible extensibility across content types. Although it has developed based on image database, it generates acceptable solutions with videos. This implies the compatibility of a color generation method with various visual contents. As a starting point, we hope that this paper inspires localized works in diverse multimedia domains to fully enjoy the aesthetic and affective effects of colors. Lastly, a versatility of crowd-sourced data was introduced in multimedia production. The tone-match method highly depends on the external databases constructed by crowds. By employing the knowledge of crowd-sourced data, the method has dynamic and evolving properties that respond to the situations, trends and even to target users. For the future investigation, utilization of social data can be a possible direction to suggest a customized solution for each user.

5.8 Summary

In this chapter, a comprehensive evaluation of the proposed method was performed through a series of user tests. Both of key color generation method and image recoloring methods were evaluated in perspective of general users, and the results revealed that the proposed method has strengths in providing a harmonious image-color harmony without people's engagement. Also, applications were proposed and evaluated whether the proposed methods provide satisfactory outcomes for a more complex and practical context. In particular, key color generation method was adopted to a promotional video editing system, and image recoloring method was applied for embedded marketing purposes. The results of user test have shown that both of applications improved attractiveness and recognition of promotional contents. This suggests that the proposed methods also may bring practical benefits when they applied to complex systems in the wild. ■

6 DISCUSSION

6.1 Overview
6.2 Implications of Designers' Practice
6.3 Applications of the Proposed Method
6.4 Summary

6. DISCUSSION

6.1 Overview

In the studies to understand and create image-color harmony, two types of research outcomes were majorly produced. The first outcome is a conceptual model that describes the process of creating image-color harmony. The model also includes a variety of features related to the perception of images and colors regarding their visual aesthetics and semantic. The second outcome is a set of computational methods to achieve image-color harmony automatically. By adopting techniques of image processing, methods to generate a key color and to recolor images were proposed to emulate a portion of practical knowledge identified from the process of designers.

Based on these major outcomes, this chapter provides a more generalized and broader perspective to discuss the implication and impacts of this research. Firstly, the implications of understanding designers' practice will be discussed to explore not only the academic values but also the practical benefits. As mentioned previously, the findings from designers were not fully transferred to the method development due to the idiosyncratic and multifaceted aspects or their irrelevance toward the method development. What kind of learnings or implications could we have from such findings? In particular, this chapter focuses on the implications for design authoring tools and design problem (context).

Regarding the methods proposed, this chapter particularly focuses on their applications and practical impacts. In the previous chapter, the methods have been applied to promotional contexts, and the user tests revealed that they showed satisfactory performance in relation to the specific purpose of promotional contents. Beyond the context investigated, this chapter suggests and envisions a broader range of applications that could be benefitted by achieving image-color harmony.

6.2 Implications of Understanding Designers' Practice

6.2.1 Implications for Design Tools

Firstly, the understanding of designers' practice suggest implications upon the development of tools and further studies to support visual design process for both novices and experts. The implications are classified into three categories: how to support the utilization of images, how to improve the ways of color manipulation, and how to provide a better way to explore alternatives.

6.2.1.1 Supporting Comprehension of Image Colors

Although an image has a bunch of color features, only a few attracted designers' attention and involved in the design process. In general, dominant or salient color features were mainly considered, and hues received more interests than the features of tone. The Eyedropper tool was the one and only tool that designers utilized to explore and simulate the color of an image.

Considering the repetitious actions of designers using the Eyedropper tool, it seems like that there is a disagreement between the purpose of the task and the capacity of the tool. The Eyedropper tool is suitable to extract a single color from few pixels but does not fit to extract multiple colors from a broader range. In the perspective of color perception, designers' main interest was the distribution of the color in order to identify dominant or salient colors. Instead of the eyedropper tool, an instrument that displays the distribution of colors or summarizes the color features of a broader space could be an alternative.

A function that automatically extracts several colors and presents them along the image could be one of the solutions that minimize the designers' effort to identify representative colors. Fortunately, Adobe Capture CC (2017a) provides the function that allows users to extract five-color themes and utilize the theme throughout the Adobe platform. However, the prime features of the service are not sufficient to aid the perception and utilization of image colors. To better represent an image, the number of colors in a theme could be flexible. In addition, the size of color swatches can be differed depending on their dominance or saliency in order to represent the importance of each color.

