行政院國家科學委員會專題研究計畫 成果報告

色彩辨別橢圓之研究
研究成果報告(精簡版)

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中 華 民 國 100 年 10 月 31 日

中文摘要： 本論文在心理物理實驗中利用液晶顯示器測量色彩辨別橢圓體，並顯示四個紅綠藍灰色的色彩辨別橢圓體的測量結果。對於一個參考色，由十位觀察者的恰好辨別色彩數據，我們利用統計方法與配適方法計算兩種色彩辨別橢圓體。結果顯示配適橢圓體比較能描述恰好辨別色彩數據的分佈特性。所測到的紅色與藍色色彩辨別橢圓體對於亮度軸有些微傾斜，而且這兩色的橢圓體在亮度軸的軸長較長。對於所測量到的四色橢圓體之亮度軸軸長，計算它們的最長軸長與最短軸長之比例。使用統計橢圓體的比例為 1.41，使用配適橢圓體的比例為 1.45。橢圓體在固定亮度的截面之長軸方向並沒有如 CIEDE2000 色差公式所預測地指向 CIELAB 座標的中心點。由於 CIEDE2000 色差公式不能預測上述實驗結果，需要建立更精確的新版色差公式。測量色彩辨別橢圓體很耗時間，我們定義簡化的配適橢圓體，其中忽略橢圓體對於亮度軸的傾斜。測量簡化的配適橢圓體可以有效節省測量時間，而且此橢圓體也可以適當地觀察者的恰好辨別色彩數據之分佈特性。

英文摘要： Chromaticity discrimination ellipsoids are measured in the psychophysical experiment by the use of an LCD. Four measured ellipsoids at red, green, blue, and gray color regions are shown. From a set of just discernible colors of ten observers corresponding to a reference color, two ellipsoids are calculated with statistic method and fitting method. The results show that the distribution of just discernible colors can be better described with the best fit ellipsoid. The measured ellipsoids of red and blue reference colors slightly tilt about luminance axis. It is shown that the length of luminance axis of an ellipsoid depends on reference color and is longer for red and blue reference colors. The ratios of the maximum and minimum length of luminance axes among the four measured reference colors are 1.41 and 1.45 for statistic ellipsoids and best fit ellipsoids, respectively. The long axis directions of the constant-luminance cross sections of measured ellipsoids do not point at the origin of CIELAB. As these experimental results cannot be predicted by CIEDE2000, the development of more accurate version of color difference formula is necessary. The measurement of a chromaticity discrimination ellipsoid is time consuming. A simplified best fit ellipsoid is defined, in which the tilt of ellipsoid about luminance axis is neglected. The required time can be significantly reduced for measuring the simplified best fit ellipsoid. The main characteristics of the distribution of observers' just discernible colors also can be well described with the simplified best fit ellipsoid.

行政院國家科學委員會補助專題研究計畫成果報告

色彩辨別橢圓之研究

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共同主持人：
計畫參與人員： 馬鶴仁，祁天駿

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中　華　民　國　100　年　10　月　31　日

中文摘要

本論文在心理物理實驗中利用液晶顯示器測量色彩辨別橢圓體，並顯示四個紅綠藍灰色的色彩辨別橢圓體的測量結果。對於一個參考色，由十位觀察者的恰好辨別色彩數據，我們利用統計方法與配適方法計算兩種色彩辨別橢圓體。結果顯示配適橢圓體比較能描述恰好辨別色彩數據的分佈特性。所測到的紅色與藍色色彩辨別橢圓體對於亮度軸有些微傾斜，而且這兩色的橢圓體在亮度軸的軸長較長。對於所測量到的四色橢圓體之亮度軸軸長，計算它們的最長軸長與最短軸長之比例。使用統計橢圓體的比例為1.41，使用配適橢圓體的比例為1.45。橢圓體在固定亮度的截面之長軸方向並沒有如CIEDE2000色差公式所預測地指向CIELAB座標的中心點。由於CIEDE2000色差公式不能預測上述實驗結果，需要建立更精確的新版色差公式。測量色彩辨別橢圓體很耗時間，我們定義簡化的配適橢圓體，其中忽略橢圓體對於亮度軸的傾斜。測量簡化的配適橢圓體可以有效節省測量時間，而且此橢圓體也可以適當地觀察者的恰好辨別色彩數據之分佈特性。

關鍵字：色差公式，色彩辨別橢圓，顯示器。

Abstract

Chromaticity discrimination ellipsoids are measured in the psychophysical experiment by the use of an LCD. Four measured ellipsoids at red, green, blue, and gray color regions are shown. From a set of just discernible colors of ten observers corresponding to a reference color, two ellipsoids are calculated with statistic method and fitting method. The results show that the distribution of just discernible colors can be better described with the best fit ellipsoid. The measured ellipsoids of red and blue reference colors slightly tilt about luminance axis. It is shown that the length of luminance axis of an ellipsoid depends on reference color and is longer for red and blue reference colors. The ratios of the maximum and minimum length of luminance axes among the four measured reference colors are 1.41 and 1.45 for statistic ellipsoids and best fit ellipsoids, respectively. The long axis directions of the constant-luminance cross sections of measured ellipsoids do not point at the origin of CIELAB. As these experimental results cannot be predicted by CIEDE2000, the development of more accurate version of color difference formula is necessary. The measurement of a chromaticity discrimination ellipsoid is time consuming. A simplified best fit ellipsoid is defined, in which the tilt of ellipsoid about luminance axis is neglected. The required time can be significantly reduced for measuring the simplified best fit ellipsoid. The main characteristics of the distribution of observers' just discernible colors also can be well described with the simplified best fit ellipsoid.

