133. Comparison among Several Methods of Specifying Colour Rendering Properties

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1.INTRODUCTION

Perceived colour appearances of object colours depend on the kind of an illuminating light source. Such property of a light source which exert influences on perceived colour attributes is termed colour rendering property. For the specification of colour rendering properties of light sources, the CIE recommended the uniform colour space *U*V*W** in 1974 to calculate colorimetric quantities of test colours under the test and the reference illuminants. However, this colour space has been used only for the calculation of the colour rendering indices and not for other colorimetric purposes. This space is inadequate to specify coordinates of colours because of spatial distortions in the regions of red and green colours.

Recently, a new method for the assessment of colour rendering using CIE chromatic adaptation formulae and the uniform colour space *L*a*b** is also proposed to CIE Technical Committee 1-33. In *L*a*b** space, however, chroma is estimated larger in the yellow region, and conversely smaller in the blue region. For the reason of these spatial distortions in the *U*V*W** space and the *L*a*b** space, three components of colour shift, i.e., differences of hue, value and chroma, cannot be represented independently. On the other hand, new uniform colour space NC-IIIC, which has been developed in our laboratory, can specifies three attributes independently.

In this study, in order to investigate perceived colour shifts under various light sources, visual evaluation experiments are executed under the illuminations of practical fluorescent lamps, a Xenon lamp and an incandescent lamps. In addition, colorimetric quantities of test colour samples prescribed in JIS and MacBeth Colour Checker samples under various light sources are calculated in the *U*V*W** space, the *L*a*b** space and the new colour space NC-IIIC. Moreover, predicted colour shifts calculated in each colour spaces are compared with perceived colour shifts. Colour rendering indices are calculated using three estimation methods, i.e., the method recommended by the CIE, the method proposed in CIE TC1-33 and the method using the NC-IIIC space.

2.NEW UNIFORM COLOUR SPACE NC-IIIC

A new uniform colour space NC-IIIC is specified by equations (1) to (7). Spatial distortions in the NC-IIIC space has been compensated by introducing nonlinear opponent functions indicated as (6) and (7), and Y-B and R-G opponent responses cross at right angles each other in this colour space. As the result, the NC-IIIC space is able to indicate colours in accordance with colour perception under the CIE standard illuminant D_{65} and A. Coordinates of Munsell colours with V=6 in the NC-IIIC space and traditional colour spaces, i.e., the *L*a*b** space and the *U*V*W** space, are shown in Fig.1.

NC-IIIC space

$$L^* = 116\left(Y/Y_n\right)^{\frac{1}{3}} - 16 \qquad \cdots(1)$$

$$a^\dagger = k_1 k_2 a'' \qquad \cdots(2)$$

$$b^\dagger = k_1 k_2 b'' \qquad \cdots(3)$$

$$a'' = 255\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left\{\gamma\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} + (1-\gamma)^{\frac{1}{3}}\left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right\}\right] \qquad \cdots(4)$$

$$b'' = 255\left\{\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right\} \qquad \cdots(5)$$

$$\Gamma = 2.614040,\quad \gamma = 0.974180,\quad 1-\gamma = 0.025820$$

$$k_1 = 1 - 0.10153\left\{1 + 0.210\sin(\theta - \theta_0)\right\}^8 \qquad \cdots(6)$$

$$k_2 = 1 - 0.00264\left\{1 - 1.830\cos(\theta - \theta_0)\right\}^4 \qquad \cdots(7)$$

$$\theta_0 = 6.6^\circ,\ \theta = \tan^{-1}(b''/a'')$$

X, Y, Z : tristimulus values of test colour
X_n, Y_n, Z_n : tristimulus values of light source

3.VISUAL EVALUATION EXPERIMENT

In order to investigate perceived shifts under various illuminants, visual evaluation experiment have been executed under a Xenon lamp, an incandescent lamp and typical practical fluorescent lamps shown in Table.1. Test colours used in this experiment are 24 colour samples which are prescribed in JIS and are MacBeth Colour Checker samples proposed in CIE TC1-33. In this experiment, the booth shown in Fig.2 is used. Colour samples are put on the background in the booth, and the chroma, the hue and the lightness of the colour samples are estimated according to the subjective estimation method.

