A New Colour Appearance Model – Kwak03

Youngshin Kwak*[*1], Lindsay W. MacDonald[*2], and M. Ronnier Luo[*2]
***Multimedia Lab, Samsung Advanced Institute of Technology, South Korea*[*1]**
***Colour & Imaging Institute, University of Derby, United Kingdom*[*2]**

Abstract

Analysis using the LUTCHI data set and a new psychophysical colour appearance data set, CII-Kwak, showed that current colour appearance models fail to predict several critical colour appearance phenomena. In this paper, a new colour appearance model, Kwak03, is introduced, which has been derived to overcome the shortcomings found in the previous models. Kwak03 follows the basic structure of CIECAM02 but makes several major changes, such as the formation of the achromatic signal and dynamic response function. It is shown that Kwak03 outperforms all previous colour appearance models, especially in predicting changes in colour appearance with different viewing parameters.

1. Introduction

Developing a colour appearance model (CAM) of high quality is very important for colour and imaging applications such as cross-media reproduction, which requires matching of colour appearances under different viewing conditions. Parameters include luminance level, background luminance factor and surround conditions. In this study, eight colour appearance models were tested using the colour appearance data sets LUTCHI and CII-Kwak. The CII-Kwak data set is a new body of psychophysical data accumulated by the authors during last three years and consists of 20 phases mostly in a dark surround condition.

Data analysis showed that all existing colour appearance models fail to predict several crucial changes in colour appearance, especially under the dark surround condition[1]. These results strongly suggested the need to develop a new colour appearance model, known as Kwak03, to improve the predictions. The Kwak03 model follows the general structure of CIECAM02, the latest colour appearance model.

Hunt[2] said in the introduction of his model Hunt94 that "in our present state of knowledge, it is not possible to construct a model of colour vision that is supported at each stage by physiological data. In particular, quantitative modelling of the effects of adaptation and induction has to be approached at present largely empirically". Things have not changed much since Hunt's introduction was written. Still most of the physiological processes of colour vision are not well known, and even the latest colour appearance models take a largely empirical approach. Such mathematical means of fitting the data suffice for practical application in the colour imaging industry, although they are generally not good enough to be used to simulate the neural processes of human vision.

In this paper is first introduced the performance of current colour appearance models. In particular we focus on the predictions of colour appearance change by absolute luminance level and background luminance level. Then the Kwak03 model is introduced step by step and its performance compared with the other models.

Table 1 Summary of experimental phases used to test CAMs and to derive Kwak03

	Group	Surround	No. of Phases	Light Source	Reference white (cd/m^2)	Background	No. of Observers	No. of Colours
CII-Kwak	P (Projector)	Dark	3	7200 K	19, 154	Grey/Black	21	32
	M (Monitor)	Dark	3	7200 K	~ 90	White Grey/Black	11 or 12	40
	C (Cinema)	Dark	4	7200/3900 K	~ 16		9 or 11	40
	A (Ambient)	Dark/Average	2	7200 K	~ 86	Grey	11	40
	F (Filters)	Dark	4	7200 K	0.1 ~ 88	Grey	10 ~ 12	40
LUTCHI	R-HL	Average	6	D50, D65, WF, A	~ 250	White Grey Black	6 or 7	~100
	R-LL	Average	6		~ 40			
	CRT	Dark	11		~ 40,20			
	35mm	Dark	6	4000 K	47~113	Grey	5 or 6	~ 99
	R-VL	Average	6	5000 K	0.4~843	Grey	4	40

2. Colour Appearance Data Sets and Colour Appearance Phenomena

Table 1 shows the list of experimental data sets used to test eight colour appearance models. CII-Kwak is divided into 5 groups. Group P[3] represents the viewing condition for the conventional presentation situation, in which an LCD projector was used in a dark room to display colour. For Group M experiments,[4] colours were displayed using an LCD flat-panel monitor in a dark room. Group C experiments[5] were done in a lecture theatre to simulate a cinema condition. Test colours were produced using both an LCD projector and a 35-mm slide projector in a dark room. Group A experiments were to test the effect of surround and experiments were done with and without ambient light using CRT monitor. Group F[6] experiments had eight phases covering two stimulus sizes and four luminance levels down to mesopic vision. Colours were displayed on a CRT monitor in a dark room. The technique for gathering CII-Kwak data was adopted from the LUTCHI experiments. Basically the same experimental method and setting were used, with the magnitude estimation technique for observer judgement of lightness, colourfulness and hue.

