The NCS-like Colour scales Based on CIECAM02

M. Ronnier Luo[1,2], Guihua Cui[3] and Yoon Ji Cho[2]; [1]Dept. of Optical Engineering, Zhejiang University, Hangzhou, China; [2]School of Design, Leeds University, Leeds, UK; [3]School of Physics & Electronic Information Engineering, Wenzhou University, Wenzhou, China

Abstract

The NCS scales of whiteness, blackness and chromaticness were developed based on CIECAM02 and CAM02-UCS. They gave satisfactory prediction to the NCS data.

Background

Development of colour appearance models can be divided into two streams: unidimentional scales and multidimentional space. Fairchild and Heckman [1] developed unidimensional colour appearance scales. The scales considered to be most important are hue, saturation, lightness and brightness. The others such as chroma and colourfulness can be derived from saturation and brightness. The colour difference can also be calculated by applying suitable weights for the difference of the individual scales selected according to different applications. Adams [2] investigated the symmetries for various colour appearance scales and defined the NCS-like whiteness, blackness and chromaticness scales. Luo *et al* [3] have been working on a comprehensive colour appearance models based on CIECAM02 including various scales for different applications. The main advantage is that different components in the model predict different visual phenomena accurately such as chromatic adaptation, dynamic transformation, colour space usages (colour difference or colour appearance). They [4] later developed CAM02-UCS, an extension of CIECAM02 to accurately evaluate colour difference, and to predict new visual effects such as the change of colour appearance due to varying sizes [5], and mesopic and unrelated viewing conditions [6].

More recently, in the same group, Cho *et al* [7] has generated experimental data to develop new scales. They found that saturation and vividness are the two most familiar attributes amongst a group of 15 to describe the third dimension of colours including chroma and colourfulness. The third dimension is relatively unfamiliar with ordinary people comparing with the other two dimensions, lightness and hue. The saturation and vividness scales should also be effective tools for enhancing image quality by making images to appear more saturated or vivid, respectively.

Cho *et al* [8] later extended their study to whiteness and blackness. Variety of whiteness scales have been developed as a quality measure of various products such as textiles, papers, plastics. More recently, it has been used to evaluate the performance of health care products such as teeth, skin etc. Blackness scale is also important for describing the black point in an imaging system such as displays and printers. The NCS system already includes whiteness and blackness scales. These scales may be suitable to unify the above applications for the evaluation of the industrial products. The models developed from the Cho *et al*'s data were tested using the blackness and whiteness of the measured NCS samples. The results showed very good agreement between the new scales developed and the NCS results. This implies that the NCS whiteness, blackness and chromaticness scales are quite robust and can be used as an experimental database to develop the corresponding scales. This may also explain why NCS system has been widely used by the designers due to its three scales are familiar by the users. Some researchers [1,2,8] have also developed scales or spaces using either the concept or data of NCS.

This paper describes methods to develop the NCS whiteness, blackness and chromaticness based on CIECAM02.

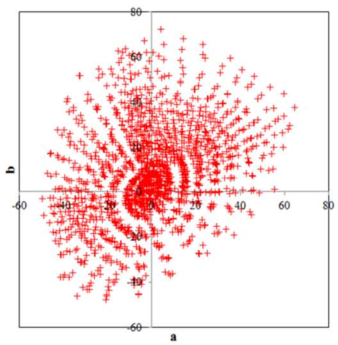
Samples

A set of samples from the NCS Atlas were measured using an X-Rite CE7000A spectrophotometer under the specular included, small aperture and UV included conditions. The results of spectral reflectance of each sample were transformed to the tristimulus XYZ values under the D65 and 1931 standard colorimetric (or 2-degree) observer.

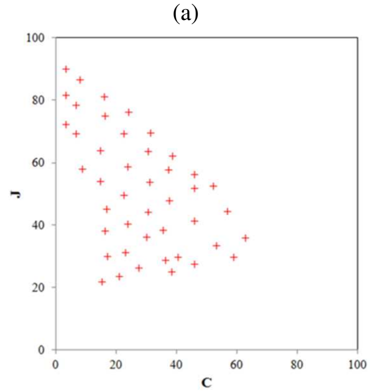
The colour appearance scales will be developed based on the NCS scale of whiteness, blackness and chromaticness. The hue scales [hue angle (h) or hue composition (H)] were already included in CIECAM02. Note that its H scale was originally developed to fit the four unitary hues of the NCS data. Hence, no attempt was made to develop a new scale here.

Figure 1a shows all the colours plotted in CIECAM02 *a, b* plane. The viewing parameters used in CIECAM02 were 20, 20 for L_a, Y_b respectively, and the 'average' surround conditions. It can be seen that they cover a large colour gamut. Also, the samples along each of the 40 NCS hues are more or less lied in straight lines. This shows that CIECAM02 has good property of hue constancy.

