應用 CIE*Lab* 色彩空間進行畫作色彩分析
—以梵谷畫作為例

摘　要

本研究主要目的在於提出一款可以快速計算畫作色彩分佈之分析方法，該分析方法係依據國際照明委員會(CIE)於 1976 年所制定的 CIE*Lab* 均勻色彩空間為基礎，進行實用之畫作色彩分佈計算與分析工具軟體之開發。研究採用知名畫家梵谷的油畫作品進行分析，透過 7 名相關領域的專家組成焦點小組，進行討論與挑選 1882 至 1890 年梵谷眾多畫作中的 370 幅代表性的作品共計 6 大類，進行色彩分析工具的建置與軟體測試。分析結果顯示，透過簡易的色差公式即可快速計算每幅作品的色彩分佈量，並以色彩體積數值來表現每幅油畫作品的色彩分佈多寡。在不同類別的畫作色彩分佈結果顯示，自 1887 年至 1890 年間，梵谷於畫作的色彩選用更為飽和且多元，明顯有別於 1886 年以前畫作的色彩選用。研究成果也顯示 CIE*Lab* 之色彩空間除了合適於分析畫作色彩分佈之外，透過本研究所開發之計算工具，即可以針對畫作之色彩分佈進行計算與量化分析。

關鍵詞：色彩體積、色差計算、梵谷畫作

1. Introduction

The eye performs the initial function of the visual system, which is to receive the visible spectrum and send electronic signals to the visual cortex of the brain through the visual nerve. It is also the only means by which the brain obtains external images. When the brain processes the more complex images, the process should be dependent on previous knowledge, cognition, and perception, such as the color distribution of an image or paintings. The personal knowledge of the viewer would affect the reading of paintings. Solso (1996) states that the meaning and interpretation of art depend on the viewer's previous specialized knowledge of painting and related phenomena. Thus, the first question addressed by this study is how to know the number of colors that have been used in the paintings. For example, when people see Leonardo da Vinci's portrait of the Mona Lisa at the Louvre museum in Paris, they observe that the physical features in the painting are similar to how all other humans see them. Owing to the same viewing conditions, such as identical illumination and color temperature of lighting, discussing the color amount used in the painting may be easy. The second question is how to effectively evaluate and easily compare the color on a serial painting. Different from the visual system, the important goals of image and color science research is to develop a numerical metric based on image quantitative analysis to assess color images. Tsai and Guan (2005) point out that the earlier image research field focused on the color metrics, such as the peak signal-to-noise ratio (Loia & Sessa, 2005) and the root mean square error (Nobuharaa *et. al*., 2006) were concerned about the physical measurement of image assessment and does not correspond well with the visual assessment results (Nguyen *et al*., 2006; Civanlar, 2004; Oda *et al*., 2002). Efforts were then made to develop color models that analyze the images and their quality. The aforementioned methods were based on a global analysis of the entire image. Numerous studies were conducted based on visual assessments by using psychophysical methods to analyze the image reproduction and its application on painting artworks. Thus, this study is motivated by the idea that image and color science could reasonably analyze the color used in an artwork (Tsai and Guan, 2005). This study differs from previous studies in that it employs a simple and effective way to analyze color images or paintings. The main purpose of this study is to develop a useful analytical tool that can be used to immediately understand the color distribution of an image or artwork.

2. Method

Each digitalized image included an R, G, and B channel. Each channel is demonstrated from integer 0 to 255 in each pixel of an image. In contrast to the numerical matrix of the CIELab color value, the RGB values cannot be easily analyzed by using basic arithmetic calculations. Thus, this study transferred the RGB to the CIELab value in each pixel of an image.