In addition to the color features of images, designers frequently devised semantic-focused perspectives. Advanced technologies related to object detection may replace a part of designers' ability within an automatic design system. However, the semantics that designers reflect upon an object or a context is significantly complicated and yet fully investigated. Further research is required to understand the way that designers deploy the semantic perspective and the tactics utilizing the semantics to construct a compelling narrative. Moreover, its relevance and values should be investigated more profoundly in prior to introducing such technology into the graphic tools for designers.

6.2.1.2 Providing Flexibility to Color Manipulation Interfaces

Regarding the tool used, the crafting of a color was mainly performed on the plane of Color Picker. When designers explore the multiple colors and try to prioritize them, it seems the Color Picker provides an adequate amount of usability. It has a hue slider that alters the hue value only, and this offers easy transitions among distant hues. Since designers depicted a greater interest in hue features rather than the brightness or saturation, providing an independent instrument seems like a good strategy. As design process proceeds, designers rarely made a huge movement on color features. Instead, they kept simulating alternatives with minimal differences and tried to identify the most satisfactory color. In this stage, the Color Picker has shown limitations in assisting the delicate manipulation of colors. The easy transition benefited from a hue slider shifts to a limitation which discourages a further elaboration of the hue feature. Few designers made attempts to adjust the numerical values of a color, but a majority of designers prefers to utilize the graphical user interfaces. Even a designer (D15) who used the numeric values commented that manipulating numbers do not provide any sense of perceiving and elaborating a color. He also mentioned that it is almost impossible to correlate the changes in color values with the ones in the appearance of a color.

Considering these issues, GUI (Graphic User Interface)-based color tools seem to be preferred by designers, because of its conceptual coherence as well as its usability. On the basis of the current interface, providing a zoom-in or magnifying ability would be a good strategy to flexibly respond to designers' needs upon color manipulation.

In a more radical way, providing a three-dimensional representation of a color space could be a significant change that breaks the limits of two-dimensional space. In general, colors are designated by three-dimensional color spaces such as RGB, HSV, and CIELAB. Thus, a three-dimensional representation could be more natural and intuitive to understand the relationship between color features and the distance between two colors. By granting a controllability over the entire features of a color, the final elaboration color could be largely smooth and fluent.

6.2.1.3 Archiving Design Moves for Alternative Exploration

In general, we also identified that there is no sufficient space to review the changes made and compare several alternatives generated from such changes. In particular, there was a limitation to compare multiple image-color combinations together in the middle of the design process. Because of this limitations, designers inevitably chose to narrow down their alternatives into two, and compare them by switching between two colors. This caused repetitive operations since designers were not able to compare even two alternatives together.

Considering the iterative nature of design process, providing a repository to save and retrieve their design movements can aid designers to manage the entire design process effectively. Even in the Color Picker, designers made a number of trials to pick a color. However, none of the trials are recorded or successively displayed during their actions. By recording the traces and presenting them properly, the tool can promote the reflection of designers that increases the design-driven activities and brings new insights (Rittel & Webber, 1973; Self et al., 2016).

It also would be useful to provide a space to juxtapose several alternatives to compare and evaluate the integrated design outcomes. In the case of our experiment, an image-color combination was a design outcome for each of the task. Thus, it was important for designers to view the image and the color together. In general, graphic design practice often incorporates different types of resources and elements. Enabling parallel comparison among various combinations of multiple resources could improve the compatibility of a graphics tool and enlarge the design space of designers. There also have been several studies related to the benefits and advantages of providing alternatives in parallel (Dow et al., 2012; O'Donovan, Agarwala, &

Hertzmann, 2015; Todi, Weir, & Oulasvirta, 2016). Based on the knowledge from these studies, a future study can be advanced further in order to suggest a novel tool for graphic design practice.

6.2.2 Importance of Considering Distinctive Design Contexts

The findings of previous experiments have revealed the unique characteristics of harmonious image recoloring in comparison with aesthetic recoloring. In terms of designers' practice, harmonious image recoloring makes designers less loyal to the original image colors as compared to the aesthetic recoloring, and also reduce their preferred tendency toward naturalness and vividness of the image itself. Among several color features, the hue feature was more actively adjusted in harmonious recoloring cases rather than aesthetic ones. A local recoloring approach was exclusively found in harmonious recoloring contexts. In additions, there were also a few cases that artificial effects such as brush strokes were applied to maximize the integrated aesthetics of an image and a color. These findings are also well-agreed with the insights that have adopted to develop image recoloring method.