Keyword: color difference formula, chromaticity discrimination ellipse, display

1. Introduction

In the 20th century, popular color displays are based on cathode ray tube (CRT) technology. After about the year 2000, color liquid crystal displays (LCDs) became popular and replaced CRT displays at astonishing speed. Nowadays, flat panel displays are everywhere in our daily life. Televisions, computer monitors and mobile phone displays are examples. Flat panel displays are successful owing to their characteristics of high resolution, low power consumption and light weight. The display of wide color gamut (WCG) is able to show more colorful and attractive images [1-5]. HDTV standard was specified in the era of CRT. As technology advances, it is a trend to design WCG displays for attractive color appearance. A new IEC specification xvYCC was defined in 2006 for the video signal format that is able to represent the color gamut much wider than HDTV color gamut [6]. xvYCC is an extension of YCC specified in ITU-R BT. 601 [7]. The specification xvYCC was adopted in the interface specification HDMI 1.3 for transmitting uncompressed digital data in the same year [8]. The color coordinates of primaries and white point specified in xvYCC are the same as that of HDTV standard. Negative values of xvYCC signals are allowed for representing the colors outside HDTV color gamut. The signal bit depth more than 24 bits is also supported in xvYCC for representation of more detailed color and for the avoidance of contour flaw [9]. A display shows a picture with contour flaw when the original picture colors of corresponding pixels are smoothly changed but the display shows the same color due to the lack of bit-depth.

Video programs are usually recorded according to HDTV specification. Primary color coordinates of WCG displays are much different from that of HDTV primaries. Color processing is required for the video programs shown on WCG displays so that the color hue shift due to primary changes can be corrected or preferred color appearance can be achieved. In color processing, the calculation of the color difference between two color points is frequently encountered. CIE color coordinate system is a non-uniform color space. The color difference between two color points is calculated by color difference formula, which is a basic tool for color science and technology.

CIE has published three versions of color difference formulas in 1976, 1995, and 2000 [10-12]. Color difference formula can be obtained by fitting chromaticity discrimination ellipses to a mathematical formula [10, 13]. The color coordinates of a chromaticity discrimination ellipse is either x and y in CIExyY or a* and b* in CIELAB. The two color coordinates relate to hue and chroma. The third color coordinate Y in CIExyY or L* in CIELAB is kept constant. The chromaticity discrimination ellipses are measured from psychophysical experiment, in which a group of observers are asked to indentify whether testing color patches are the same as a reference color patch or not [10]. From the data collected from the psychophysical experiment, the chromaticity discrimination ellipse centered at the color coordinates of the reference color patch can be calculated by statistic method. The color patches were usually prepared with a set of color chips, which are made of tiles and textiles for examples, so that their color appearance can be stable under a given illumination [13]. The pigments of the color chips are usually not fluorescent and not highly saturated. Therefore, they do not include high saturation colors in nature including the colors of butterfly wings and fluorescent light. Visible LED is made of band gap material and the bandwidth of its emission spectrum is narrow and highly saturated. Thus, current CIE color difference formulas may not be suitable for calculating the color difference between two high saturation colors that can be shown by wide-color-gamut displays. Therefore, it is necessary to study the color difference formula that is suitable for the application of WCG displays.

The color patches with tiny color difference are required in the chromaticity discrimination experiment. Cathode-ray tube (CRT) displays have been used as the experimental apparatus for displaying color patches in psychophysical experiments [14-17]. In [14-17], the signal processing in CRT is analog and the required color patches can be displayed by careful tuning signal voltages.

Nowadays, the signal processing in LCDs is digital and the displayed color patches are limited by the bit depth. Furthermore the chromaticity characteristic of an LCD is complicated. The relationship of input signal and output tristimulus values is not linear. We proposed a method by the use of an LCD for measuring chromaticity discrimination ellipse with the psychophysical experiment [18]. 3D-LUT was taken as the color device model of the display. A spatial-dithering method was used for the increase of effective bit-depth. The RGB signal of the LCD is 24-bit (8 bits for each primary signal). We defined a super pixel comprising 9 pixels. The applied RGB signals of the 9 pixels can be different and are given as required. Because the visual acuity of human eye is 1 minute of arc, if the viewing angle of the super-pixel is less than 1 minute of arc, the details of the 9 pixels cannot be observed. Thus, we are able to generate more than 256 levels for a primary by the use of super pixels and the effective 11 bits per channel can be achieved.

From chromaticity discrimination ellipses, the color difference due to the combined variation of hue and chroma can be derived. In the published CIE color difference formulas, the contribution of color difference from lightness is assumed to be independent of hue and chroma. That is lightness does not interact with hue and chroma in CIE color difference formulas. In this paper we check this assumption from the measurement of chromaticity discrimination ellipsoids with the method presented in [18]. The color coordinates of a chromaticity discrimination ellipsoid are xyY. The experimental results clearly show that the contribution of color difference from lightness depends on hue and chroma. Thus an accurate color difference formula should be derived from chromaticity discrimination ellipsoids rather than chromaticity discrimination ellipses. Furthermore such an accurate color difference formula is helpful for the determination of bit-depth for avoiding contour flaw [9].

Table I. Color coordinates of reference colors

Color	Red	Green	Blue	Gray
x	0.475	0.258	0.228	0.305
y	0.300	0.450	0.250	0.323
Y(cd/m^2)	48	48	48	48

2. Measurement of chromaticity discrimination ellipsoid

The experimental setup is the same as [18] except that an LCD LG-L227WT is used for displaying color patches. The dimension and resolution are the same as the LCD used in [18]. Room temperature is kept within 24°C and 25°C. The warm up time is two hours. The display is characterized with the spectrophotometer Photo Research PR-670. 3D-LUT is taken as the color device model of the display. Each displayed color patch is prepared with spatial-dithering method and measured with PR-670. Ten observers are asked to change the color coordinates of the test color so that the test and reference colors are just discernible. The considered reference color coordinates are shown in Table I, in which they are chosen to be the same as four reference colors of original MacAdam ellipses [10]. The background color is set be the illuminant C with the luminance value of 24 cd/m^2 as original MacAdam ellipses are measured.