Figure 1b shows that all the samples in NCS Y90R hue page are plotted in CIECAM02 *J*, *C* plane. It can be seen that the samples form a triangle shape. The samples in the top and bottom sides of the triangle are known as 'light' and 'dark' series respectively. The slopes of the light and dark series are different, having positive and negative signs respectively. The samples in each line having similar slope of light series from the top to bottom have the same 'whiteness' value. Similarly, the samples from bottom to top to have the same 'blackness' value. The cross point between the light and dark series is 'full' colour. It is defined as the colour having the maximum chromaticness in each hue. They do not physically exist and are the fundamentals for the development of all the 3 NCS scales (see later).



(a)



(b)

***Figure 1**. a) NCS colour samples plotted in CIECAM02 a, b plane, and b) NCS samples in Y90R hue page plotted in CIECAM02 J, C plane, respectively.*

Modelling

Various scales were developed. Two of them were found to be most promising and are able to explain the visual phenomena in colour space. These were originally developed by Adams [2] and by Cho *et al* [5, 6]. The two types of scales are described below.

1) The Model based on Adams

$$W = J - (C/C_p)J_p \quad (1)$$

$$B = (100 - J) - (C/C_p)(100 - J_p) \quad (2)$$

$$Ch = 100(C/C_p) \quad (3)$$

where

$$J_p = 47.09 + 13.00\cos(h - 106) - 6.01\cos(2h + 13) + 4.69\cos(3h + 123) + 1.49\cos(4h + 29) \quad (4)$$

$$C_p = 74.43 - 4.60\cos(h + 1.56) - 7.54\cos(2h + 74) + 0.85\cos(3h + 128) + 0.99\cos(4h + 24) \quad (5)$$

and *W*, *B* and *Ch* are the whiteness, blackness and chromaticness attributes, respectively; *J*, *C* are the CIECAM02 lightness and chroma of the test colour, and *Jp* and *Cp* are the lightness and chroma of the 'full colour' (Figure 1b), which are the functions of CIECAM02 hue angles (h).

Equations (4) and (5) were developed to first find the 'full' colour in terms of *J* and *C* values respectively for each of the 40 hue pages by minimising the predicted W and B to fit the NCS visual data. Subsequently, a function of sine-wave curve was optimised to fit full colours for *Jp* and *Cp* functions, respectively. Figure 2 shows the plot of the 40 optimised 'full' colours in CIECAM02 *J* and *C* against its hue angle (h). It can be seen that there is a smaller change in Cp values than *Jp* values. Figure 2 also shows the curves of equations (4) and (5). It can be seen that both curves fit the data well and the maximum *Jp* value of the 'full' colour is located in the yellow region. Another version was also developed, which is a simplified version by using a constant for *Jp* and for *Cp*.

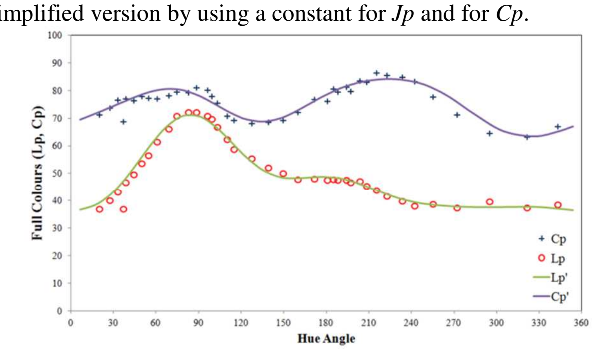


***Figure 2**. The plot of full colours, and Jp and Cp functions in equations (4) and (5) respectively*

2) Models based on Cho et al's model

The Cho *et al* model was also used to develop NCS whiteness and blackness scales. These are given in equations (6) and (7), respectively. They are in the form of ellipsoid colour-difference equation. The colour centre is to have the *J*, *a* and *b* values been perceived as the least white or least black colours, respectively. Hence, the more departure from this centre, a colour will appear whiter or blacker.

$$w = 110.96 - 1.18\sqrt{1.20(J - 100)^2 + 0.91(a - 2.92)^2 + 1.20(b + 6.47)^2} \quad (6)$$

$$s = 110.00 - 0.78\sqrt{2.44(J)^2 + 3.86(a + 1.83)^2 + 2.15(b - 4.95)^2} \quad (7)$$

where *J*, *a* and *b* are the CIECAM02 lightness, redness-greenness, yellowness- blueness respectively. Finally, the chromaticness can be calculated by 100-*w*-*s*, as defined by the NCS.

Note that the current colour centre of whiteness is a bluish tinted white [*J, a, b*] of [100, 2.92, -6.47]. This agrees with the visual phenomena that a bluish white appears whiter than the tinted white having same lightness. However, for the blackness, the current result disagrees the previous findings [9,10] that a bluish black appears blacker than the other tinted blacks having same lightness.

Performances

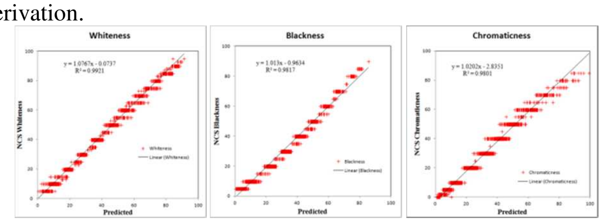
Above models' performance to fit the NCS data are reported here in terms of *STRESS* [11] as shown in Table 1 using the model number of 1-6, M1 to M6.