In the perspective of general users who judge the quality of outcome, it was also shown that the presence of a target color alters their judgment criteria. Since there was no qualitative or in-depth investigation regarding the reason for changes, it is hard to clarify the factors that influence their judgment regarding their preference. However, the significant changes in their preference indicate that aesthetic recoloring could not be a good solution when a certain color is dominantly utilized along with an image.

6.3 Impacts and Applications of the Proposed Methods

This section firstly visits the impact of the proposed methods in design practice in the perspective of design practice and education. Then it provides a number of application ideas inspired by key color generation (Section 6.3.3) or image recoloring (Section 6.3.2) in order to illustrate how such methods enhance user experience and interaction in perceiving visual content in digital platforms.

6.3.1 Implications of the Proposed Methods in Design Practice

6.3.1.1 Utility of the Proposed Methods in Generative Design Paradigm

Due to the improved programming environment and related technology, the generative design is now becoming more popular and important in the design discipline. Based on an algorithm or a rule, a generative design system can create variations that can satisfy the predefined design goal. The process or capability of generative design enables designers to obtain a wide range of alternatives beyond what a single designer alone could create, to achieve an effective design process.

On this paradigm, a range of approaches has been investigated, mostly at the laboratory stage (Gruber & Russell, 1996), and the proposed methods of this study are also included as a case of those attempts. In order to develop an effective and practical system for generative design, it is important to establish a concrete and reliable rule that represents design knowledge and rationale in a comprehensive manner. Then the knowledge should be transformed into a utilizable format for the generative system. Moreover, this study has tried to address these issues by deploying both quantitative and qualitative methods in capturing and transforming the design knowledge into a computational algorithm. Throughout the method development process, several quantitative factors should be fixed. The bandwidth value of mean-shift segmentation is an example of them. Depending on the bandwidth value used for mean-segmentation, the number of color palettes and the color values are changed. Although this study has employed a fixed bandwidth value, the proposed method can provide a large number of feasible solutions by diversifying the bandwidth value. The values of other factors including the quantization units, kernel estimation, and a saliency measure also can be flexibly changed to provide various outcomes. In this manner, it is expected that the method can be a basis of generative design for image-color harmony.

6.3.1.2 Implications on Expertise and Role of Professional Designers

As the technology related to design tools or systems has developed, the role of designers has been continuously changed. For instance, there is no more hand-sketched drawing for an architecture or a product. Most of the modeling programs automatically produce a drawing based on the three dimensional (3D) model that designers made. In addition, there is no need to cut and sand a block of foam in order to explore various forms of a product. The 3D models can be directly produced by 3D printers without extra work. Those changes have brought considerable changes in designers' role and expertise in design practice. Similarly, if the proposed methods that automatically achieve image-color harmony become prevailing and significant in design practice, a certain portion of graphic designers' will be replaced by the automatic methods. Since recoloring an image is a time-consuming and difficult task even for designers, being good at image recoloring could be a competitiveness of a graphic designer. If the function is largely done by an automatic method, the importance of recoloring and color selection ability will be reduced among professional designers. Instead, designers may need a more acute sense of layout design or typography design. Like this example, the advent and spread of a new technology often challenge the conventional paradigm. Thus the researcher expects more in-depth and practical studies are cultivated in design discipline to understand the impact of new technology on design pedagogy.

6.3.2 Applications with Key Color Generation

6.3.2.1 Color Recommendation for Design and Documentation Works

In content creation, users need to determine a set of colors which will be used throughout a piece of design works or documentation in order to enhance the readability of the contents and make them pleasing to the eye. While this need seems to be more desperate to non-designers, selecting appropriate colors is also a challenging task to designers. The proposed color generation method can be applied in a color recommendation system in order to provide a harmonious set of colors for a visual content that users want to utilize. The recommendation system could be a part of documentation or a design software, but it also can be embedded in a web-based application that automatically generates a certain type of design work to minimize the burden of users. The prototypes described in Chapter 5 are exemplary cases that the proposed color generation method is applied for graphic design and video editing respectively.

6.3.2.2 Color Suggestion for a Flexibly Identity System

A brand identity has a fixed identity color to establish a firm ground of its visual characteristic. The rigidness of color usages in such design context has been investigated in Chapter 4. However, an increasing number of corporate break the boundary of color usages in their identity by adapting a dynamic and flexible color system. Figure 6.1 shows the flexible identity system of Casa da Música, a major concert hall space located in Porto, Portugal. Instead of utilizing a static set of colors, the concert hall is dynamically changing the color of their logo by extracting colors from the poster of up-coming events. By doing so, the brand identity is able to build a strong association with the events happened in the place and delivered news beyond the identity. Like this example, the proposed color generation method can be a part of an identity system which seeks for a dynamic characteristic to reflect changes and issues happen in a brand or a corporate.

