Colour Appearance Estimation under Cinema Viewing Conditions

Youngshin Kwak, Lindsay W. MacDonald, and M. Ronnier Luo
Colour & Imaging Institute, University of Derby
Derby, United Kingdom

Abstract

Experiments were conducted for scaling colour appearance under cinema viewing conditions. The results were compared with previous experimental results for 35mm slide projection. Also the effect of luminance level on image colour appearance was investigated. Performances of various colour appearance models were tested and the model parameters for dark surround were optimised.

Introduction

Understanding the change of colour appearance under cinema viewing conditions is essential for developing digital cinema. Typically image sequences are edited and pre-viewed on the CRT monitor of a computer graphic workstation in a normal office environment, and these images are then projected in the cinema with a dark surround. It is not possible to achieve an effective preview unless the perception of colours with the dark surround of the cinema, at relatively low screen luminance levels, can be accurately modelled. However previous experiments for scaling colour appearance have generally been performed for reflective colours in an average surround, which means a surround luminance similar to the average luminance of the colours in the viewing field.[1] In the case of dark surround, previous experiments were performed in a meeting room rather than in the real cinema condition. It is well known that dark surround reduces the contrast, compared with average surround.[2] The main differences between conventional presentation and cinema viewing conditions are the size of screen and the viewing distance, which have not previously been investigated.

In this study, a new set of colour appearance data was accumulated for the cinema viewing situation – a large projection screen in a darkened lecture theatre. Images of size 319 by 239 cm were projected using an LCD projector and a 35-mm slide projector with a luminance of about 15.5 cd/m^2 for the reference white and a mid-grey background. During each session, 50 test colours subtending an angle of approximately 1° from the observer's viewing position were presented. The perceived lightness, colourfulness and hue were assessed using the magnitude estimation method. Nine to eleven observers having normal colour vision participated in this experiment. For the experiment using the 35-mm slide projector, the same slides previously used for the LUTCHI experiment were employed.[4] The new colour appearance data were compared with those for the conventional presentation condition accumulated by the authors[6] and LUTCHI.

The performances of seven colour appearance models were tested: CIELAB, LLAB, RLAB, Hunt95, CIECAM97s,[1] FC[7] and Fairchild[7]. CIECAM97s was further analysed to obtain an optimised parameter for dark surround.

Experiment

Figure 1 illustrates the experimental situation and viewing pattern of the image in a darkened lecture theatre using an LCD projector and a 35-mm slide projector. All observers sat within the observer zone and conducted the psychophysical experiment simultane-ously. The distance between screen and observer/ spectroradiometer was adjusted to be within the recommended distance by ANSI[3] (3±1 picture heights from the screen) for normal cinema viewing. The displayed images from both LCD and slide projectors had reference white of 15.5 cd/m^2, with a mid-grey background of luminance approximately 3 cd/m^2. Image size on the screen was 319 x 239 cm for the LCD projector and 280 x 184 cm for the 35-mm slide projector. The size of each patch in the Mondrian pattern was 15 x 15 cm (corresponding viewing angle ranging from 0.97° to 1.39° according to the position of the observer) for the LCD projector and 16 x 16 cm (from 1.03° to 1.48°) for the 35-mm slide projector.

Forty colours were chosen as test colours and ten colours were repeated to investigate the intra-observer repeatability (therefore 50 colours presented in each phase). For the LCD projector experiment, the same 30 colours were used as in the authors' previous study[6] and 10 new colours were added. For the 35-mm slide projector experiment, 40 transparencies were chosen from the original set of 99 used in the LUTCHI experiment.[4]

The magnitude estimation method was used to assess three attributes of colour appearance: Lightness, Colourfulness and Hue. To determine the average colour appearance value of each test colour, the arithmetic mean was calculated for Lightness and Hue and the geometric mean for Colourfulness. To quantify the performance of the observers and colour appearance models, the coefficient of variation (*CV*) was used as a statistical measure to investigate the agreement between any two sets of data, say x and y, using the equation below. Also scatter diagrams were used to compare the two data sets visually.