(1) CIELAB color space

In 1976, the International Commission on Illumination (CIE) defined the CIE*Lab* color space, which was created to serve as a device-independent function to be used as a reference. Equations 1–8 were used to describe the tristimulus values normalized to the reference white. The CIE*Lab* color space also defines the three dimensions, including *X*, *Y*, and *Z*, which are the tristimulus values of the stimulus, and *Xn*, *Yn*, and *Zn*, which are the tristimulus values of the reference white point (CIE, 1986; Fairchild, 2005). The CIE*Lab* color space sets up the color as three dimensions of the CIE*L** for lightness from zero (black) to one hundred (white) and the CIE*a** and CIE*b** for the hue and chroma. The CIE*Lab* color space was also designed as a “perceptually uniform or uniform color space,” which means that “the same amount of numerical color value change corresponds to roughly the same amount of visually color perceived change” (CIE, 1986; Brainard, 2003). This study calculates the numerical color volume of an image by using CIE*Lab* color space.

$$L^* = 116\sqrt[3]{\frac{Y}{Yn}} - 16 \qquad \text{(Eq.1)}$$

$$a^* = 500\left(\sqrt[3]{\frac{X}{Xn}} - \sqrt[3]{\frac{Y}{Yn}}\right) \qquad \text{(Eq.2)} \qquad b^* = 200\left(\sqrt[3]{\frac{Y}{Yn}} - \sqrt[3]{\frac{Z}{Zn}}\right) \qquad \text{(Eq.3)}$$

When the X/X_n, Y/Y_n, and Z/Z_n are greater than 0.008856.

$$L^* = 903.3\left(\frac{Y}{Yn}\right) \quad \text{(Eq.4)}$$

$$a^* = 500\left\{\left[7.87\left(\frac{X}{Xn}\right)+\frac{16}{116}\right]-\left[7.87\left(\frac{Y}{Yn}\right)+\frac{16}{116}\right]\right\} \quad \text{(Eq.5)}$$

$$b^* = 200\left\{\left[7.87\left(\frac{Y}{Yn}\right)+\frac{16}{116}\right]-\left[7.87\left(\frac{Z}{Zn}\right)+\frac{16}{116}\right]\right\} \quad \text{(Eq.6)}$$

When the X/X_n, Y/Y_n, and Z/Z_n are equal to or less than 0.008856.

$$C_{ab}^* = \sqrt{(a^{*2} + b^{*2})} \quad \text{(Eq.7)}$$

$$h_{ab} = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{(Eq.8)}$$

Where the C_{ab} is the value of Chroma, which is the distance from the lightness axis CIEL^* and starts at zero, and h_{ab} is the hue angle which starts at the $+a^*$ axis and is expressed in degrees**.**

(2) Color analysis of CIELAB

Figure 1 shows the workflow used to obtain the RGB value of each pixel in the source image and transfer the color value of each pixel to CIE$L^*a^*b^*$. Each pixel of an image started as sRGB data that is standardized from the RGB value. Each pixel is then transformed into the CIE*XYZ* color space and then CIELAB L^*, a^*, and b^* values (see Eqs. 1–6). The median of each L^*, a^*, and b^* value would be used to calculate the distance between it and each L^*, a^*, and b^* value on the pixel of an image. On the other hand, all of the calculated values of distances were reported in terms of delta E_{ab} by using CIE*LAB* color difference formula (see Eq. 9). Figure 2 shows that the delta E_{ab} was calculated from the distance between the median value, which is represented as L_m *, a_m*, and b_m* value and each L_n *, a_n*, and b_n* value on the CIE*Lab* color space (see Fig. 2). Finally, the calculation of the sum of numerous deltas E_{ab} would be used to figure out the color volume of an image (see Eq. 10).

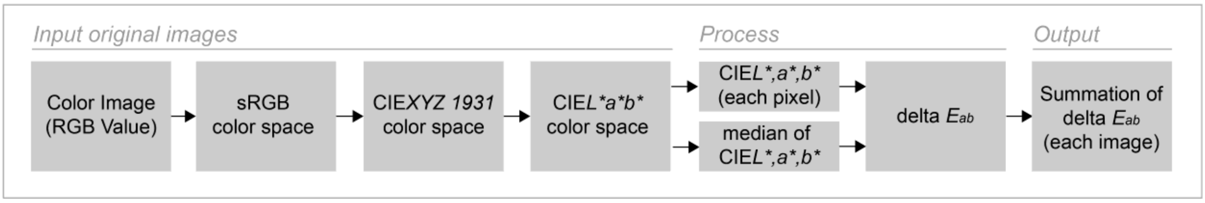

Fig. 1 Workflow to calculate the color image (from sRGB value to CIE$L^*a^*b^*$)