The complete LUTCHI data consists of eight groups according to the experimental viewing conditions with 59 phases. In the present study, however, only those groups having the same viewing condition as the CII-Kwak data set are used, which exclude LT (cut-sheet), R-Textile (textile) and BIT (unrelated colours). Experimental groups used were R-HL[7], R-LL[7], R-VL[8] for average surround and CRT[7] and 35mm[9] for dark surround condition. All LUTCHI data used in this study can be found in the web site: http://colour.derby.ac.uk/ colour/info/lutchi/.

The CII-Kwak and LUTCHI data sets cover the colour appearance changes by the luminance level of a reference white, background luminance factor and the surround conditions. These two independent colour appearance data sets showed the same colour appearance changes by these factors. The main findings are summarised below.

(1) A colour with a higher luminance level of reference white would reduce lightness contrast (higher lightness) and increase colourfulness compared with a lower luminance level. There was little effect on hue.

(2) A higher background luminance factor induces a higher lightness contrast (lower lightness) and increases colourfulness with no effect on hue. However for an increment of colourfulness, there is a subtle difference between dark and light colours. Colours having lightness less than 40 appear to be more colourful against a dark background. This effect is small relative to overall colourfulness increments.

(3) A colour appears more colourful but darker (higher lightness contrast) under average surround than under dark surround. There is no hue change by surround condition change.

3. Testing the Colour Appearance Models

The experimental data in Table 1 were used to test eight existing colour appearance models: CIELAB, LLAB, RLAB, Hunt94, CIECAM97s, FC, Fairchild and CIECAM02. The performances of the models were calculated as coefficient of variation (CV) values. (See Table 2) In general the performances of all the models except CIELAB and RLAB were good and similar in terms of CV values. The Fairchild model had relatively poor performance for chroma and colourfulness and CIECAM02 had the worst brightness prediction.

A particular focus of this study was the prediction of colour appearance change by the viewing conditions, as discussed in the previous section. It was found that all the models tested gave poor prediction of some colour appearance phenomena. Most notably they all failed to predict lightness contrast change by luminance level and colourfulness change by background luminance factor, especially under the dark surround condition.

By way of illustration, Figure 1 compares the visual data and model predictions of lightness contrast change by luminance level under a dark surround. The *x*-axis represents one of the phases in Group F, namely CRT monitor colours with reference white of 1.0 cd/m^2 and grey background. The *y*-axis shows the self-luminous colours in Group F with reference white of 87.4 cd/m^2 and grey background. Visual and predicted data of these two phases can be directly compared, because the only difference between the phases was the luminance level of reference white. It is clear from this diagram that all models failed to predict the increase in lightness of darker colours, and hence the lower lightness contrast, reported by observers.

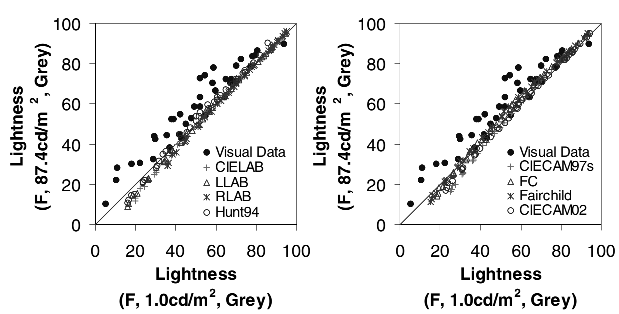

Figure 1. Predictions of lightness contrast change by luminance level under dark surround

4. New Colour Appearance Model, Kwak03

A new colour appearance model, Kwak03, was developed especially to perform better in predicting colour appearance phenomena under the dark surround condition. Kwak03 follows the general structure of CIECAM02, the latest colour appearance model, since it has been refined to correct several mathematical problems found in previous models.