For a reference color coordinates at (x_0, y_0, Y_0), the coordinate deviation vector between a color coordinates (x, y, Y) and the reference color coordinates is defined as

$$\left(\Delta x, \Delta y, \Delta Y\right) = \left(x - x_0, y - y_0, Y - Y_0\right). \quad (1)$$

Assume that δr and δY are the maximum sampling intervals in Δx Δy plane and ΔY axis, respectively. A scaled axis is defined as $\Delta\bar{Y} = (\delta r / \delta Y)\Delta Y$. We define a spherical coordinates (R, θ, ϕ) with the reference color coordinates as origin, in which R is the radial distance from the origin and is defined as

$$R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta\bar{Y}^2}\ ; \tag{2}$$

θ is the polar angle from the scaled $\Delta\bar{Y}$ axis; ϕ is the azimuth angle from Δx axis. The testing color patches are equally sampled in the radial directions with polar angle interval $\Delta\theta$ and azimuth angle interval $\Delta\phi$, in which $0 \le \theta \le 180^\circ$, and $0 \le \phi \le 360^\circ$. The number of sampled radial directions is

$$N_d = \left(180^\circ / \Delta\theta - 1\right)\left(360^\circ / \Delta\phi\right) + 2 \tag{3}$$

Along each radial direction, the color coordinates of sampled testing color patches are given by

$$x_i = x_0 + i\delta r \sin\theta \cos\phi\ , \tag{4a}$$

$$y_i = x_0 + i\delta r \sin\theta \cos\phi\ , \qquad i = 1, 2, 3, \ldots, N_r \tag{4b}$$

$$Y_i = Y_0 + i\delta Y \cos\theta\ , \tag{4c}$$

where N_r is the number of sampled testing color patches.

We take δr = 0.00075 and δY = 0.2 cd/m^2. It is noticed that, according to the specification of PR 670, measured color accuracy is $\pm$0.0015 in CIExy and luminance accuracy is $\pm$2% at the luminance level of 0.51 cd/m^2 with 1$^\text{o}$ aperture against an illuminant A NIST traceable standard. As the luminance values of reference colors are 48 cd/m^2, practical color accuracy and luminance accuracy are better owing to higher signal-to-noise ratio. The total number of sampled testing color patches is $N_t = N_r N_d$. We take $\Delta\theta$=15$^\text{o}$, $\Delta\phi$=15$^\text{o}$, and N_r =20. Consequently, the maximum color coordinate deviation is 0.015 in Δx and Δy axes and 4 cd/m^2 in ΔY axis; N_d= 266 and N_t= 5320. Because the number of sampled radial directions is large, the psychophysical experiment takes about two weeks for a reference color. Four chromaticity discrimination ellipsoids are measured and their reference colors are shown in Table I.

From a set of just discernible colors (JDCs) corresponding to a reference color, two chromaticity discrimination ellipsoids are calculated. The first is the statistic ellipsoid that is calculated following the method shown in [10]. The second is best fit ellipsoid that is calculated by fitting the formula

$$\mathrm{g}_{11}(\Delta \mathrm{x})^2 + \mathrm{g}_{22}(\Delta \mathrm{y})^2 + \mathrm{g}_{33}(\Delta Y)^2 + 2\mathrm{g}_{12}\Delta \mathrm{x}\Delta \mathrm{y} + 2\mathrm{g}_{23}\Delta \mathrm{y}\Delta Y + 2\mathrm{g}_{31}\Delta \mathrm{x}\Delta Y = 1, \tag{5}$$

where the g coefficients are fitting constants. The formula of statistic ellipsoid is the same as Eq.(5). Eq.(5) can be transformed to the cardinal coordinates $(\Delta x', \Delta y', \Delta Y')$ so that the ellipsoid is represented as

$$\left(\frac{\Delta x'}{a_x}\right)^2 + \left(\frac{\Delta y'}{a_y}\right)^2 + \left(\frac{\Delta Y'}{a_Y}\right)^2 = 1\ , \tag{6}$$

where a_x, a_y, and a_Y are the lengths of ellipsoid axes in $\Delta x'$, $\Delta y'$, and $\Delta Y'$ directions, respectively. The value of a_x is chosen to be larger than that of a_y, i.e., $\Delta x'$ is the long axis of the ellipse on $\Delta x'$ and $\Delta y'$ plane.