$$CV = 100\frac{\sqrt{\sum (x_i - y_i)^2 / n}}{\bar{y}},$$

n : number of samples in x and y sets

$\bar{y}$: the mean value of the y set

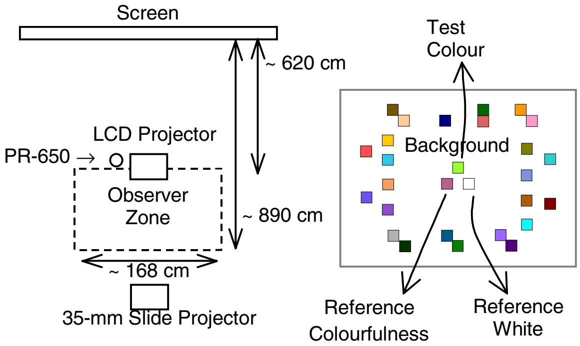

Figure 1 Experimental situation and viewing pattern

The repeatability of each observer was examined using the ten colours repeated in each session. The *CV* value between two sets of estimation results was calculated as the repeatability for each observer. Also the *CV* between the individual's and the mean visual result was computed for each phase, indicating the accuracy of each observer. The mean *CV* values of overall repeatability and accuracy for each attribute are given in Table 1. Both observer repeatability and accuracy showed performances similar to the authors' previous study.[6]

This new experimental data set obtained under cinema viewing condition was compared with other data for projected colours in conventional projection conditions (i.e. data projection in a normal-size room) to investigate the effect of screen size, luminance of reference white, and luminance of adapting field. Experimental phases used in this study are summarised in Table 2.

They include 2 phases of cinema conditions, 2 phases of conventional presentation conditions – data from the authors' previous study[6] – and 2 phases of the LUTCHI data set.[4,9] All of them were based upon a mid-grey background condition.

Table 1 Observer Performances

	Repeatability			Accuracy		
L: Lightness *C*: Colourfulness *H*: Hue	*L*	*C*	*H*	*L*	*C*	*H*
Average CV	7	25	9	16	20	9

Effect of Screen Size

Phases C-Grey and P-Filter were compared to investigate the effect of absolute screen size. Both phases had similar luminance and colour temperature for reference white and adapting field with same visual angle of the displayed image, which was about 25° for image width and 19° for image height, but different screen sizes. Note that the screen area of the cinema condition (C-Grey) was 7.4 times larger than that of presentation condition (P-Grey). Both phases had 30 common colours, for which measurement and psychophysical results were directly compared.

Visual lightness and colourfulness comparison results are shown in Figure 2. The mean colour difference was 7.4 ΔE^*_{ab}. For lightness, the larger screen (C-Grey) showed a slightly higher value. This difference possibly arises from the observer bias, which will be discussed later. In the case of colourfulness and hue there was little difference between the two phases.

Table 2 Experimental Phases

Viewing Condition	Name of Phase	Display Device	Screen Size (WxH cm)	Viewing Distance (cm)	Angular Patch Size	Luminance Ref. White (cd/m^2)	CCT (K)	Adapting Field (cd/m^2)	No. of Test Colours	No. of Observers
Cinema Condition	C-Grey	LCD projector	319x239	620~890	0.97° ~ 1.39°	15.68	7200	2.7	40	9
	C-35mm	35mm Slide Projector	280x184	620~890	1.03° ~ 1.48°	15.42	3900	3.1	40	11
Conventional Presentation Condition	P-Grey	LCD projector	117x88	300	1.05°	154.0	7200	28.2	32	21
	P-Filter	LCD projector	117x88	300	1.05°	18.8	7200	3.5	32	21
LUTCHI Data (Presentation)	Lutchi-1	35mm Slide Projector	110x80	360	1.1°	113	4000	21.4	99	6
	Lutchi-3	35mm Slide Projector	110x80	360	1.1°	45	4000	8.5	99	6