$$\Delta E_{ab}^* = \sqrt{(L_m - L_n)^2 + (a_m - a_n)^2 + (b_m - b_n)^2} \quad \text{(Eq.9)}$$

$$S_{vol} = \sum_{i=1}^{n} \Delta E_{ab_i} \quad \text{(Eq.10)}$$

where the delta E_{ab} is the distance between each pixel and the median of all delta E_{ab} value in the single image, S_{vol} is the sum of delta E_{ab} for each image, the n is the total number of pixels for each image.

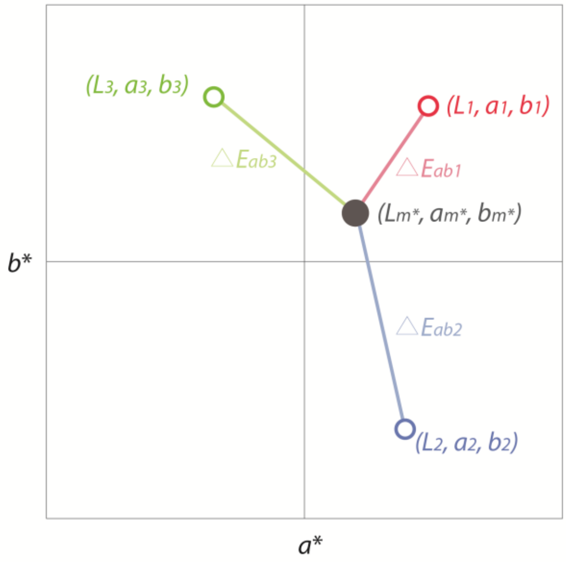

Fig. 2 Hints of the distance (delta E_{ab}) calculation between median value and all value of L_n*, a_n*, *and* b_n* in the CIE*Lab* color space.

3. Analysis of Van Gogh's Oil Paintings

Van Gogh (1853–1890) created over 2,100 artworks consisting of 860 oil paintings and more than 1,300 watercolors, drawings, and sketches. He was one of the most famous and influential painters in the history of Western art. His oil paintings included still lifes, portraits, landscapes, and self-portraits. Most of the oil paintings were created from the last 10 years of his life. His late artworks were characterized by bold colors as well as dramatic and expressive brushwork. Many of his oil paintings contributed to the foundations of modern art and education.

In this study, 370 oil paintings were selected from over 800 oil paintings by the focus group. The seven group members consisted of one scholar who specializes in Van Gogh's oil paintings, two assistant professors who teach Western arts in design school, one oil painter, two senior graphic designers, and one design manager from an arts and graphic design company. After two discussions, the experts distinguished the 370 oil paintings between 1882 and 1890 into 6 categories, including vegetation (AV), building (BD), landscape (LS), portrait (PT), still lifes (SL), and self-portraits of Van Gogh (VG), as shown in Table 1.

Table 1 Sample of six categories.