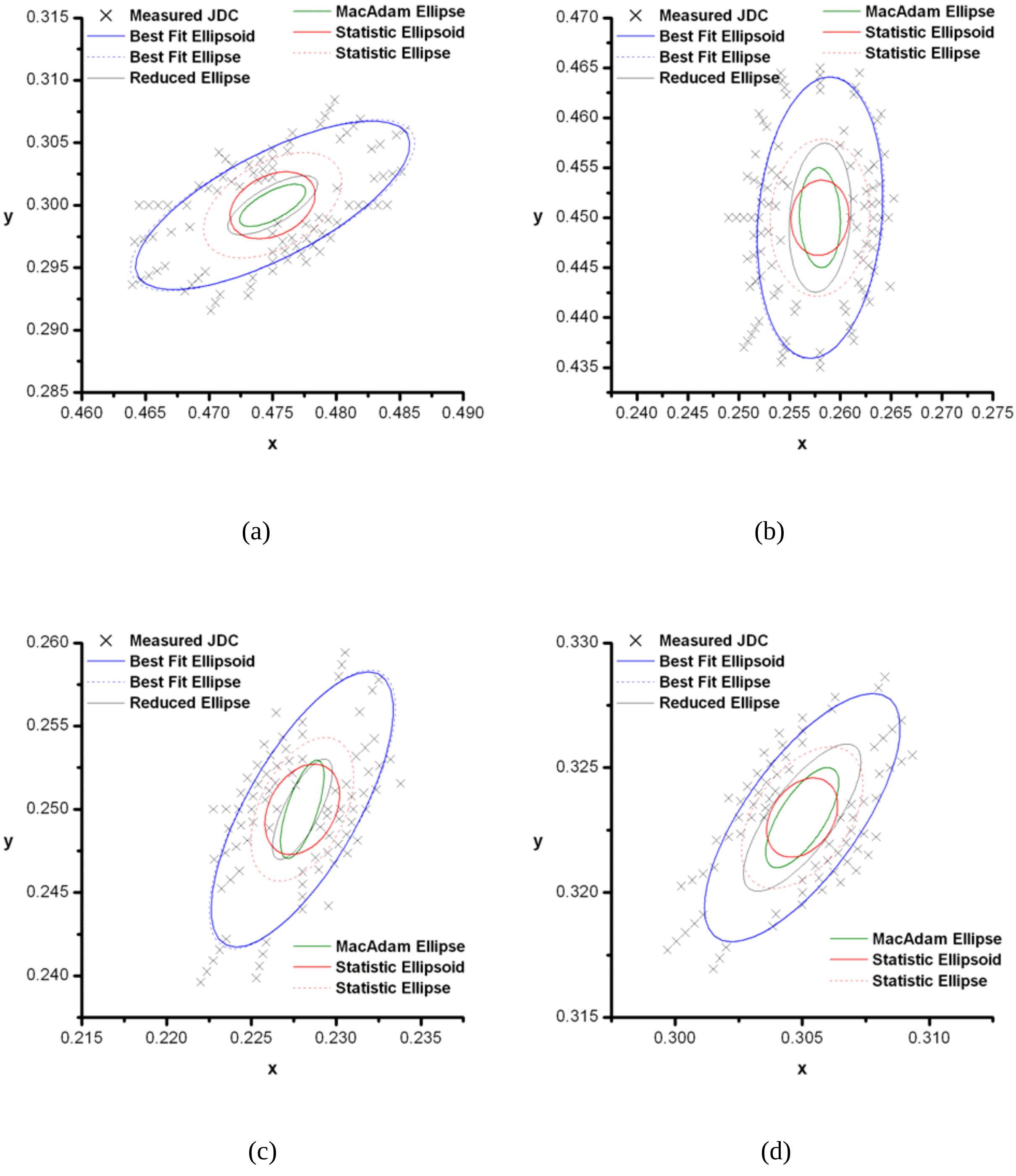


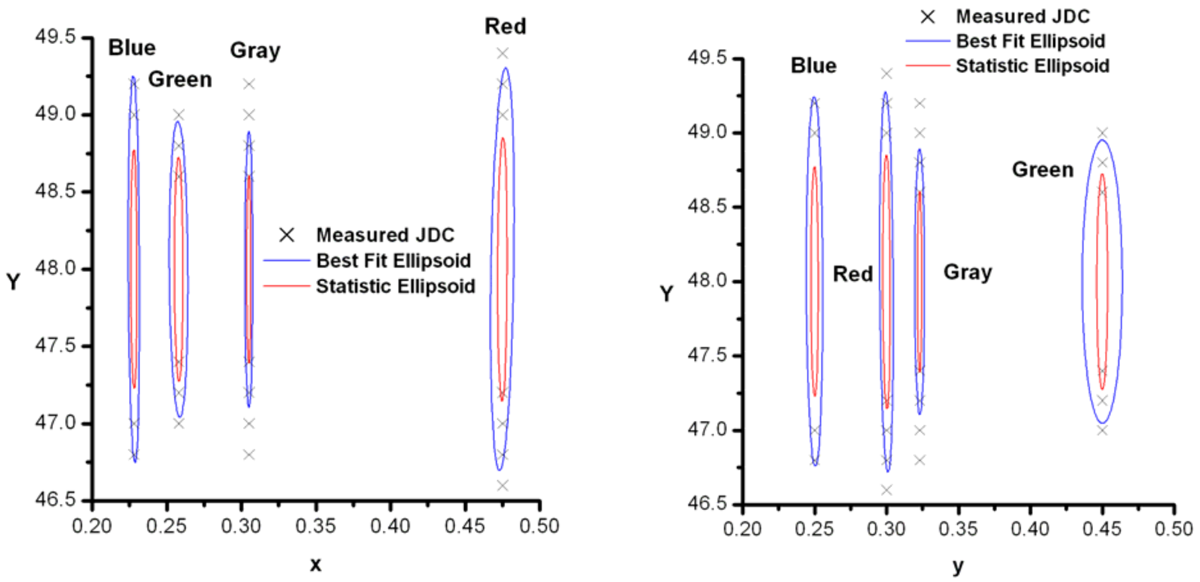
Fig 1. The cross sections of measured ellipsoids at Y= 48 cd/m^2 for (a) red, (b) green, (c) blue, and (d) gray reference colors. The measured JDCs of ten observers at Y= 48 cd/m^2 are shown. Corresponding MacAdam ellipses and reduced ellipses are also shown for comparison.