However most of the equations in the Kwak03 model have been modified from CIECAM02 to give better fit to the collection of data sets studied.

Kwak03 can be divided into three stages like CIECAM02. Firstly the input tristimulus values in the test condition are transformed to compressed cone signals in the reference condition after a chromatic adaptation process. Secondly opponent colour signals are calculated using compressed cone signals. Thirdly colour appearance predictors are calculated using three opponent colour signals. Colour appearance predictors are grouped in three categories, i.e. achromatic, hue and chromatic predictors.

4.1 Starting Data

The input data required in Kwak03 include the relative tristimulus values *XYZ* of each test colour, together with the information of reference white, background and surround condition, as for other CIECAM97s-based colour appearance models. For the specification of reference white, the relative tristimulus values and luminance (cd/m^2) are needed. Kwak03 is limited to neutral backgrounds, so only the *Y* value of the background is needed in the model.

Kwak03 uses the luminance of reference white instead of the luminance of the adapting field that is used in CIECAM97s-based models. Using luminance of reference white was mathematically convenient and it was an attempt to distinguish between the effects of luminance of reference white and background luminance factor. Luminance of the adapting field is derived by multiplying the luminance of reference white by the background luminance factor divided by 100. These two parameters, luminance of reference white and background luminance factor, were treated as independent variables to derive Kwak03.

Surround is used as a categorical term in colour appearance models, defined by the relative ratio between the luminance of reference white in the image and the luminance of the surround, i.e. the peripheral area outside the immediate background of the test patch. Surround conditions are categorised as Average, Dim and Dark. The average condition covers reflective colours and self-luminous or projected images with ambient lighting of luminance level similar to that of the image. The dark condition is for self-luminous or projected colours in a dark room. The dim condition is possible only for self-luminous or projected colours, with ambient lighting creating a surround of significantly lower luminance than the luminance of the displayed image. Note that reflective colours always belong to the average surround condition. Display colours shown in a dark room always have dark surround condition, regardless of the luminance level of the image, since the surround condition is determined by the "relative luminance ratio" which is not affected by absolute luminance level of the display itself.

4.2 Chromatic Adaptation

The first step of Kwak03 is to transform the tristimulus values of the test colour under a given viewing condition to cone signals in a reference condition using chromatic adaptation. The chromatic adaptation equation has been taken directly from CIECAM02[10], which is the latest revision of CIECAM97s.

Relative tristimulus values X,Y,Z measured in the test viewing condition are transformed to the R,G,B space by a 3x3 matrix – the modified Li *et al* matrix[11] M_{CAT02} – followed by incomplete chromatic adaptation based on the simple von Kries type model. The chromatic adaptation model converts the R,G,B values under the test viewing condition to R_C,G_C,B_C values under the reference viewing condition, i.e. an equi-energy illuminant. R_C,G_C,B_C are then transformed to the Hunt-Pointer-Estevez cone space.

$$\begin{vmatrix} R \\ G \\ B \end{vmatrix} = M_{CAT02} \cdot \begin{vmatrix} X \\ Y \\ Z \end{vmatrix} = \begin{vmatrix} 0.7328 & 0.4296 & -0.1624 \\ -0.7036 & 1.6975 & 0.0061 \\ 0.0030 & 0.0136 & 0.9834 \end{vmatrix} \cdot \begin{vmatrix} X \\ Y \\ Z \end{vmatrix}$$

$$Q_C = \left[D \cdot \left(\frac{Y_W}{Q_W} \right) + 1 - D \right] \cdot Q$$

$$D = F \cdot \left[1 - \frac{1}{3.6} \cdot e^{\frac{-L_W \cdot Y_b / 100 - 42}{92}} \right]$$

where $Q : R, G$ or B

Q_W, Y_W : Q and Y values of the reference white

F : 1, 0.9 and 0.8 for average, dim and dark surround

L_W : luminance of the reference white (cd/m^2)