In addition to the harmony with given images, the proposed method takes account of the affective quality of the image-color pairs. Even with the same image, the method is able to provide different colors according to the desired style. Thus any application that a style, a mood or emotion is engaged can be benefited by the method. Figure 6.2 shows a dynamic logo system of Nordkyn, the northernmost region on the European mainland, which changes its color according to meteorological data such as wind and temperature.

6.3.2.3 Responsive Color Generation for Interfaces

Changing the layout of web-content according to a screen size is not a common and a natural of presenting contents in a web platform. It is called as a responsive web design and now is a leading paradigm of the web design development. To make the contents compatible with any display devices, a large amount of

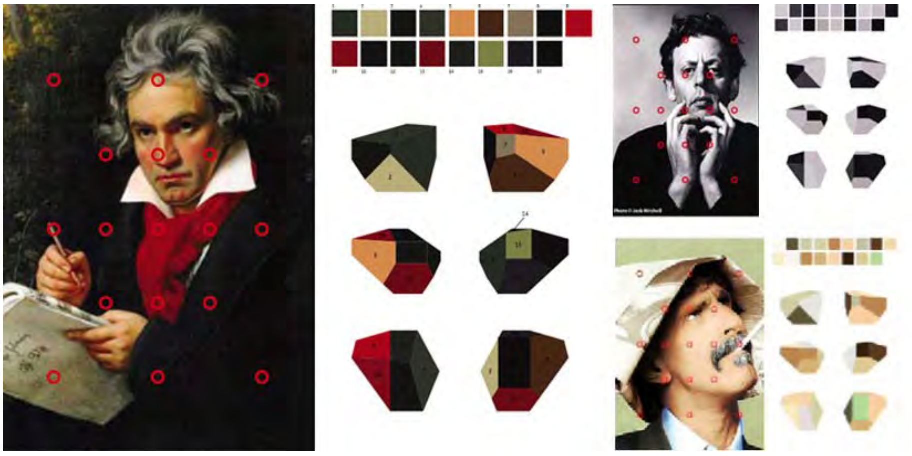


Figure 6.1 Flexible identity system of Casa da Música.
The colors of the logo are dynamically changing depending on the on-going event of the hall.

Figure 6.2 Dynamic logo system of Nordkyn. Reprinted from Neue.no
The colors of the Nordkn logo are continuously changing according to the meteorological data such as temperature and a wind speed.

techniques and methods have been investigated and developed in both academia and practice. Due to such endeavor, we now can enjoy web contents in a readable and pleasing layout regardless of the screen size and resolution of devices.

Like the case of Nordkyn logo, the color of an identity or interface can also be interactively changed according to related moods or styles. A plausible application is the interface color of a music player, of which the background color is continuously changing as a pitch, or a beat of the on-playing music is changed.

6.3.2.4 Multimedia Production in Consideration of Emotional Diversity

Contrary to previous color extraction studies, the key color generation method can generate colors beyond the color features of a given images due to the tone-match. This feature makes our method novel and be capable of generating creative color solutions. We believe that this feature could bring not only a wider range of alternatives but also unexpected insights to designers in the multimedia discipline. Our key color generation method also showed a possible extensibility across content types. Although it has developed based on image database, it generates acceptable solutions with videos. This implies the compatibility of a key color generation method with various visual contents. As a starting point, we hope that this paper inspires localized works in diverse multimedia domains to fully enjoy the aesthetic and affective effects of colors. Lastly, a versatility of crowd-sourced data was introduced in multimedia production. The tone-match algorithm highly depends on the external databases constructed by crowds. By employing the knowledge of crowd-sourced data, the method has a dynamic and evolving properties that respond to the situations, trends and even to target users. For the future investigation, utilization of social data can be a possible direction to suggest a customized solution for each user.

6.3.3 Applications with Image Recoloring

6.3.3.1 Automatic Image Adjustment Functions for Images in a File

As a direct application, general office software for writing, documentation and presentation can be benefited by the proposed method. In content creation, for instance, users often utilize multiple images or videos to convey visual information or to support written information. Although each of the images or videos have distinctive contents and looks, a single file requires a coherent appearance as well as an aesthetic and harmonic look. As shown in Figure 6.3, there are available functions to adjust images within a documentation software such as Microsoft PowerPoint. However, such functions do not offer a way to adjust multiple image together in consideration of color themes used for the documentation work. If a color or a color theme is specified for a document, the proposed method enables users to create a satisfactory visual without an aid of external software to edit and adjust visual contents.