					
1890	1890	1889	1889	1889	1887
AV	BD	LS	PT	SL	VG

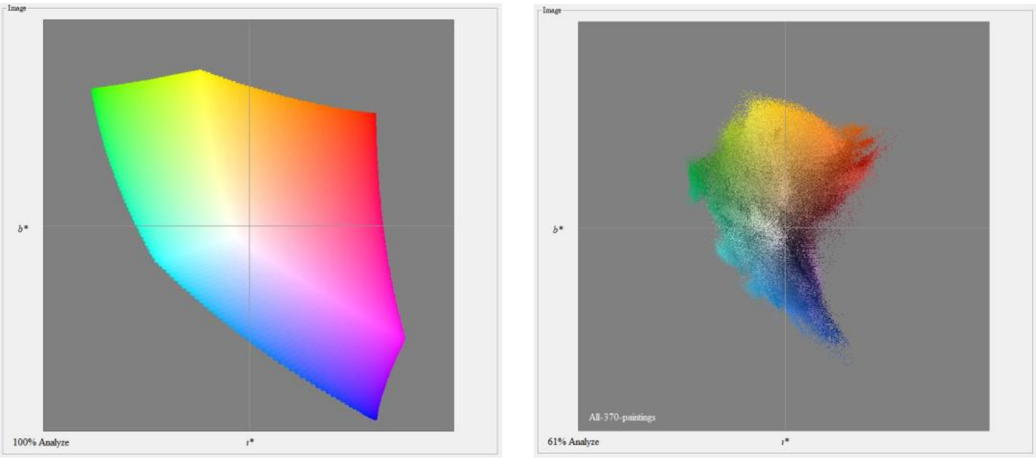

Fig. 3 Color gamut of CIE*L*a*b** color space
(left: typical color gamut based on CIE*L*a*b** 1976 color space;
right: color gamut of Van Gogh's oil paintings from 1882 to 1890)

The 370 oil paintings were analyzed in terms of color distribution. The right side of Figure 3 shows the color gamut of VG's oil paintings. Many colors used in his paintings, such as light blue, light orange, yellow, light red, brown, cyan, teal, light gray, and dark gray, were compared to the left side of Figure 3, which shows the typical color gamut base on the CIE*L*a*b** color space. The figure also shows that purple, pure red, and pure green were hardly used in his paintings.

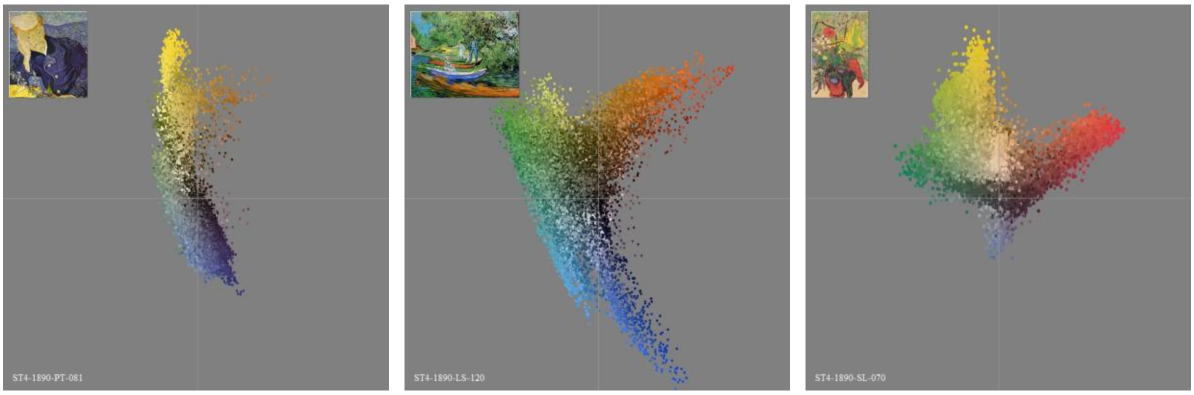

Fig. 4 Sample of color distribution at CIE*L*a*b** color space (bird's view)

In general, the color used would be according to various categories such as portraits, landscapes, and SL (see Figure 4). These three samples demonstrate the different color distributions among various categories in the CIE*L*a*b** color space. The marginal mean of color volume analysis shows a large increase in the color used after 1887 on each category of oil paintings (see Figures 5 and 6). This condition also shows that more than half of the high marginal mean of color volume (from 25% to 75% of the quartiles) would focus on the late artworks from 1887 to 1890. The landscape category significantly increases in the high marginal mean of color volume more than the other categories; it also shows a large increase in the color used after 1887. The second increase in color volume is in the portrait category (see Figure 7). The analysis results of the distribution of color volume in each year show that a significant number of colors were used in the building, landscape, portrait, and still life categories after 1888 (see Figure 8).

