# Constructing uniform color space in CIECAM97s*

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**Abstract** The uniformity of two pairs of color spaces based on CIE 1997 color appearance model (CIECAM97s) is analyzed according to color-discrimination ellipses that are constructed using color-difference evaluation data. A new uniform color space named $J_{ucs}a_{ucs}b_{ucs}$ is deduced by re-scaling the coordinates of lightness, redness-greenness and yellowness-blueness in two initial color spaces using linear regression method. The uniformity of the new color space is obviously improved compared with the initial color spaces.

**Keywords:** CIECAM97s, uniform color space, color-discrimination ellipses.

The CIECAM97s[1, 2] was recommended as the first color appearance model by the Commission International de I'Eclairage (CIE) in May, 1997. The CIECAM97s was deduced by evaluating the existing color appearance models, which combines the advantages of those models. It is only a simple version in practical use under limited conditions.

To utilize the CIECAM97s in evaluating color-difference, a uniform color space suitable for the CIECAM97s has to be constructed. Two initial color spaces $Ja_1b_1$ and $Ja_2b_2$ defined by the color appearance descriptors of CIECAM97s and suggested by Professor Luo[1)] are as follows:

$$Ja_1b_1\text{: } a_1 = 100(10/130)a,\ b_1 = 100(10/13)b;\ Ja_2b_2\text{: } a_2 = C\cos(h),\ b_2 = C\sin(h),$$

where $a$ is the redness-greenness, $b$ the yellowness-blueness, $J$ the lightness, $C$ the chroma and $h$ the hue angle for describing the color appearance in the CIECAM97s. These descriptors are calculated using input data and environmental parameters.

In this paper, the uniformity of these color spaces will be analyzed and a new uniform color space will be deduced from color-discrimination ellipses constructed using color-difference evaluation data.

## 1 Examination of uniformity of $Ja_1b_1$ and $Ja_2b_2$

The color-discrimination ellipsoids (or ellipses at some sections) constructed with the visual data of color-difference evaluation can test the uniformity of a color space[3]. The color-difference evaluation data named BFD-CP[4] obtained by Bradford University using gray-scale method were employed in our research.

In the study the BFD-CP data expressed in CIE $L^*a^*b^*$ color space[5] were first transformed into

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1) Luo, M. R. A preliminary plan for the study group on CIECAM97s applied to colour-difference evaluation. In: Report of the October 1 Meeting to Develop the TC1-47 Working Program (ed. Almanm, D. H.) 1998, 5.

$Ja_1b_1$ and $Ja_2b_2$ spaces, and then 45 reliable ellipsoids were constructed in the two spaces. The shape and distribution of the ellipses on the chromaticity planes $a_1$-$b_1$, $J$-$a_1$, $J$-$b_1$, $a_2$-$b_2$, $J$-$a_2$ and $J$-$b_2$ were also obtained. The ellipses on the chromaticity planes $a_1$-$b_1$ and $a_2$-$b_2$ are shown in Figure 1.