Table 1 Summary of the Models' performance

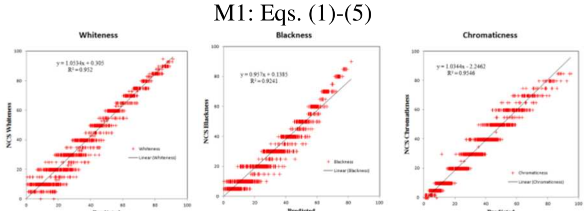
	Black-ness	White-ness	Chromatic-ness	MEAN
CIECAM02				
M1: Eqs. (1) - (5)	8.2	5.9	10.0	8.0
M2: Simplified L_p and C_p	15.9	11.8	12.2	13.3
M3: Eq. (6)-(7)	12.1	8.3	20.2	13.5
CAM02-UCS				
M4: Eqs. (1) - (5)	10.3	10.7	14.1	11.7
M5 Simplified L_p and C_p	17.4	13.5	15.7	15.5

The results showed that the M1 based on CIECAM02 outperformed the others. The simplified versions (M2 and M3) performed a lot worse than the full version (M1). Comparing CAM02-UCS models, M4 performed best for blackness and whiteness, and gave similar performance in chromaticness. Overall, M1 and M4 performed best for CIECAM02 and CAM02-UCS respectively. This implies that although CAM02-UCS is a modified version of CIECAM02, the characteristics of the colour spacing of the two models are different in consideration of full colours alone the hue range.

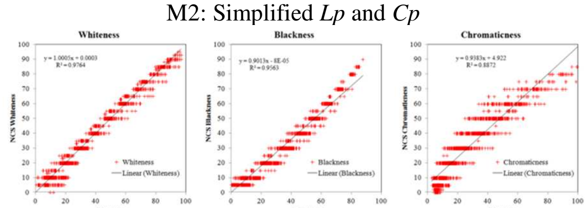
The predictions of the M1 to M3 models are plotted against the NCS results in Figure 3. As it can be seen, M1 had the least scatter. The CIECAM02 is preferred than CAM02-UCS, not only it performs better but also it is the base of the comprehensive colour appearance model, rather than to develop new scales from its derivation.



M1: Eqs. (1)-(5)



M2: Simplified *Lp* and *Cp*



M3: Eqs. (6)-(7)

***Figure 3**. Plots of the predictions from the CIECAM02 based models against the NCS visual data.*

Conclusions

The NCS samples were measured in terms of XYZ under CIE D65 and 2-degree observers. The data were used to fit NCS whiteness, blackness and chromaticness scales based on CIECAM02 and CAM02-UCS. Finally, successful scales were developed and the one based on CIECAM02 are proposed [equations (1) to (5)]. It should be further tested for various industrial applications such as for imaging devices, materials, and health care products.

References

[1] M. D. Fairchild, and Heckaman, Deriving appearance scales, CIC, 20th Color and Imaging Conference, 7-11 November 2012, Los Angeles, CA 281-286.

[2] L. W. Adams, Using symmetry to understand the attributes of color, Color Res. Appl., 35, 27-44. (2010)

[3] M. R. Luo, 20 years of colour appearance research at CIC, 20th Color and Imaging Conference, 7-11 November 2012, Los Angeles, CA 259-263.

[4] M. R. Luo, G. Cui, C. Li, Uniform Colour Spaces Based on CIECAM02 Colour Appearance Model, Color Res. Appl., 31, 320-330. (2006)

[5] K. Xiao, C. Li, M. R. Luo and C. Taylor, Colour Appearance for Dissimilar Sizes, CGIV 2004, Technology Centre AGIT, Aachen, Germany, 5-8 April, 2004, 12-16.

[6] C. Y. Fu, C. J. Li, G. Cui, M. R. Luo, R. W. G. Hunt and M. R. Pointer, An investigation of colour appearance for unrelated colours under photopic and mesopic vision, Color Res. Appl., 37, 238-254. (2012)

[7] Y. J. Cho, L. C. Ou and M. R. Luo, Alternatives to the third dimension of colour appearance, Nineteenth Color and Imaging Conference, 7-11 November 2011, San Jose, CA, USA, 88-93.

[8] Y. J. Cho, L. C. Ou, S. Westland and M. R. Luo, Methods for assessing blackness, AIC2012– Colour and Environment, Taipei, Taiwan, pp606-609.

[9] L. Tao, S. Westland and V. Cheung, Blackness: preference and perception, Proc. of the 19th Color Imaging Conference, November 2011, 270-275.

[10] Y. J. Cho, L. C. Ou, S. Westland and M. R. Luo, Methods for assessing blackness, Proc. of AIC 2012 meeting, Taipei, Taiwan, 2012 606-609.

Author Biography

Ming Ronnier Luo is a Professor at Zhejiang University (China) and at the University of Leeds (UK). He is also the Director of the Division 1 (Colour and Vision) of the International Commission on Illumination (CIE). He received his PhD in 1986 at the University of Bradford in the field of colour since. He has over 400 publications in relation to colour science, imaging science and illumination engineering.

.