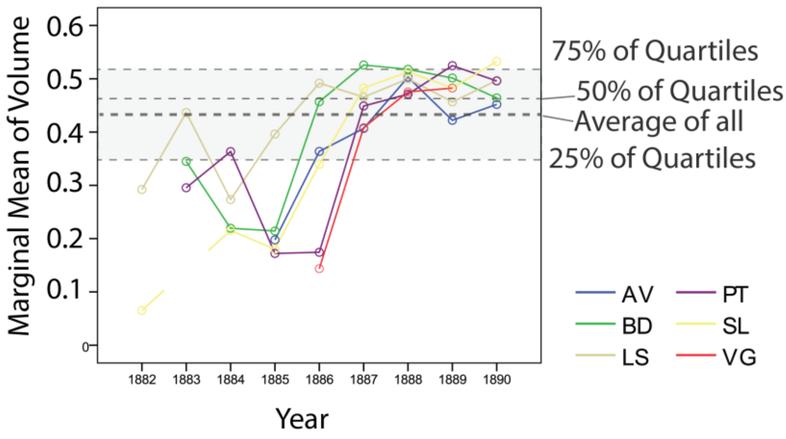

Fig. 5 Marginal mean of color volume (trend by year)

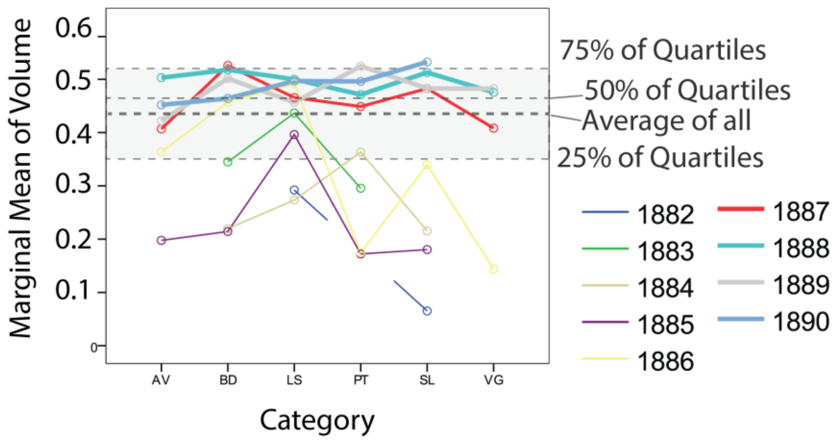

Fig. 6 Marginal mean of color volume (trend by oil painting category)

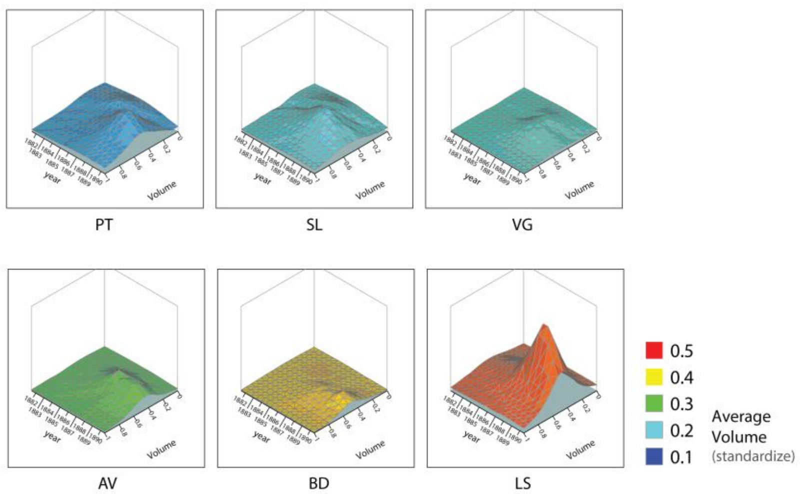

Fig. 7 Distribution of color volume.