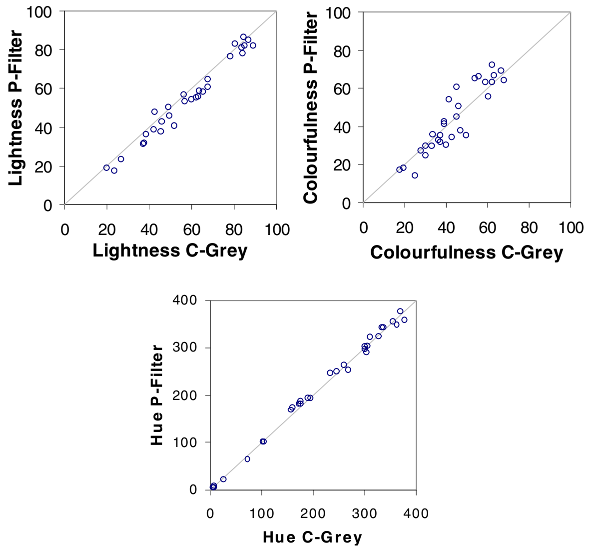

Figure 2 Effect of screen size for visual lightness and colourfulness

The effect of screen size was also tested by comparing LUTCHI data and C-35mm phase. The C-35mm experiment had screen area approximately 6 times larger than that of LUTCHI experiment. Since the same slides used in the LUTCHI experiment were employed in the C-35mm phase, the new colour measurement and appearance data could be compared directly with those of Phases 1 and 3 of the LUTCHI 35-mm projection experiment, which had colour temperature similar to Phase C-35mm. It was found that the colour differences between the new measurement data and corresponding colours from the LUTCHI data set were quite small, with an average of only 3.5 ΔE^*_{ab} in spite of a 10 year gap between these two experiments and the use of different slide projectors and screens.

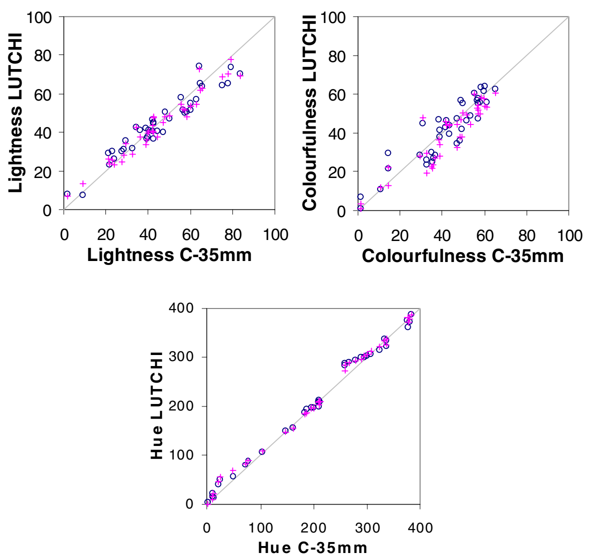

Figure 3. Colour appearance comparison between C-35mm and LUTCHI projection experiments

To compare colour appearance results between the two experiments, lightness and hue were directly compared but the new colourfulness results were scaled by a single factor to have the same scale as the LUTCHI data. These two experiments had a different luminance level for the reference white and did not have same reference colourfulness values. The results shown in Figure 3 had a good agreement between the two independent experiments. Note that there is no effect for lightness found in the C-Grey vs. P-Filter case. However it is clear from Figure 3 that the LUTCHI data showed lower lightness for light colours. This was possibly caused by the observer bias induced by the reference colourfulness patch, which for the slides had a very high lightness (L*=84.8). Although this reference colour is supposed to be used only for colourfulness judgement, it could also affect the lightness judgement making observers reluctant to give high values of lightness. This bias was reduced for the new C-35mm experiment because this particular phase was conducted last so that observers had already memorised the overall range for scaling lightness.

Considering both cases, it can be concluded that there was little change in colour appearance resulting from the change of image size.

Effect of Luminance Level

The experiment in cinema viewing conditions had not only a larger screen size but also lower luminance than previous experiments. The effect of the luminance of reference white was investigated by direct comparison between phases using common test colours. Figure 4 shows comparison of visual lightness and colourfulness between high luminance level (P-Grey) and two low luminance levels (P-Filter, C-Grey). These diagrams clearly show that the higher luminance colours had higher lightness and colourfulness, even though relative luminances were equal. It confirms the Hunt effect,[10] i.e. that colourfulness increases with luminance. A lightness increment with luminance was also shown in LUTCHI experiment for surface colours[5] but no difference for LUTCHI experiment using 35-mm slide projector.[4] However LUTCHI experiment using 35-mm slide projector had relatively smaller difference in luminance between the two phases.

Phases C-Grey and P-Filter had similar luminance levels, and were therefore expected to show similar results. However as depicted in Figure 2, C-Grey showed slightly higher lightness than P-Filter. The P-Filter experiment was done after P-Grey by the same observer group, which might have exaggerated the effect because observers still felt the P-Filter session darker than previous experiment, even when fully adapted, thus making lower lightness judgements. It was found that CIECAM97s predicted the Hunt effect quite well, but although it could also predict lightness change due to luminance level by manipulating the luminance adaptation factor F_L, the model's predictions were far smaller than found in the experiments.