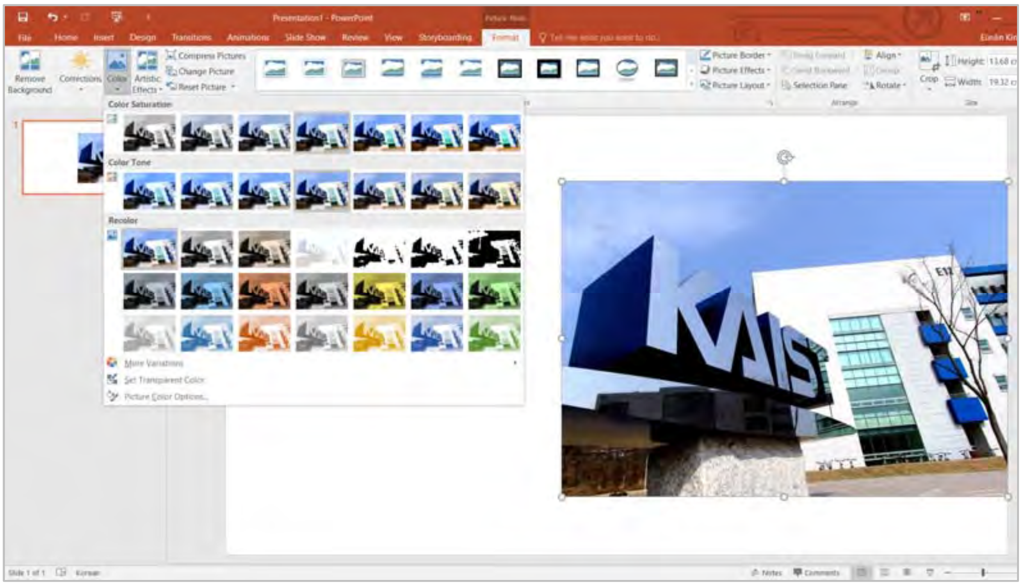


Figure 6.3 Image recoloring functions provided in Microsoft PowerPoint.
The current image adjustment function of PowerPoint does not offer an option to make an image harmonious with a certain color.

6.3.3.2 Functions for Responsive Content Presentation in Web

More generally, the proposed image recoloring method can be embedded in interfaces that display multiple visual contents. At the beginning of this dissertation, an example of a website was presented which displays photographs related to recent news (Figure 1.1). Like the website, there are numerous interfaces that display images under their brand identities. A majority of brands operate their news channels and publish newsletter regularly. Since the major purpose of newsletters is promoting own institute, it is important to deliver their corporate identity effectively without compromising the contents the institute wants to deliver. Due to the amount and/or frequency of the tasks, however, it is almost impossible to carefully process each content. In such case, the proposed image adjustment method could be a solution to manage a large amount of visual data in a coherent and aesthetic way.

In line with the case described above, the importance of visual social network services including Instagram and Pinterest increases rapidly. Thus the publication of graphic contents of companies and individuals is

Table 6.1 Plausible applications along with major features

Embedded Methods	Plausible Applications	Major Features
Color generation for harmony with images	Plug-in functions for content creation software	• Providing a set of colors that can be used for components such as texts, shapes, and background.
Color generation for harmony with images	Web platforms for graphic design automation	• Determining harmonious color for the use of graphic design • Suggesting alternatives to reflect users' preference
Palette extraction of the proposed Image recoloring method	Image suggestion in a web image search engine	• Suggesting images that are more harmonious with a selected color • Sorting images according to the degree of harmony with a color
Image recoloring for harmony with a color	Plug-in functions for documentation/graphics software	• Adjusting images for a harmonious match with a color • Suggesting alternatives using different adjustment approaches
Image recoloring for harmony with a color	Web platforms for visual content publication	• Adjusting images for harmony with color elements of a web interface • Particularly the image recoloring can be used for promotional purpose to advertise a brand identity

now increasing. Despite the increased demand, it now becomes less feasible that designers manually manipulate each content with careful consideration. In this context, the proposed method can be a good solution that provides an automatic adjustment for the contents uploaded in the web or interfaces.