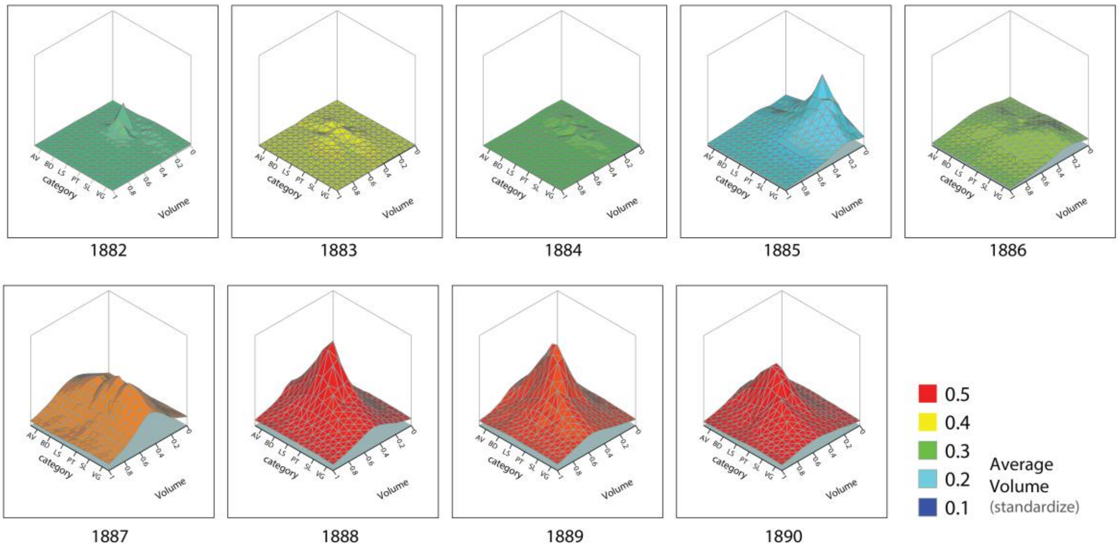

Fig. 8 Distribution of color volume each year

4. Results and Discussion

In general, paintings are analyzed by art experts and qualitative researchers. This study used a novel method, which is identifying the color distribution of oil paintings through color volume analysis. The results demonstrate that this method could rapidly state the numerical color distribution by using a simple color difference formula. The color volume can also be used to represent the color distribution status of an oil painting. The result of this study showed that in the various categories of oil paintings, a significant difference was observed between 1886 and 1887. The distribution of color volume indicated that VG used a large number of colors in categories of buildings, landscapes, portraits, and SL after 1888. Berezhnoy *et al*. (2007) pointed out that VG started employing complementary colors to emphasize the contours of objects or parts of scenes after his relocation to Provence in southern France in 1887. The time he spent in southern France may have affected the colors he used in his oil paintings. The results of the quantitative research method used in this study showed that we could analyze the color distribution of oil paintings through color volume analysis. This study also proposes an easy and reasonable method to analyze the colors of the paintings. The color space of CIE*Lab* is suitable for conducting an analysis of paintings. The marginal mean of color volume analysis shows a large increase in the number of colors used by VG after 1887 on each category of his oil paintings.

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USING CIELAB COLOR SPACE IN ANALYZING THE COLORS OF VAN GOGH'S PAINTINGS

ABSTRACT

The main purpose of this study is to propose an easy and rapid method for analysis of colors in paintings. Calculations of paintings' color volume and the prototype of an analysis tool were also developed in this study, according to the CIE*Lab* uniform color space created by the International Commission on Illumination (CIE). The oil paintings of Vincent Van Gogh, a Dutch post-impressionist painter, were used to analyze the color volume and test the analysis method. Seven experts were invited to discuss and select the typical oil paintings from Van Gogh's artworks during the period 1882 to 1890. A total of 370 oil paintings were selected and classified into 6 categories. Results demonstrate that using the simple color difference formula could rapidly show the numerical color distribution. Furthermore, the color volume could be used to represent the color distribution status of an oil painting. The results also indicated that in the various categories of oil paintings, a significant difference was observed between 1886 and 1887, and that Van Gogh created numerous colorful oil paintings after 1887. The color space of CIELab is suitable for developing the analysis of paintings.

Keywords: Color volume, Color different calculation, van Gogh