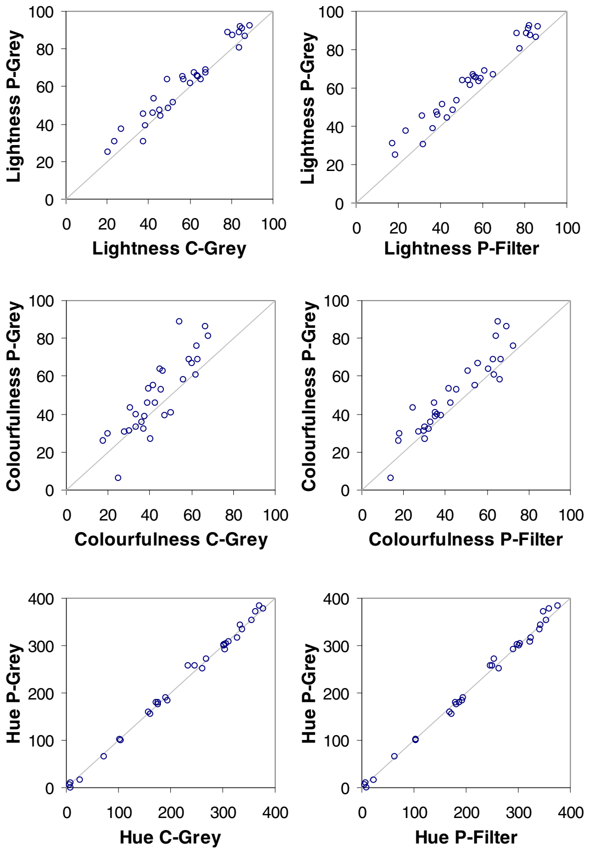

Figure 4. Lightness and colourfulness changes according to luminance of reference white

Performance of Colour Appearance Models

Previous study of the projection condition (P-Grey, P-Filter) showed that CIECAM97s performs best.[6] It must be remembered, however, that the CIECAM97s model parameters were derived from the LUTCHI data. The new data sets for colour appearance under cinema viewing condition (C-Grey, C-35mm) were used to evaluate the performances of seven colour appearance models. In the case of the Hunt94 model, the lightness predictor J_p for projection viewing is used. The averaged *CV* values are summarised in Table 3.

Table 3 Performance of colour appearance models (average CVs for cinema condition)

Average *CV*	CIE LAB	LLAB	RLAB	Hunt 94	CIE-CAM97s	FC[7]	Fair-child[7]
Lightnes s	17	17	30	17	16	16	18
Chroma	27	22	30	19	19	19	23
Colour-fulness		24		20	21	20	26
Hue		10	13	9	8	8	8

CIELAB *L** performed well for lightness. Hunt94, CIECAM97s and FC performed well for all attributes. The FC and Fairchild models are modifications of CIECAM97s, having simplified chromatic adaptation transforms and modified colour appearance predictors. The Fairchild model showed a poor performance for chroma/colourfulness compared with CIECAM97s or FC. It under-predicted low chroma and over-predicted high chroma, perhaps because the chroma/colourfulness predictors of the Fairchild model are based on Munsell chroma, whereas CIECAM97s and FC are based on the LUTCHI data set, derived using the magnitude estimation method. The authors' independent study using the magnitude estimation method showed a good agreement with the LUTCHI data, and therefore with the CIECAM97s and FC models, indicating the stability and repeatability of the magnitude estimation method. More research is needed to understand the difference between predictors based on Munsell chroma and those derived from magnitude estimation experiment. This might be caused by the different psychophysical techniques and sample sizes and arrangements.