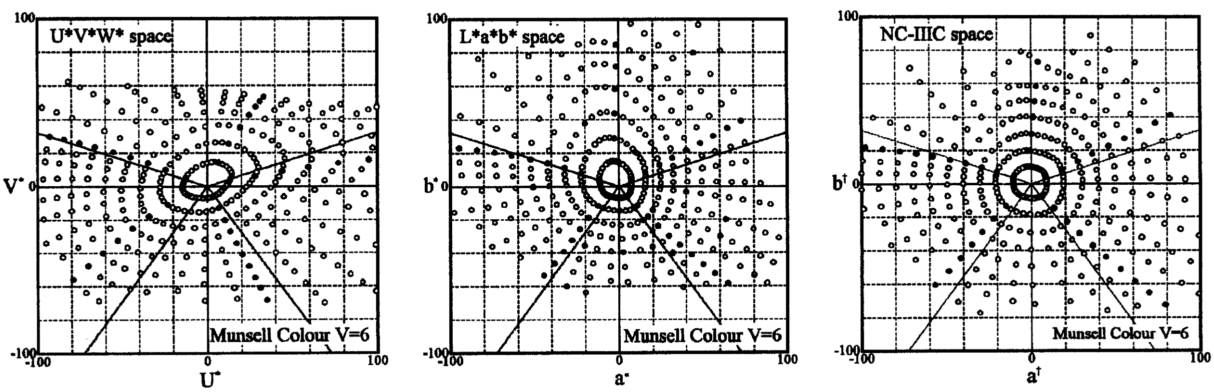

Fig.1 Coordinates of Munsell colours with in colour spaces

To take examples of results of experiments, comparison between perceived attributes and metric quantities in the three colour spaces are shown in Fig.3. It is found that differences between perceived attributes and metric quantities in the U*V*W* space are large in whole region, especially very large in red region. In the L*a*b* space, the differences in yellow region are large. In the NC-IIIC space, these difference are exceedingly small. As the result, the NC-IIIC space is superior to traditional colour spaces for specifying colour appearances.

4.COLOUR RENDERING INDICES

Colour rendering indices calculated by the method prescribed in JIS and the method proposed in CIE TC1-33 are shown in Table 2 and Table 3, respectively. The indices calculated by using the NC-IIIC space are indicated in Table 2 and Table 3.

Table 1 Lamps used in experiment

Lamp	Correlated Colour Temperature
D	6500K
WW	3500K
N-EDL	5000K
EX-N	5000K
EX-L	3000K
EX-D	6700K
D_{65}-FL	6500K

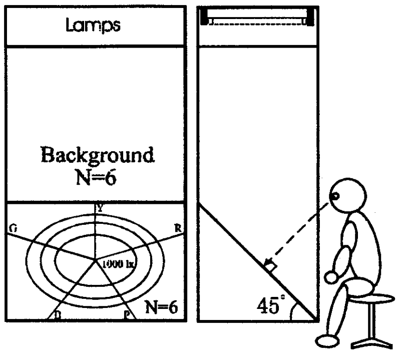

Fig.2 Booth used in experiment

5.CONCLUSION

In Table 2, the indices using the *U*V*W** space are different all over from those using the NC-IIIC space. The indices using the *L*a*b** space are different in yellow region from those using the NC-IIIC space. The same fact is found also for indices in Table 3. This fact is caused by spatial distortion in the *L*a*b** space.

Indices in Table 3 show the fact that the application of CIE colour adaptation formulae has no means. In conclusion, it is not need to use CIE colour adaptation formulae in calculating colour rendering indices.

A new uniform colour space NC-IIIC is superior to traditional colour spaces for specifying colour rendering properties of light sources.