Y_b : Y value of the background

$$\begin{vmatrix} R' \\ G' \\ B' \end{vmatrix} = M_H \cdot M_{CAT02}^{-1} \begin{vmatrix} R_C \\ G_C \\ B_C \end{vmatrix} = \begin{vmatrix} 0.7410 & 0.2180 & 0.0410 \\ 0.2854 & 0.6242 & 0.0904 \\ -0.0096 & -0.0057 & 1.0153 \end{vmatrix} \cdot \begin{vmatrix} R_C \\ G_C \\ B_C \end{vmatrix}$$

4.3 Compression of Cone Signals

The next step after chromatic adaptation in CIECAM97s-based models is to apply a dynamic adaptation function to the three cone signals R',G',B'. Dynamic adaptation means adjusting the cone signals relative to the adapted 'operating point' of the observer's visual system, which depends on the average retinal illuminance over the entire visual field.

It has been found that the dynamic adaptation function used in CIECAM97s has a shortcoming, in that the correlates of hue and saturation exhibit some changes if a test colour of a given chromaticity has its luminance factor changed. CIECAM02 therefore modified the function.[12] However study by the authors has found that the function used in CIECAM02 fails to compensate the change in lightness contrast by luminance level.[1] Therefore, in Kwak03 it was decided to compensate the effect of luminance level not by use of a dynamic function applied to the cone signals but by a different function at a later stage in the model. Nevertheless, to improve the model's performance, the cone signals R',G',B' need to be compressed non-linearly as R_k',G_k',B_k' using the equation below. The exponent in the power function follows that of the dynamic adaptation function in CIECAM02.

$$R_k' = \left(\frac{R'}{100}\right)^{0.42}, \quad G_k' = \left(\frac{G'}{100}\right)^{0.42}, \quad B_k' = \left(\frac{B'}{100}\right)^{0.42}$$

4.4 Opponent Colour Signals

Compressed cone signals are then converted to opponent colour signals, which are required for colour appearance predictors. Opponent colour signals consist of an achromatic signal, *A*, and two colour difference signals, *a* and *b*, similar to other CIECAM97s-based models.

The achromatic signal, *A*, is constructed as a weighted sum of signals from the three different cone types. Current colour appearance models follow Hunt in using the ratios of R_k':G_k':B_k' as 40:20:1. In this study, however, it was found empirically that by changing the cone signal ratios to 2:1:0.5, instead of the usual 2:1:0.05, the performance of the lightness predictor improved dramatically.

$$A = 2 \cdot R_k' + G_k' + 0.5 \cdot B_k'$$

The new ratio 2:1:0.5 for R_k':G_k':B_k' was determined purely from numerical fitting to colour appearance data without any physiological evidence to support it. The improved performance obtained by Kwak03 with this modified ratio suggests that the *B* cones may make a more substantial contribution to achromatic vision than the population density of retinal photoreceptors would suggest.

Colour difference signals *a* and *b* are calculated from the difference of cone signals. Equations of redness-greenness *a* and yellowness-blueness *b* used in CIECAM97s-based models are also applied in Kwak03.

$$\text{Redness - Greenness} \quad a = R_k' - \frac{12}{11} \cdot G_k' + \frac{1}{11} \cdot B_k'$$

$$\text{Yellowness - Blueness} \quad b = \frac{1}{9}\left(R_k' + G_k' - 2 \cdot B_k'\right)$$

4.5 Achromatic Predictors

Achromatic predictors include both lightness and brightness predictors. These follow the same structure as in CIECAM97s-based models. Firstly the lightness predictor is established using the achromatic signal, which is a function of R_k', G_k', B_k'. The brightness predictor is then based on the lightness predictor.