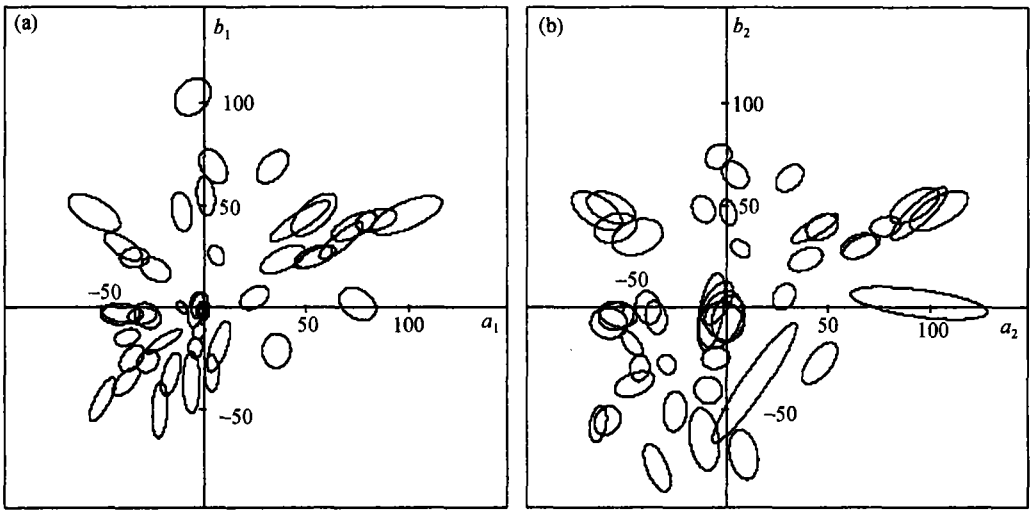


Fig. 1 Color-discrimination ellipses on the planes $a_1$-$b_1$(a) and $a_2$-$b_2$(b).

As shown in Fig. 1(a), on the $a_1$-$b_1$ plane the ellipses in different color areas are of regular angles of deviation, and the sizes of the ellipses increase with the increasing absolute values of $a_1$ and $b_1$, which is consistent with the situation on $x$-$y$ and $a^*$-$b^*$ chromaticity planes[4,5]. In Fig. 1(b), however, the foregoing phenomena are not obvious but the ellipticity of the ellipses is smaller in general.

The average size $A_s$, the standard deviation of size $D_{ss}$, the average of ellipticity $A_e$ and standard deviation of ellipticity $D_{se}$ on different chromaticity planes are listed in Table 1, with the ellipse's sizes calculated by $(\pi ab)^{1/2}$ and the ellipticity by $a/b$, where $a$ is the longer axis and $b$ the shorter axis of an ellipse.

Table 1 Statistical results of ellipse's sizes and ellipticity on different chromaticity planes in color spaces $Ja_1b_1$ and $Ja_2b_2$

| Chromaticity plane | $A_s$ | $D_{ss}$ | $A_e$ | $D_{se}$ |
|---|---|---|---|---|
| $a_1$-$b_1$ | 3.7696 | 0.7889 | 2.1658 | 0.6386 |
| $J$-$a_1$ | 2.5751 | 0.7393 | 3.0915 | 1.4866 |
| $J$-$b_1$ | 2.6411 | 0.7903 | 3.1443 | 1.7282 |
| $a_2$-$b_2$ | 4.6485 | 1.0616 | 1.9508 | 0.6428 |
| $J$-$a_2$ | 2.8586 | 0.7532 | 3.6326 | 2.0132 |
| $J$-$b_2$ | 2.9369 | 0.8724 | 3.6045 | 1.8326 |

In Table 1, $D_{ss}$, $D_{se}$ and $A_e$ are the indications to evaluate whether the chromaticity plane is uniform or not. The standard deviations of the sizes and ellipticities on $a_1$-$b_1$ plane are smaller than those on $a_2$-$b_2$ plane, but the average of the ellipticities on $a_2$-$b_2$ plane is smaller, which can be

seen directly in Fig. 1(b). In addition, the three indications mentioned above on $J$-$a_1$ and $J$-$b_1$ planes are all smaller than on $J$-$a_2$ and $J$-$b_2$ planes. This demonstrates that the chromaticity planes $J$-$a_1$ and $J$-$b_1$ in color space $Ja_1b_1$ are more uniform than the planes $J$-$a_2$ and $J$-$b_2$ in color space $Ja_2b_2$. But the two color spaces are not uniform enough, so it is necessary to construct a more uniform color space.