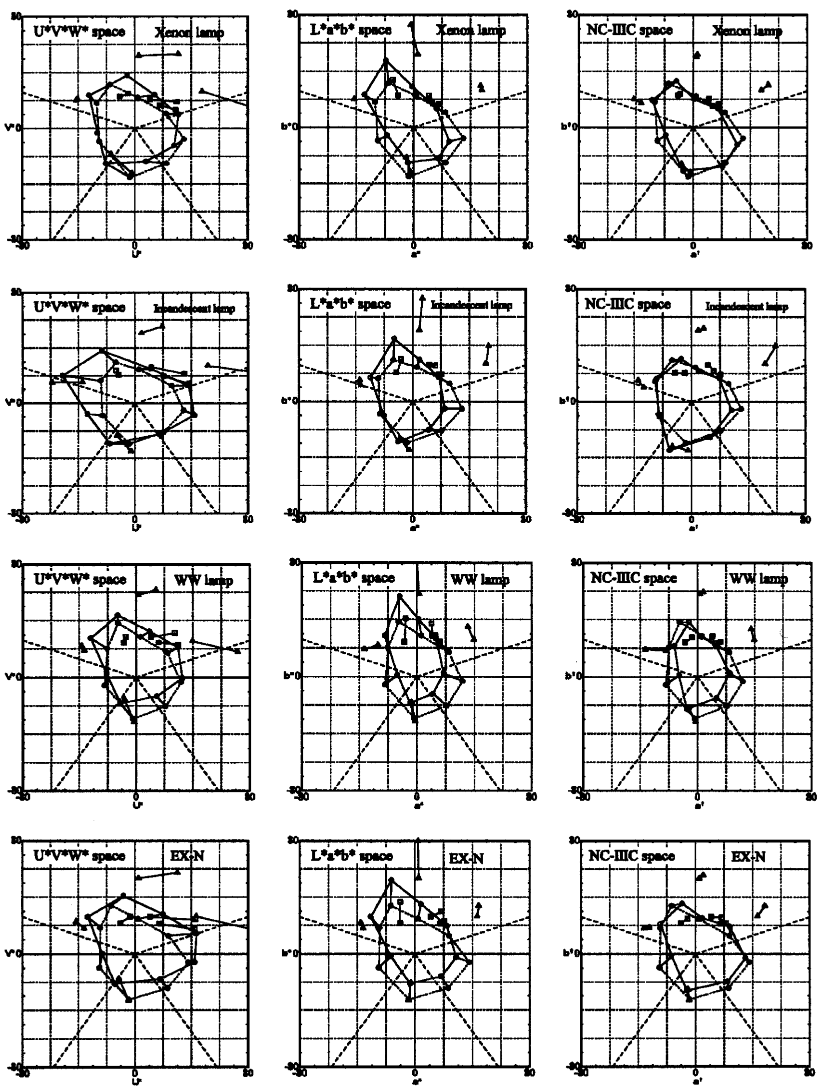

Fig.3 Comparison between perceived attributes(●▲■) and metric quantities(○△□) in colour spaces for test colour samples prescribed in JIS

Table 2 Colour rendering indices calculated by the method prescribed in JIS

	WW			EX-N		
	U*V*W*	L*a*b*	NC-IIIC	U*V*W*	L*a*b*	NC-IIIC
R_1	51	63	58	99	98	98
R_2	75	71	83	98	98	99
R_3	91	69	80	64	60	70
R_4	49	52	54	93	91	93
R_5	53	57	60	91	93	93
R_6	63	56	48	87	85	82
R_7	69	68	62	94	92	91
R_8	23	43	32	81	86	83
R_a	59	60	60	88	88	89
R_9	-94	-27	58	30	59	54
R_{10}	42	34	83	63	67	80
R_{11}	35	36	80	77	76	77
R_{12}	46	17	54	71	51	41
R_{13}	56	63	60	96	94	95
R_{14}	94	84	48	76	71	77
R_{15}	43	87	62	99	98	98

Table 3 Colour rendering indices calculated by the method proposed in CIE TC1-33

	CIE colour adaptation formulae and colour space				only colour space			
	WW		EX-N		WW		EX-N	
	L*a*b*	NC-IIIC	L*a*b*	NC-IIIC	L*a*b*	NC-IIIC	L*a*b*	NC-IIIC
R_1	34	24	78	73	35	27	76	71
R_2	47	49	91	90	52	53	89	88
R_3	59	74	80	88	60	75	80	87
R_4	77	85	81	85	75	84	81	86
R_5	70	70	81	85	71	72	83	87
R_6	48	40	78	76	50	46	76	75
R_7	73	66	87	84	72	64	85	81
R_8	51	40	86	83	47	35	85	82
R_9	69	63	94	95	71	66	95	95
R_{10}	73	69	97	98	75	71	97	97
R_a	60	58	85	86	61	59	85	85