6.4 Summary

In this chapter, a variety of prospective applications that could be benefited from the proposed methods in this dissertation. The suggested applications range from an embedded function to a stand-alone software. In the case of image recoloring method, it can automatically adjust images which will be used in a document, graphics work, and a web publication. It can also improve the user experience in an image search engine by sorting images according to the degree of harmony with a selected color. In the case of color generation method, it could be embedded in various tools such as Microsoft Powerpoint, Adobe Photoshop, and Sony Vegas. Instead of providing a fixed set of colors, such software may provide a customized set of colors using the proposed color generation method. Table 6.1 summarizes the plausible application ideas suggested in this dissertation.

In order to explore the potential of the suggested applications and investigate the benefits of the methods proposed, two application ideas were materialized into working prototypes, and one of them was evaluated through a user test. The results showed that the prototype provides a satisfactory outcome without users' assistance. In particular, the affective quality of outcomes was appreciated by utilizing the colors suggested by the color generation method of this dissertation. In addition to the application ideas suggested in this dissertation, it is expected that the proposed method can contribute to a better user experience in perceiving, exploring and creating visual contents with images and colors. ■

7 CONCLUSION

7.1 Summary of Major Findings
7.2 Contribution of this Research
7.3 Limitations and Further Study

7. CONCLUSION

7.1 Summary of Major Findings

This chapter outlines the major findings of this research in line with the three aims listed in Chapter 1. In short, this research aims at developing two computational methods – image recoloring and color generation – based on the principles of designers in order to suggest a responsive and interactive way of creating image-color harmony. To achieve the goal, a set of research activities was performed to understand the latent knowledge of designers using protocol analysis. It satisfies the Aim 1 of this research, and its main findings are described in section 7.1.1. Based on the findings, two computational methods were developed, and their performance was evaluated in the context of visual design practice. Section 7.1.2 illustrates the major findings related to method development and evaluation, which embrace the Aim 2 of this research. Finally, a variety of prospective applications was explored, and two different prototypes were developed in order to estimate the practicality and advantages of proposed methods within the applications.

7.1.1 Color-related Visual Design Process of Designers

7.1.1.1 Adjusting Image Colors for a Color

Through the experiments with designers, a general process of adjusting image colors was disclosed, and major strategies were also identified which are devised by designers to adjust images for a harmony with a given color. Based on the findings, the conceptual framework of an image recoloring method was suggested. In particular, four properties were deployed to the method to elaborate its technical approaches. First, the method adjust hue values only, instead of manipulating lightness or saturation together with the hue. Second, the local transfer is chosen for the method. By doing so, the adjusted image was able to remain as much as faithful to the original image. Third, a palette-based approach was selected. A color palette was used as a color descriptor of an image to identify the viability of the proposed method and to validate the adjustment results. Lastly, like designers' strategies, the method suggests three adjustment alternatives following the principle of analogous, complementary, and monochromatic schemes.

7.1.1.2 Selecting a Color for an Image

As described in Chapter 3.4, through the experiments with designers, it was investigated how designers select a color for an image and how they create integrated aesthetics of colors and images. The findings revealed a comprehensive color design process which comprises three activities – understanding images, crafting colors, and creating integrated visual of an image and a color. For each activity, we also identified factors that influence the decision making of designers. Based on the findings, the conceptual framework of an aesthetic color generation method was constructed. In particular, two aspects were revealed, and these were embedded as a technical feature of the developed color generation method. First, the hue values of image colors were emphasized throughout the color generation process. Second, the tone of n stylized color was defined by the given style keyword due to the discrete influence of tone on eliciting affective responses.

7.1.2 Methods to Create Aesthetic and Affective Image-Color Pairs

7.1.2.1 Aesthetic and Stylized Color Generation

In Chapter 4, a color generation method was proposed to construct an aesthetic and affective harmony between a color and an image. Inspired by the color generation process of designers, the proposed method is composed of two steps including *hue-prioritization* and *tone-match*. With a given image and an affective term, a color was generated by combining a dominant hue of an image and a specific tone defined by the affective term. To identify the most dominant hue of an image, k-means clustering was devised due to its simplicity that supports a quick and easy embodiment of the initial concept of *hue-prioritization* method. The second step *tone-match* defines saturation and value of the dominant hue by identifying the prevalent tone of colors among color themes related to a specific emotion. A crowd-sourced database was utilized in this step, which comprises approximately 45,000 color themes with respective names that describe characteristics of each theme. Since a stylized color has a tone independent of a given image, the stylized color of the proposed method possesses an eccentric but creative feature beyond the color features of the image. This specificity differentiates the proposed method with previous studies related to color extraction.