## 2 Deduction of a more uniform color space

### 2.1 From the space $Ja_1b_1$ to the space $J'a'_1b'_1$

Take $\Delta J/\Delta E_1 > 0.85$ as a criterion, where $\Delta J$ is the lightness-difference and $\Delta E_1$ the color-difference of samples in the space $Ja_1b_1$. Then 68 pairs of color-difference samples can be obtained from the BFD-CP data. The relation between $\Delta J/\Delta V$ (where $\Delta V$ is the visual evaluation of color-difference) and $J$ can then be obtained as plotted in Fig. 2(a) in accordance with these data which have only difference in lightness. The values of $\Delta J/\Delta V$ of dots have an obviously increasing tendency with the increase of $J$ as shown in Fig. 2(a), which demonstrates that the lightness-difference depends obviously on the lightness variation in $Ja_1b_1$ space. By the linear regression of these data, the relation between $\Delta J/\Delta V$ and $J$ can be written as

$$\Delta J/\Delta V = 0.0144J + 0.5419. \tag{1}$$

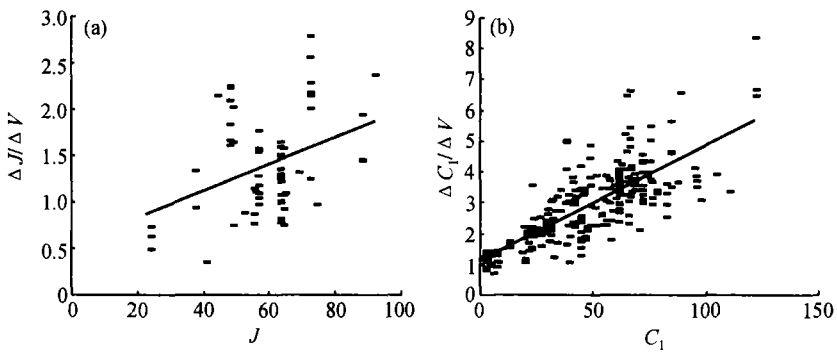


Fig. 2 Relations between lightness-difference and lightness (a), and between chroma-difference and chroma (b) in $Ja_1b_1$ color space.

In order to ensure that the lightness-difference does not change with the variation of lightness in the new color space of $J'a'_1b'_1$, Formula (1) is rewritten as the following differential formation:

$$dJ' = dJ / (0.0144J + 0.5419), \tag{2}$$

where $J$ is the lightness which is calculated based on CIECAM97s without scale adjustment. Integrating Eq. (2), the uniform lightness scale $J'$ can be obtained

$$J' = \int_0^J dt/(0.0144t + 0.5419) = (\ln(0.0144J + 0.5419) + 0.6127)/0.0144. \tag{3}$$

By the criterion of $\Delta C_1/\Delta E_1 > 0.95$, 242 pairs of color-difference data can be obtained, where

$\Delta C_1$ is the chroma-difference of samples in the color space $Ja_1b_1$. From Fig. 2(b), the relation between $\Delta C_1/\Delta V$ and $C_1$ in color space $Ja_1b_1$ can be defined by linear regression as

$$\Delta C_1/\Delta V = 0.0375C_1 + 1.1389. \tag{4}$$

In order to ensure that the chroma-difference does not change with the variation of chroma in the new color space of $J'a'_1b'_1$, in the same way we obtain the uniform chroma scale $C'_1$

$$dC'_1 = dC_1 / (0.0375C_1 + 1.1389), \tag{5}$$

$$C'_1 = \int_0^{C_1} dt/(0.0375t + 1.1389) = (\ln(0.0375C_1 + 1.1389) - 0.1301)/0.0375, \tag{6}$$

where $C_1$ is the chroma in the initial color space $Ja_1b_1$ without scale adjustment.

Assume that the adjustments of coordinates $a_1$ and $b_1$ mainly relate to the variety of the chroma. Then the uniform red-green chromaticity $a'_1$ and the uniform yellow-blue chromaticity $b'_1$ can be calculated with

$$a'_1 = a_1 f(C_1), \quad b'_1 = b_1 f(C_1), \tag{7}$$

where

$$f(C_1) = C'_1/C_1 = \frac{\ln(0.0375C_1 + 1.1389) - 0.1301}{0./0375C_1}.$$

The expression for $J'a'_1b'_1$ are Equations (3) and (7).