Table II. Numerical parameters of measured statistic ellipsoids

Color	Red	Green	Blue	Gray
a_x	0.003558	0.003772	0.002902	0.001725
a_y	0.002389	0.002833	0.001957	0.001215
a_Y	0.8570	0.7262	0.7758	0.6077
ψ_{YY}	1.13°	0.672 °	1.14 °	0.0574°

Table III. Numerical parameters of measured best fit ellipsoids

Color	Red	Green	Blue	Gray
a_x	0.01244	0.01418	0.009464	0.005876
a_y	0.004209	0.006192	0.003311	0.002252
a_Y	1.305	0.95851	1.302	0.8951
ψ_{YY}	5.58 °	2.59 °	7.33 °	0.247 °



(a) (b)

Fig 2. The cross sections of measured ellipsoids at (a) Δy =0 and (b) Δx =0 for red, green, blue, and gray reference colors. The measured JDCs of ten observers at $\Delta x = \Delta y$ =0 are shown.

3. Experimental Results

Tables II and III show the axis lengths of measured statistic ellipsoids and best fit ellipsoids, respectively. The angle between ΔY and $\Delta Y'$ axes are also shown in the two tables. The cross sections of measured ellipsoids at Y= 48 cd/m^2 for red, green, blue, and gray reference colors are shown in Fig. 1, in which the cross sections of statistic ellipsoids and best fit ellipsoids are shown with red and blue solid lines, respectively. The cross sections are ellipses on xy plane. In Fig.1, corresponding MacAdam ellipses are also shown with green solid lines for comparison. MacAdam ellipses are calculated with statistic method [10]. We can see that the cross sections of best fit ellipsoids are much larger than that of statistic ellipsoids. The measured JDCs of ten observers at Y= 48 cd/m^2 are shown in Fig.1 with cross symbols. The JDCs are well fitted by cross sections of best fit ellipsoids. The ratios of the axis lengths of cross sections of best fit ellipsoids represent the distribution of JDCs better than that of statistic ellipsoids.

Fig. 2(a) shows the cross sections of measured ellipsoids at (a) Δy =0 and (b) Δx =0, in which the cross sections of statistic ellipsoids and best fit ellipsoids are shown with red and blue solid lines, respectively.. The measured JDCs of ten observers at $\Delta x = \Delta y$ =0 are also shown in Fig.2 with cross symbols. Fig. 2 clearly shows that the just discernible luminance (JDL) depends on reference color. The dependence is not predicated by CIEDE2000. The ellipsoids slightly tilt about Y axis for red and blue reference colors. The axis lengths a_Y and tilt angles ψ_{YY} of the ellipsoids are shown in Tables II and III. The JDLs of red and gray reference colors are the maximum and minimum among the four reference colors. From Tables II and III, the ratios of the maximum JDL and minimum JDL are 1.41 and 1.45 for statistic ellipsoids and best fit ellipsoids, respectively. The tilt angles ψ_{YY} is larger for red and blue reference colors.

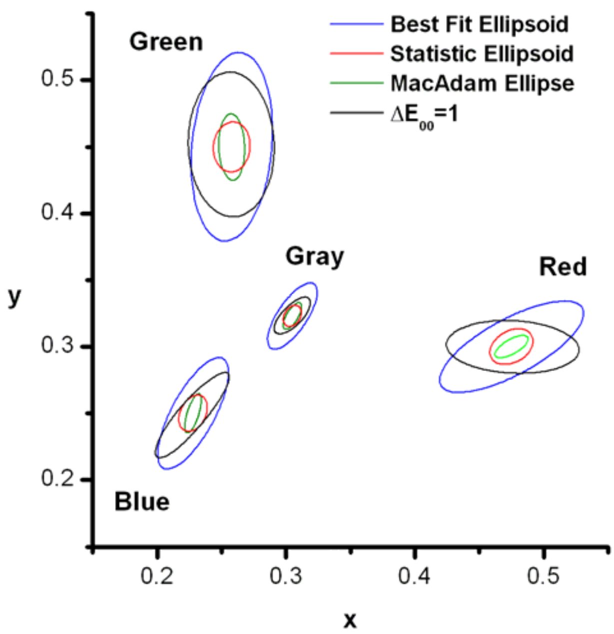


Fig. 3. The cross sections of measured ellipsoids at Y= 48 cd/m^2 for red, green, blue, and gray reference colors. Corresponding MacAdam ellipses and CIEDE2000 ellipses with ΔE_{00} =1 are also shown for comparison.

A statistic ellipsoid is calculated on the assumption of normal distribution. The axis length of a statistic ellipsoid is the standard deviation of the normal distribution. This is the reason that the size a statistic ellipsoid is smaller than that of a best fit ellipsoid. Since there are only ten observers in our experiment, the use of statistic method for calculating a chromaticity discrimination ellipsoid may not be proper. From the results shown above, when the number of observers is not large enough, the use of fitting method is a better choice so that the characteristics of measured JDCs can be better described by the calculated chromaticity discrimination ellipsoid.

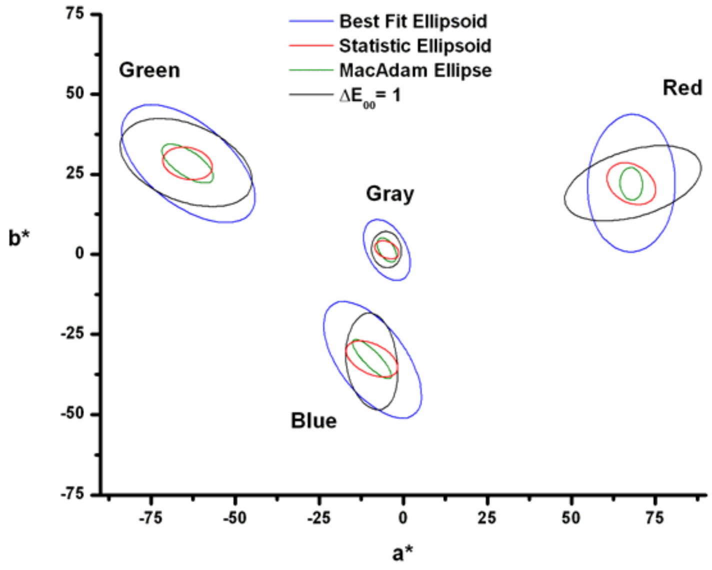


Fig. 4. The same as Fig. 3 except that the cross sections are shown in a*b* plane of CIELAB.