The color generation method was examined through two user tests. The prior test aimed at comparing the performance of the proposed method with the ability of designers. The later one weighed the proposed method in a more complex situation – video editing tasks – against existing video editing tools. The results of both tests indicated that the proposed method is good at generating stylized affective colors while aesthetic performance is needed to be refined further. As the first attempt to bring the strategy of designers into a computational method, the researcher believes that this study can broaden the design space in multimedia production by promoting creative and stylized color usages.

7.1.2.2 Aesthetic and Affective Image Recoloring

In Chapter 4, an image recoloring method was proposed to achieve harmony with a target color in the context of visual design. Based on the findings from designers, a palette-based approach was taken for local hue adjustment, and three approaches were suggested based on the principles of color harmony including analogous, complementary and monochromatic harmony. Technically, the proposed method made a unique attempt in the palette-based method by utilizing a palette of an image not only for color adjustment but also for validating the adjusted results.

Through a user test, the researcher was able to verify the performance of the proposed method, as well as identify its limitation. The result shows that participants prefer the outcomes of the proposed method in general, as the graphic works look more harmonious and aesthetic. It was suggested that the proposed method is particularly useful for photographs including nonliving objects. In contrast, photographs of human skin, foods, and animals constrained the acceptable range of color adjustment and thus led to lower preference. In further studies, advanced techniques in object detection or semantic feature analysis could be adapted to provide a refined method. Most of all, we hope that the practical context investigated in this study can promote a variety of related studies that satisfy the tangible needs of industries and academia.

7.2 Contributions of this Research

This study was conducted to investigate designers' tacit knowledge, particularly related to image and color manipulation. It also aims to transfer the practical knowledge into a computational domain to emulate the designers' tacit without their engagement. With these aims and objectives, in a macroscopic view, this study has suggested two grand research outcome – a comprehensive description of how designers deal with image and colors and a set of computational methods that automate key color generation and image recoloring. Throughout these research activities and their outcomes, this study argues following things as its expected contribution.

7.2.1 Advanced Understanding of Image-Color Harmony

A series of experiments with designers has conducted to understand the intricate aspects of color and image manipulation in the context of design practice. In overall research framework, a portion of the findings was transferred to the successive step of the research. However, regardless of its level of implementation, the findings allow us to have a better understanding about how designers perceive images and colors and how they create integrated aesthetics of colors and images based on their expertise and idiosyncratic characteristics. The findings firstly revealed a comprehensive color design process which comprises three activities – understanding images, crafting colors, and creating integrated visual of an image and a color. For each activity, we also identified factors that influence the decision making of designers. In particular, the engagement of object-semantics and personal interpretation regarding the object-semantics provided a probable explanation about how designers make their design distinctive and idiosyncratic. Based on the findings, implications for graphics tools were suggested to support image utilization, color manipulation, and alternative comparison during the design process. Although it provides relevant findings, this study has limitations including its context confined to a color generation task. The suggested ideas for graphics tools are also needed to be implemented and verified. As a primitive attempt, we expect this study brings forth in-depth studies to understand constituent characteristics of the design process and inspires further investigation to promote the creation of visual aesthetics.

7.2.2 Methods that Automate Harmonization of Image and Color

In image processing, extracting colors from an image and recoloring images were one of the most common and conventional research topics. Despite a variety of solutions provided by previous studies, there was limited consideration of their practical application. In this manner, this study introduces a novel context that image-color harmony can significantly contribute to enhancing the quality of its application. Based on the findings from a formative study with designers, appropriate techniques were identified among various alternatives. Although individual techniques devised in the proposed methods do not have strengths in their novelty, their combination and the performance provide a unique contribution to this research. Furthermore, we expect this research could also provide insights to image processing discipline through the process of finding practical design situations and reworking designer's knowledge in a technical form.

7.3 Limitations and Further Study

7.3.1 Understanding Designers' Practice

As Dorst and Dijkjuis (1995) stated, despite of many systems for investigating design activity, we yet have a firm and robust model to frame the nature of design activity. In a macroscopic view, one view design as a rational problem-solving process, while others take a constructivist perspective that emphasizes 'reflection in action'. The first perspective defines design process as a rational search process that could be generalized and objective. The second perspective rather argues that each design activity is unique and individual. Thus the knowledge from each process could not be formulated into generalized principles.