Lightness Predictor J

The lightness predictor *J* in Kwak03 has the same form as in other CIECAM97s-based models. The achromatic signal, *A*, normalised by that of reference white, A_w, is compressed using the power function shown below.

$$J = 100 \cdot \left(\frac{A}{A_w}\right)^{c(L_w)\, z(Y_b)}$$

$$\text{where} \quad c(L_w) = q \cdot L_w^{\ n}, \quad z(Y_b) = 0.9 + 0.5 \cdot \left(\frac{Y_b}{100}\right)$$

Surround	**Average**	**Dim**	**Dark**
q	1.30	1.35	1.40
n	-0.060	-0.040	-0.025

The exponent in the equation controls the degree of lightness contrast. Since lightness contrast varies according to both the luminance of the reference white and background luminance factor, the exponent should be a function of these two parameters. Note that the achromatic signal in Kwak03 is independent of luminance and background luminance factor. It is assumed that these two parameters are independent of each other. Function $c(L_w)$ controls the lightness contrast change due to luminance level and $z(Y_b)$ compensates for the contrast change due to background luminance factor.

Brightness Predictor Q

Currently the only available colour appearance data set for brightness is from Group R-VL experiments in LUTCHI data, which has been used to derive brightness predictors of CIECAM97s-based models. The brightness predictor *Q* of Kwak03 is also derived from the R-VL experiments, with the equation shown below.

$$Q = J \cdot (L_w)^{0.16}$$

4.6 Hue Predictors

In Kwak03, the same equations as CIECAM02 were applied for hue angle, *h*, and hue quadrature, *H*, but the hue angles corresponding to the unique hues were changed since a different compression method was applied to the cone signals.

$$h = \tan^{-1}(b/a), \quad H = H_1 + \frac{100 \cdot (h - h_1)/e_1}{(h - h_1)/e_1 + (h_2 - h)/e_2}$$

$$\text{where} \quad e = \frac{1}{4} \cdot \left[\cos\left(h\frac{\pi}{180} + 2\right) + 3.8\right]$$

h_1, h_2 / e_1, e_2 : nearest unique hue angles(h) /eccentricity values(e) having lower and higher values than h / e

H_1 : H value corresponding to h_1

Unique Hue	**Red**	**Yellow**	**Green**	**Blue**	**Red**
Hue angle *h*	13.0	93.5	153.6	246.8	373.0
Eccentricity *e*	0.8	0.7	1.0	1.2	0.8
Hue quadrature H	0	100	200	300	400

4.7 Chromatic Predictors

Kwak03 predicts saturation, chroma and colourfulness for chromatic attributes. According to the CIE definition, colourfulness is an absolute chromatic scale varied by luminance level of reference white, background luminance factor and surround condition. Chroma is colourfulness without luminance level dependency since it is judged relative to the brightness of reference white. For a saturation predictor, the lightness dependent part has to be excluded from the chroma predictor. The equations for saturation, chroma and colourfulness are summarised below.

Saturation

$$s = f\left(R_k^{'}, G_k^{'}, B_k^{'}\right) \cdot f\left(Y_b\right) \cdot f\left(\text{Surround}\right)$$
$$= 300 \cdot \frac{e^{0.5} \cdot \left(a^2 + b^2\right)^{0.4}}{\left(R_k^{'} + G_k^{'} + B_k^{'}\right)^{0.8}} \cdot \left(0.79 + 0.21 \cdot \frac{Y_b}{100}\right) \cdot N_c$$

Chroma

$$C = s \cdot f(J) = s \cdot \sqrt{J/100}$$

Colourfulness

$$M = C \cdot f(L_w) = C \cdot L_w^{0.08}$$

Surround	Average	Dim	Dark
N_c	1.00	0.92	0.85

One of the notable changes in chromatic predictors compared to CIECAM97s based models is the background dependency. The chromatic predictors of Kwak03 follow the colour appearance phenomena found in the LUTCHI and CII-Kwak data, namely that colours look more colourful with a lighter background. However models based on CIECAM97s predict that colours appear less colourful with higher background luminance factor.