Fig.3 shows the cross sections of measured ellipsoids at Y= 48 cd/m^2 for red, green, blue, and gray reference colors. Corresponding MacAdam ellipses and CIEDE2000 ellipses with ΔE_{00} =1 are also shown for comparison. All cross sections and ellipses are enlarged fivefold so that they can be clearly shown. Fig. 4 shows the same case as Fig. 3 except that that the cross sections and ellipses are shown in a*b* plane of CIELAB. The illuminant C is taken as the reference white of CIELAB. From Fig.4, we can see that the directions of the long axes of the CIEDE2000 ellipses with ΔE_{00}=1 point at origin, in which (a*, b*) = (0, 0). Also from Fig.4, the long axis directions of the cross sections of measured ellipsoids and MacAdam ellipses do not point at origin, especial for the cases of red and blue reference colors.

From Fig.1, the differences between the cross sections of measured ellipsoids and MacAdam ellipses may be due to the observer factor, room lighting, and other viewing conditions. However, it is evident that the predictions of JDL and the long axis direction of the cross section of chromaticity discrimination ellipsoid by CIEDE2000 are not accurate

4. Simplified Chromaticity Discrimination Ellipsoid

From Section III, the development of more accurate color difference formula is necessary. However, it requires a large number of reference colors with a variety of xy color coordinates and Y luminance for deriving a color difference formula. If xy color coordinates and luminance of reference colors are sampled in steps of 0.05 and 25 cd/m^2, respectively, it is estimated that the number of reference colors is about 500 for a WCG display with 450 cd/m^2 luminance. The measurement of a chromaticity discrimination ellipsoid is time consuming. The measurement of 500 chromaticity discrimination ellipsoids takes 250 months for two weeks per reference color in our experiment. The small tilt angle ψ_{YY} shown in Tables II and III suggests that we may neglect the tilt angle of chromaticity discrimination ellipsoid. Then, for a reference color, the JDCs at its luminance and the JDLs at its xy color coordinates are measured for calculating its simplified chromaticity discrimination ellipsoid without the tilt angle about Y axis. A chromaticity discrimination ellipse is calculated from the measured JDCs. The length of ΔY axis is calculated from the measured JDLs. Thus, the number of sampled radial directions in psychophysical experiment can be reduced from 266 to 22 for a reference color. Total required experimental time is reduced to 21 months accordingly.

The statistic ellipses and best fit ellipses are shown Fig. 1 for red, green, blue, and gray reference colors, in which statistic ellipses and best fit ellipses are shown with red and blue dashed lines, respectively. We can see that best fit ellipses agree with the cross sections of best fit ellipsoids well, while statistic ellipses do not agree with the cross sections of statistic ellipsoids. As is indicated in Section III, the use of best fit ellipsoid is better for describing the characteristics of distribution of JDCs. The average JDLs are taken as the length of ΔY axis of the simplified best fit ellipsoid and they are 1.13 cd/m^2, 0.82 cd/m^2, 1.19 cd/m^2, and 0.83 cd/m^2 for red, green, blue, and gray reference colors, respectively. The average JDLs are smaller than the corresponding axis lengths a_Y shown in Table III mainly due to the tilt of chromaticity discrimination ellipsoid about Y axis.

It is noticed that most of the measured JDCs lie outside of the cross sections of statistic ellipsoids. This represents that the colors within statistic ellipsoids cannot be discriminated by most observers. We define a reduced simplified best-fit ellipsoid so that the measured JDCs just outside of the best fit ellipse. The reduced ratios are 0.332, 0.486, 0.332, and 0.548 for red, green, blue, and gray reference colors. The reduced best fit ellipses are shown Fig. 1 with black solid lines for red, green, blue, and gray reference colors. We can see that the sizes of reduced best fit ellipses are close to that of the cross sections of statistic ellipsoids and MacAdam ellipses. Although the value of a reduced ratio quite depends on observer factor, it is a useful reference from the results shown in Fig.1.

5. Conclusions

Chromaticity discrimination ellipsoids are measured with an LCD. Spatial-dithering method is applied to the LCD for effectively increasing bit depth per channel from 8 to 11 so that color patches of tiny color difference can be displayed. The measured ellipsoids of four reference colors at red, green, blue, and gray color regions are shown. From a set of just discernible colors of ten observers corresponding to a reference color, two ellipsoids are calculated with statistic method and fitting method. The results show that the distribution of just discernible colors can be better described with the best fit ellipsoid. The measured ellipsoids of red and blue reference colors slightly tilt about luminance axis. It is shown that the length of luminance axis of an ellipsoid depends on reference color and is longer for red and blue reference colors. The ratios of the maximum and minimum length of luminance axes among the four measured reference colors are 1.41 and 1.45 for statistic ellipsoids and best fit ellipsoids, respectively. The long axis directions of the constant-luminance cross sections of measured ellipsoids do not point at the origin of CIELAB. As these experimental results cannot be predicted by CIEDE2000, the development of more accurate color difference formula is necessary. The measurement of a chromaticity discrimination ellipsoid is time consuming. The measurement time is two weeks for a reference color in our experiment. Several hundreds of chromaticity discrimination ellipsoids are required for deriving a new color difference formula for display applications. It is impractical to measure all the required ellipsoids. A simplified best fit ellipsoid is defined, in which the tilt of ellipsoid about luminance axis is neglected. The required time can be significantly reduced for measuring the simplified best fit ellipsoid. The main characteristics of the distribution of observers' just discernible colors also can be well described with the simplified best fit ellipsoid. The collection of experimental data is undertaken and results will be published elsewhere.