## 2.2 From the space $Ja_2b_2$ to the space $J'a'_1b'_1$

The uniform lightness scale $J'$ in the color space $J'a'_2b'_2$ is the same as in the space $J'a'_1b'_1$ and also given by Eq. (3). The deduction of the uniform chroma scale $C'_2$ is similar to that of $C_1$. Take $\Delta C_2/\Delta E_2 > 0.95$ as a criterion. Then 176 pairs of color-difference data can be obtained, where $\Delta C_2$ and $\Delta E_2$ are the chroma-difference and total color-difference in the color space $Ja_2b_2$ respectively. By processing the data shown in Fig. 3 by linear regression, the relation between $\Delta C_2/\Delta V$ and the chroma $C_2$ in the color space $Ja_2b_2$ can be obtained

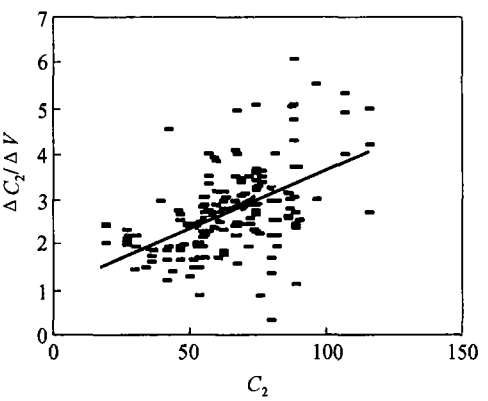


Fig. 3 Relation of chroma-difference and chroma in $J_2a_2b_2$ color space.

$$\Delta C_2/\Delta V = 0.0256C_2 + 1.0896. \tag{8}$$

In the same way, the uniform chroma scale $C'_2$ can be obtained as follows:

$$dC'_2 = dC_2 / (0.0256C_2 + 1.0896), \tag{9}$$

$$C'_2 = \int_0^{C_2} dt/(0.0256t + 1.0896) = (\ln(0.0256C_2 + 1.0896) - 0.0858)/0.0256, \tag{10}$$

where $C_2$ is the chroma in the initial color space $Ja_2b_2$. And

$$a'_2 = a_2 f(C_2), \quad b'_2 = b_2 f(C_2), \tag{11}$$

where

$$f(C_2) = C'_2/C_2 = \frac{\ln(0.0256C_2 + 1.0896) - 0.0858}{0.0256C_2}.$$

Equations (3) and (11) are the expressions of space $J'a'_2b'_2$.

## 3 Uniformity testing of color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$

To test the uniformity of color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$, the color-difference data in the space CIE $L^*a^*b^*$ should be transformed into the one in color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$, and color-discrimination ellipses can then be constructed in color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$. By processing data and testing the reliability of the ellipsoids, 60 reliable ellipsoids have been obtained. The shape and distribution of 60 corresponding ellipses on planes $a'_1 - b'_1$, $J' - a'_1$, $J' - b'_1$ and $a'_2 - b'_2$, $J' - a'_2$, $J' - b'_2$ have also been obtained, and the ellipses on the chromaticity planes $a'_1 - b'_1$ and $a'_2 - b'_2$ are shown in Figure 4.