Although we also identified individual and idiosyncratic characteristics of each designer, this study was mainly conducted based on the perspective describing the design as a rational problem-solving process. This allows us to capture the design process as a series of problem-solving steps that can be transferred to computational techniques. However, this perspective has a limitation in capturing the content and procedural components of the design process. We think that this is a probable reason that we were not able to clearly identify the difference between the graduate student-level and professional designers during data analysis. Considering the richness of tacit knowledge embedded in design expertise and practice, it is expected that investigating the design activity with constructivist perspective could provide distinguishable insights and learnings that compensate the limitation of this study.

7.3.2 Technical Issues in the Proposed Methods

7.3.2.1 Limitations in the Key Color Generation Method

In computer vision and image processing discipline, a variety of color extraction algorithms have been developed and verified. By utilizing established knowledge of the field, the researcher will fully consider the various color features that images possess. In addition to color features, contextual information will be considered in the future study. We noticed that similar colors could evoke distant feelings depending on the objects that each color represents. For instance, yellow from fruits was regarded as warm and tender, while the yellow from a New York taxi was rarely associated with warm and tender images. By incorporating the meanings and contexts of a given content, hue-prioritization method could be strengthened in order to produce persuasive results for various contents. Also, other types of images such as drawings and illustrations could be used for further investigation.

For each keyword, the current method utilizes 200 colors from the searching results of Adobe Color CC® database. Although we selected these colors based on their ratings in the most recent database, there are several pitfalls that should be handled in the future study. First of all, 200 colors may not be enough to gratify the comprehensive needs and wants of users considering the diversity of colors and emotions that people pursue. Increasing the number of colors used can be a possible solution, but it also increases the amount of possible noises that crowd-sourced data innately has. Especially the data from Adobe Color CC® has possibilities of an internal dissonance since there could be a discrepancy between the emotion of a color theme and the one of an individual color belongs to the theme. In order to maximize the benefits of a crowd-sourced data, we will firstly filter the database by employing acknowledged color emotion theories and increase the number of colors that to be used for the tone-match step. In addition, real-time data crawling could leverage the advantages of a crowd-sourced database, which is susceptible to changes and adjustments. Moreover, each affective term can be interpreted differently depending on the contexts, retails and events the term is used for. The context-specific color searching process can enhance the congruency between desired emotion and retrieved colors.

7.3.2.2 Limitations in the Image Recoloring Method

Although this study proposes a satisfactory method for image recoloring, its strength does not rely on the advancement or improvement of the method to perform a color adjustment. It rather argues achievements in identifying a novel application of color adjustment and developing a concise and straightforward solution that satisfies the needs of users without any user input. Therefore, in the further study, a more sophisticated approach should be developed to overcome the limitations raised in this study and to improve its performance. For instance, the current method iteratively extracts a palette from an image to evaluate the hue similarity with the target color. To accelerate this process, a more concise and simpler way of extracting a palette and comparing hue similarity can be devised. The hue adjustment function takes into account the only one color from a palette, which has the minimum hue difference with the target color. Although this approach enables us to maintain the original colors as much as possible, it sometimes fails to converge to the target color. In the future study, it is expected to investigate a more elaborated way of determining the colors to be adjusted and adjusting the original colors toward the target color.

7.3.3 Transferring Design Knowledge to Technical Methods

In order to transfer a type of tacit knowledge into a measurable and describable type of knowledge, it is important to have an understanding both of the design language and the technical language related to the domain of which design knowledge is to be transferred. In that perspective, this research was an attempt to transform the qualitative and implicit behavior of designers into technical methods which emulate a portion of their essence. Due to not only the technical difficulties but also the multifaceted nature of design knowledge, the transfer intrinsically has limitation. Unlike mathematic problems, design problems rarely have optimal solutions, and the problem-identification and solution generation process are highly subjective and idiosyncratic among designers. Similarly, the assessment of a design case is also subjective and preference-dependent among all the users.

If so, how much a technique can capture the essence of the tacit aspects of design knowledge? This also raises an issue regarding the extent of which technique or a system emulate the diversity of human creativity regarding visual aesthetics. As a mean attempt, this research has tried to shed light on the huge body of design knowledge and again tried to transform a portion of it to a technical form. Through this endeavor, it is expected this study could bring forth in-depth studies to understand tacit knowledge of design practice and inspires further investigation to propagate the knowledge to broader applications. ■

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