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行政院國家科學委員會補助團隊參與國際學術組織會議報告

100 年5 月 27日

報告人姓名	溫盛發	服務機構	中華大學	職稱	教授
會議正式名稱	中文：資訊顯示器學會 2011 國際學術會議 英文：Society for Information Display (SID) 2011 International Symposium				
會議時間	自 100 年 5 月 15 日 至 100 年 5 月 20 日	地點（國、州、城市）	美國，加州，洛杉磯		

報告內容應包括下列各項：

一、參加會議經過

二、與會心得

三、考察參觀活動（無是項活動者省略）

四、建議事項

五、其他

一、參加會議經過

國際最著名的顯示器學術組織 SID 每年於五月舉辦學術會議，是世界規模最大的顯示器學術會議，今年(2011)是第 49 屆在美國加州洛杉磯會議中心舉辦。由於顯示器產業蓬勃發展，參與人數眾多。按照大會提供的資料，今年有 669 篇論文投稿，接受發表的有 280 篇口頭報告論文與 221 篇壁報論文。所發表的論文主要特色有 3D 顯示器、觸控螢幕、OLED、電子紙、軟版顯示器、投影機、節能綠色技術與固態照明等。

圖一　展覽會入口左邊現場照片

圖二　展覽會入口右邊現場照片

歷年 SID 會議的主角其實是國際知名大公司，如韓國的 Samsung 與 LG，美國的 3M，日本的 Sony、Toshiba 與 NEC，與荷蘭的 Philips 等。這些大公司積極參論文發表與展覽會(Exhibition)。台灣的友達與奇美過去也曾積極參與 SID，2008 年金融風暴後已逐漸淡出。今年比較特別的是 Samsung 獨佔熬頭，不僅是論文發表積極，在展覽會現場的攤位也可以明顯看出與其他公司的消長。圖一與圖二分別為展覽會入口左右兩邊的現場照片，入口第一線攤位僅有 Samsung 是顯示器廠商而已，其攤位不但最大，而且接待與說明人員主要都是西方人，有別於以往由韓國人擔綱，以顯示其國際化程度。值得一提的是 SONY 沒有參展，而且除 Samsung 有展示新型家用顯示器以外，其他有參展的公司如 LG、Toshiba 與 NEC 所展示的項目主要是特殊用途顯示器與零組件。總之，Samsung 已確立全世界顯示產業龍頭的地位。很多人批評 Samsung 有韓國政府支持與品牌，使得其沒有後顧之憂，可以全力拼研發與開拓市場。由本人幾年來觀察顯示器產業的消長，Samsung 除了有韓國政府的支持與品牌，比其他

公司重視研發是更重要的因素。Samsung 除了內部研發規模龐大，非其他公司可比，外部更與全世界其他數一數二的公司與研發人員技術合作。他們的工程師對技術合作對象問的問題很深入，其探索問題態度與台灣的工程師只要能解決問題就好是有很大的不同。另一個比較的例子是 SONY，在 20 世紀 SONY 由於其 Triniton CRT 技術，成為世界 CRT 顯示器產業的霸主。但後來 SONY 著重品牌經營，在 LCD 的研發不如 Samsung，終於在 21 世紀初將顯示器產業霸主拱手讓與 Samsung。由此可見研發的重要性。

台灣工研院參展的軟版觸控式 AMOLED 顯示器榮獲大會年度顯示器零組件銀牌獎，是多年來台灣在 SID 少見的獲獎項目，可說是台灣之光。年度顯示器零組件金牌獎得主是 E-Ink 的彩色電子紙。今年在台北花博展中，工研院已有展示其得獎的軟版 AMOLED 顯示器，並對其研發過程在媒體上做詳細介紹。工研院近年來經費拮据，仍有重要研發突破，可謂相當難得。由這個例子可以看出，台灣還是有一定的研發實力。但放眼未來，除非台灣產官學能夠整合足以與 Samsung 匹敵的研發量能，否則還是只能淪為代工的命運。由 CRT TV 的歷史，當 CRT 顯示器產業成熟後，只有老大與老二還能獲利，老三頂多打平，排在後面的不能獲利。現今 LCD TV 產業的老大是 Samsung，老二是 LG，因此其他公司危矣。今年 SID 展覽會中的 Toshiba 主要展示特殊用途 LCD，有可能是認清情勢，往利基型顯示器發展，避免與韓國公司正面競爭。畢竟 LCD 用途廣泛，不只是 LCD TV 而已。

本人在 5 月 19 日下午做壁報論文展示，題目是 A Color Space Derived from CIELUV for Display Color Management。這篇論文提出使用視覺均勻色彩空間座標表示視訊的方法，這方法具有利於色彩管理與節省信號位元數目的優點。以視覺均勻色彩空間座標表示視訊的一大問題是需要能即時算出顯示器色域邊界，本論文中也提出快速計算方法，使得能運用於視訊及時運算，實現即時有彈性與精確的顯示器色彩管理。現場對此論文發問的與會者多不瞭解為何要用視覺均勻色彩空間座標表示視訊，以及計算顯示器色域邊界的重要性。這是因為業界使用 RGB 信號的延伸色彩空間如 YCbCr、YIQ 與 YUV 等做色彩管理，經本人解說後都能接受這個方法的重要性。預期若這個方法能為各方接受，未來將是顯示器色彩管理技術的一大突破。發表壁報論文的好處是，透過現場展示在壁報上的論文內容，作者可以直接跟與會人士做更深入的討論，溝通效果要比口頭報告與大會安排的 Author Interview 的效果好。