5. Performance of Kwak03

The performance of Kwak03 was examined using the same methods as for other colour appearance models in the previous section and compared with the other models. First the CV values were calculated between the visual data and predicted values by Kwak03. Table 2 summarises the average CVs of each attribute of Kwak03 along with other eight colour appearance models. Kwak03 shows most significant improvement for lightness and brightness prediction. Second the predictions of colour appearance change by the luminance of the reference white, background and surround condition are investigated and it was proven that Kwak03 can predict all phenomena that failed to be predicted by the other models.

Figure 2 shows the same visual data as in Figure 1 with the predictions by Kwak03. It is clear that Kwak03 successfully predicts the lightness contrast change by luminance level under dark surround condition.

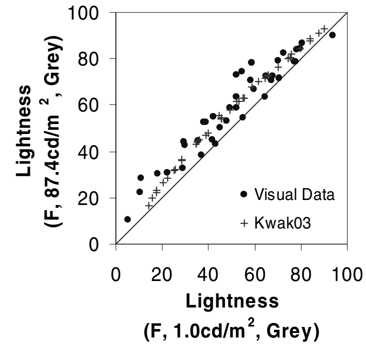

Figure 2. Prediction of lightness contrast change by luminance level under dark surround by Kwak03

6. Conclusions

The LUTCHI data set has been a major source of colour appearance data used to derive colour appearance models. In this study, a new colour appearance data set CII-Kwak, which was accumulated by the authors, has been introduced. It was used to investigate the colour appearance changes by the luminance of the reference white, background luminance factor and surround condition. Both CII-Kwak and LUTCHI data showed similar visual phenomena, confirming the validity of the magnitude estimation technique for the study of colour appearance.

It was found that a higher luminance level of the reference white in an image makes colours look lighter (i.e. lower lightness contrast) and more colourful. Colours look darker but more colourful with a lighter background. Average surround also induces lower lightness (i.e. higher lightness contrast) and colourfulness compared to a dark surround.

The LUTCHI and CII-Kwak data sets were used to test the performances of eight colour appearance models, i.e. CIELAB, LLAB, RLAB, Hunt94, CIECAM97s, FC, Fairchild and CIECAM02. In this study the focus was not only on CV values but also on the predictions of colour appearance phenomena. The results showed that all eight models tested failed to predict lightness contrast change by luminance of the reference white and colourfulness change by background luminance factor, especially under the dark surround condition.

A new colour appearance model, Kwak03, was developed to improve the prediction of colour appearance phenomena, especially under the dark surround condition. Basically Kwak03 is a modified form of CIECAM02 but contains several major changes.

Firstly, the dynamic function is not used in the Kwak03 model since it was found that the dynamic function used for CIECAM97s-based models was not effective enough in compensating lightness change by the luminance level of reference white. Instead, colour appearance change by luminance level is compensated at the later stage using a new equation for each attribute.

Table 2 Average CVs of each attribute of eight colour appearance models and Kwak03

Attribute	CIELAB	LLAB	RLAB	Hunt94	CIECAM97s	FC	Fairchild	CIECAM02	Kwak03
Lightness	19.2	14.9	26.0	12.6	14.6	14.3	14.2	14.5	*11.8*
Brightness				11.5	13.6	13.0	12.1	22.3	*11.4*
Chroma	26.3	21.3	27.6	20.3	19.5	19.8	23.5	20.0	*18.9*
Colourfulness		22.7		23.6	21.9	22.2	27.1	23.4	*21.4*
Hue		8.9	11.2	8.3	7.9	8.0	7.9	7.6	*7.4*

Secondly, for the achromatic signal, *A*, the ratios between three types of compressed cone signals, $R_k':G_k':B_k'$, are modified from 2:1:0.05 to 2:1:0.5. This modification does not have any physiological evidence to support it but significantly improves the performance of the lightness predictor.

Thirdly, the effect of colourfulness change caused by background luminance factor is remodelled to fit the colour appearance data set, which contradicts the predictions of other colour appearance models. Note that both LUTCHI and CII-Kwak data sets showed the same effect that colours look darker and more colourful with a lighter background, while CIECAM97s based models predict that colours would look darker and less colourful.