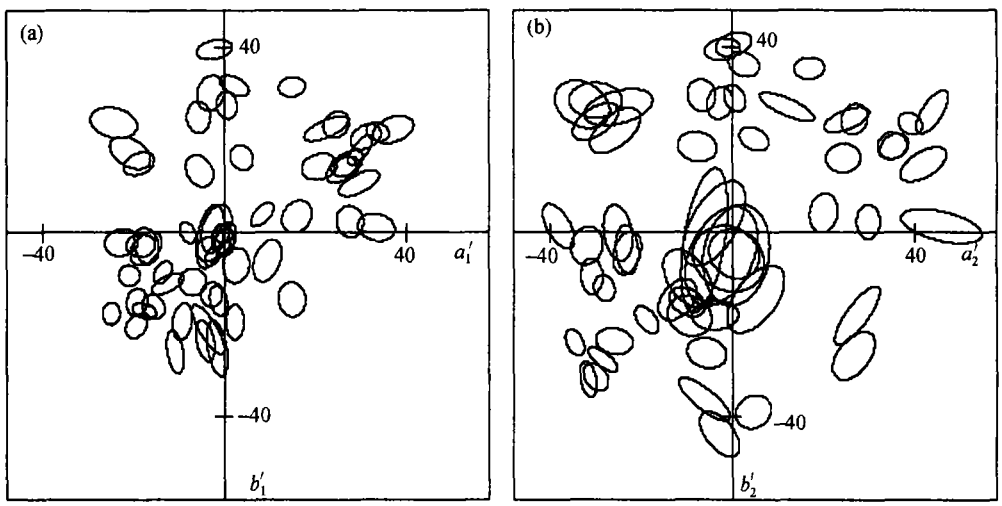


Fig. 4 Distribution of color-discrimination ellipses on planes $a'_1 - b'_1$(a) and $a'_2 - b'_2$(b).

Figure 4 shows that the difference in ellipse sizes and the ellipticity of the ellipses are small in general and the uniformity of the two color spaces is obviously improved. In addition, the uniformity of ellipse's sizes and ellipticities in Fig. 4(a) is much better than that in Fig. 4(b). Some statistical results on each chromaticity plane are listed in Table 2.

As shown in Table 2, the averages of sizes $A'_s$ and ellipticities $A'_e$, the standard deviation of sizes $D'_{ss}$ and ellipticities $D'_{se}$ on each chromaticity plane in color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$ are smaller than those on corresponding chromaticity planes in color spaces $Ja_1b_1$ and $Ja_2b_2$. The uniformity of the color space is improved. Furthermore, the values of four statistical results in $J'a'_1b'_1$ are all smaller than those on corresponding chromaticity planes in $J'a'_2b'_2$. So we can select the $J'a'_1b'_1$ as the new uniform color space based on CIECAM97s and name it $J_{ucs}a_{ucs}b_{ucs}$, which can be ex-

pressed by Equations (3) and (7).

Table 2 Statistical results of ellipses' size and ellipticity at each chromaticity plane in color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$

| Chromaticity plane | $A'_s$ | $D'_{ss}$ | $A'_e$ | $D'_{se}$ |
|---|---|---|---|---|
| $a'_1$-$b'_1$ | 1.7001 | 0.2664 | 1.6626 | 0.3837 |
| $J'$-$a'_1$ | 1.5603 | 0.4326 | 2.1571 | 0.7937 |
| $J'$-$b'_1$ | 1.6607 | 0.4924 | 2.4393 | 1.0850 |
| $b'_2$-$b'_2$ | 2.4009 | 0.6632 | 1.7738 | 0.4612 |
| $J'$-$a'_2$ | 1.7780 | 0.5046 | 2.8897 | 1.4788 |
| $J'$-$b'_2$ | 1.7912 | 0.5664 | 2.8782 | 1.4830 |

## 4 Conclusion

By investigating the uniformity of the color spaces $Ja_1b_1$ and $Ja_2b_2$ based on CIECAM97s by processing the experimental data, two new color spaces $J'a'_1b'_1$ and $J'a'_2b'_2$ are deduced. The results show that $J'a'_1b'_1$ and $J'a'_2b'_2$ are more uniform than $Ja_1b_1$ and $Ja_2b_2$ respectively, and $J'a'_1b'_1$ is more uniform than $J'a'_2b'_2$. So we propose $J'a'_1b'_1$(named $J_{ucs}$-$a_{ucs}b_{ucs}$) as the uniform color space based on CIECAM97s.

## References

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