一般學術會議的口頭報告，報告人當場能回答問題的時間很有限。SID 有一特別的安排以彌補這缺陷。論文發表當天的議程結束後，大會提供大型場地，舉行一個小時的 Author Interview。每位報告人一個攤位，使報告人與聽眾能直接面對面討論問題。另外，有些報告人在口頭報告中沒時間展示的軟硬體，便在其攤位上展示給觀眾看。不管是壁報論文展示或口頭報告的 Author Interview 都可看到有若干作者在其攤位上安排硬體展示，供與會人士實際參觀與現場討論其研究成果。

在壁報論文展示前，有兩篇來自日本的論文之作者各自花了約兩個小時現場組裝他們的實驗裝置，都是展示新型的 Integral Imaging 立體顯示器。論文展示期間，兩個攤位的參觀者絡繹不絕，作者與參觀者熱烈討論，很有學術交流的氣氛。Integral Imaging 立體顯示器雖然還不成熟，但未來會是立體顯示器熱門的研究項目，主要是因為觀賞時不用帶眼鏡，而且對視力也沒有負擔。

二、與會心得

1. 由這幾年參與 SID 會議的觀察，四、五年前各國的顯示器公司還仍在 SID 的論文發表與展覽會上呈現百家爭鳴的競爭態勢。但現在各國的顯示器公司表現消長很明顯，韓國已確立其霸主地位。產業現實上，台灣公司淪為代工公司，日本公司則在掙扎中，希望能另闢生存之道。

2. 十年前，韓國顯示器產業遠不如台灣，更不必說與日本相比，現今回首不禁令人噓唏。Samsung 除了公司內部研發量能龐大，以前便很能善用各國的研究資源。去年(2010)年初 Samsung 更透過 SID 廣發英雄帖，目的在透過 SID 這個平台，建立全世界研發人員的資料庫，並對外委託研究計畫。身為產業霸主的 Samsung，不只是有韓國政府的支持與品牌效應而能致之。在當代自由貿易與保護智慧財產的世界，注重研發才是王道。

3. 經本人在壁報論文發表現場解說，參觀人員都能接受使用視覺均勻色彩空間座標表示視訊的方法之重要性。預期若這個方法能為各方接受，未來將是顯示器色彩管理技術的一大突破。

三、建議事項

1. 鑑於上述與會心得，放眼未來，除非台灣產官學能夠整合足以與 Samsung 匹敵的研發量能，否則還是只能淪為代工的命運。

2. 本人在會議論文中所提出的使用視覺均勻色彩空間座標表示視訊的方法，值得國內相關業者重視。

四 、攜回資料名稱及內容

1. 會議論文光碟。

國科會補助計畫衍生研發成果推廣資料表

日期:2011/10/31

國科會補助計畫	計畫名稱: 色彩辨別橢圓之研究
	計畫主持人: 溫盛發
	計畫編號: 99-2221-E-216-015- 學門領域: 顯示技術

無研發成果推廣資料

99 年度專題研究計畫研究成果彙整表

計畫主持人：溫盛發			計畫編號：99-2221-E-216-015-				
計畫名稱：色彩辨別橢圓之研究							
成果項目			量化			單位	備註（質化說明：如數個計畫共同成果、成果列為該期刊之封面故事...等）
			實際已達成數（被接受或已發表）	預期總達成數(含實際已達成數)	本計畫實際貢獻百分比		
國內	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%		
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（本國籍）	碩士生	2	2	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		
國外	論文著作	期刊論文	0	0	100%	篇	
		研究報告/技術報告	0	0	100%		
		研討會論文	1	1	100%		
		專書	0	0	100%	章/本	
	專利	申請中件數	0	0	100%	件	
		已獲得件數	0	0	100%		
	技術移轉	件數	0	0	100%	件	
		權利金	0	0	100%	千元	
	參與計畫人力（外國籍）	碩士生	0	0	100%	人次	
		博士生	0	0	100%		
		博士後研究員	0	0	100%		
		專任助理	0	0	100%		

其他成果 (無法以量化表達之成果如辦理學術活動、獲得獎項、重要國際合作、研究成果國際影響力及其他協助產業技術發展之具體效益事項等，請以文字敘述填列。)	無

	成果項目	量化	名稱或內容性質簡述
科教處計畫加填項目	測驗工具(含質性與量性)	0	
	課程/模組	0	
	電腦及網路系統或工具	0	
	教材	0	
	舉辦之活動/競賽	0	
	研討會/工作坊	0	
	電子報、網站	0	
	計畫成果推廣之參與（閱聽）人數	0	

國科會補助專題研究計畫成果報告自評表

請就研究內容與原計畫相符程度、達成預期目標情況、研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）、是否適合在學術期刊發表或申請專利、主要發現或其他有關價值等，作一綜合評估。

1. 請就研究內容與原計畫相符程度、達成預期目標情況作一綜合評估

■達成目標

□未達成目標（請說明，以 100 字為限）

□實驗失敗

□因故實驗中斷

□其他原因

說明：

2. 研究成果在學術期刊發表或申請專利等情形：

論文：□已發表 □未發表之文稿 ■撰寫中 □無

專利：□已獲得 □申請中 ■無

技轉：□已技轉 □洽談中 ■無

其他：（以 100 字為限）

3. 請依學術成就、技術創新、社會影響等方面，評估研究成果之學術或應用價值（簡要敘述成果所代表之意義、價值、影響或進一步發展之可能性）（以 500 字為限）

色差公式是色彩學的基本工具，目前最新版的色差公式 CIEDE2000 由色彩辨別橢圓所推導。由本計畫所測量的色彩辨別橢圓體明顯指出，目前的色差公式在顯示器應用上存有問題，主要是長短軸方向與沒有考慮亮度色差與色彩之色調和飽和度的關係。我們提出建議的實驗，未來能由實驗結果推導適用於顯示器的更精確色差公式。