It has been proven that Kwak03 shows improved performance in terms of CV values especially for lightness and brightness predictors. More importantly, Kwak03 can better predict colour appearance changes by the luminance level of reference white and background luminance factor, especially under the dark surround condition, than any other models tested in this study.

7. References

1. Y. Kwak, Quantifying the colour appearance of displays, *PhD Thesis*, University of Derby (2003)
2. R.W.G. Hunt, *The reproduction of colour*, Fifth Edition, Fountain Press, (1995) p.706
3. Y. Kwak, L. W. MacDonald & M. R. Luo, Quantifying colour appearance for projected images, *Proc. 2000 AIC Meeting*, Seoul, Korea, Nov. (2000)
4. Y. Kwak, L. W. MacDonald, M. R. Luo, Colour appearance comparison between LCD projector and LCD monitor colours*, Proc. 2001 AIC*, Rochester, USA, Jun. (2001)
5. Y. Kwak, L. W. MacDonald, M. R. Luo, Colour appearance estimation under cinema viewing conditions, *Proc. CGIV'2002 First European Conference on Color in Graphics, Imaging and Vision*, Poitiers, France, Apr. (2002)
6. Y. Kwak, L. W. MacDonald, M. R. Luo, Mesopic colour appearance, *Proc. IS&T/SPIE's 15th Annual Symposium on Electronic Imaging: Science and Technology*, San Jose, California USA, Jan. (2003)
7. M. R. Luo, A. A. Clarke, P. A. Rhodes, A. Schappo, S. A. R. Scrivener & C. J. Tait, Quantifying colour appearance. Part I. LUTCHI colour appearance data, *Color Res. Appl.* **16**, 166-180 (1991)
8. M.R. Luo, X.W. Gao, P.A. Rhodes, H.J. Xin, A.A. Clarke, & S.A.R. Scrivener, Quantifying colour appearance. Part III. Supplementary LUTCHI colour appearance data, *Color Res. Appl*. **18**, 98-113 (1993)
9. M.R. Luo, X.W. Gao, P.A. Rhodes, H.J. Xin, A.A Clarke & S.A.R. Scrivener, Quantifying colour appearance. Part IV. Transmissive Media, *Color Res. Appl*. **18**, 191-209 (1993)
10. N. Moroney, M.D. Fairchild, R.W.G. Hunt, C. Li, M.R. Luo, T. Newman, The CIECAM02 colour appearance model, *Proc. The 10th Color Imaging Conference*, Scottsdale, USA, Nov. (2002)
11. C.J. Li, M.R. Luo, B. Rigg and R.W.G. Hunt, CMC2000 Chromatic adaptation transform: CMCCAT2000, *Color Res. Appl*. **27**, 49-58 (2002)
12. R.W.G. Hunt, C.J. Li and M.R. Luo, Dynamic cone response functions for models of color appearance, *Color Res. Appl*. (submitted)

Biographies

Youngshin Kwak received her BSc (physics) and MSc (physics) degrees in 1995 and 1997 from Ewha Womans University, Seoul, South Korea. From 1997 until 1999 she worked as a researcher at the Ewha Colour and Design Research Institute. In September 1999 she joined the Colour & Imaging Institute as an MPhil/PhD student. She completed her PhD study in July 2003 and joined the multimedia laboratory at Samsung Advanced Institute of Technology, South Korea. Her main research topics are colour appearance modelling and device characterisation.

Lindsay MacDonald is Professor of Multimedia Imaging at the Colour & Imaging Institute of the University of Derby in the UK. He is actively involved in many research projects related to digital imaging, and is leading the European project 'Veridical Imaging of Transmissive and Reflective Artefacts' (VITRA).

He has been co-author or co-editor of seven books in the past eight years on the subjects of colour, displays, interaction and digital imaging. He has been closely involved with the IS&T/SID Color Imaging Conference (CIC) since its inception in 1993, and this year he has been made a Fellow of IS&T.