Analysis of Dark Surround Condition of CIECAM97s

Four surround categories (average, dim, dark and cut-sheet) were arbitrarily defined by CIECAM97s. Each condition has different surround parameters *F*, *c* and N_c to compensate the colour appearance changes, among which *c* is most important. Using the experimental data shown in
Table 2, the optimised parameter *c* for dark surround in the CIECAM97s model was investigated. For this task, an optimised *cz* value was used because every phase had similar background, and therefore also a similar *z* value. The background effect was not considered here. Optimised *cz* values were calculated by fitting the lightness predictor *J* to the mean visual lightness. Equation for *J* is shown below.

$$J = 100 \cdot \left(\frac{A}{A_w} \right)^{c \cdot z} \quad \text{where } z = 1.0 + \left(\frac{Y_b}{Y_w} \right)^{1/2}$$

where *A* is the achromatic signal and Y_b and Y_w are relative tristimulus values for the background and reference white respectively.

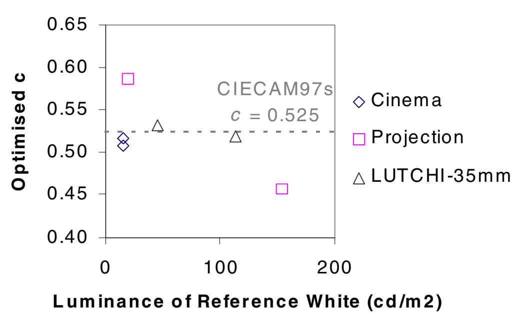

Figure 5 Optimised surround parameter c for CIECAM97s

Optimised c values are represented as a function of the absolute luminance of reference white in Figure 5. The dotted line represents the parameter $c = 0.525$ used in CIECAM97s. This result suggests that that c might be better modelled as a function of the luminance of reference white. Although the constant value used in CIECAM97s roughly corresponds to the average of the optimised c values, 0.520, developing a new function for dark surround might be necessary to predict accurately colour appearance changes due to luminance changes.

Conclusions

Data sets were accumulated for colour appearance under cinema viewing conditions. One of them used the same slides as the LUTCHI 35mm experiment. The results showed a very good agreement between those two data sets, indicating the reliability of magnitude estimation method.

Surround conditions were compared between cinema and conventional presentation, for which the main difference is the image size and viewing distance. There was little difference between the results for the two screen sizes.

It was found that visual lightness, which is relative brightness scaled to reference white, changed according to the luminance level. A colour viewed at higher luminance appears to have higher lightness and colourfulness, even though their relative luminances are identical.

Performance testing of colour appearance models showed that CIECAM97s works well for the dark surround condition, including cinema and conventional presentation conditions. Also the newly-derived colour appearance model FC, a modified version of CIECAM-97s, showed similar or better performance. An optimised surround parameter for dark surround with grey background was calculated for CIECAM97s model. Deriving a new function containing the lightness change due to luminance level might be necessary to achieve a better result, especially for dark surround covering a wide range of luminance levels.

References

1. M.R. Luo and R.W.G. Hunt, The Structure of the CIE 1997 Colour Appearance Model (CIECAM97s), *Color Res. Appl.* **23**, 138-146 (1998)
2. R.W.G. Hunt, *Reproduction of Colour, 5th Edition*, Fountain Press, p.93 (1998)
3. ANSI/SMPTE 196M-1986, Screen Luminance and Viewing Conditions – Indoor Theater Projection
4. M.R. Luo and X.W. Gao, P.A. Rhodes, H.J. Xin, A.A. Clarke and S.A.R. Scrivener, Quantifying colour appearance. Part IV. Transmissive Media, *Color Res. Appl.* **18**, 191-209 (1993)
5. M. Ronnier Luo and Anthony A. Clarke, Peter A. Rhodes, André Schappo, Stephen A. R. Scrivener, Chris J. Tait, Quantifying colour appearance. Part I. LUTCHI colour appearance data, *Color Res. Appl.* **16**, 166-180 (1991)
6. Y. Kwak, L.W. MacDonald and M.R. Luo, Quantifying Colour Appearance for Projected Images, *Proc. 2000 AIC Meeting Seoul*, Seoul, Korea, (2000)
7. R.W.G. Hunt, C.J. Li, L.G. Juan and M.R. Luo, Further Improvements to CIECAM97s, *Color Res. Appl.*, in press (2001)
8. R.W.G. Hunt, *Measuring Colour, 3rd Edition*, Fountain Press (1998)
9. LUTCHI Colour Appearance Data, http://colour.derby.ac.uk/ colour/info/lutchi/
10. R.W.G. Hunt, Light and dark adaptation and the perception of colour, *J. Opt. Soc. Am.* **42**, 190-199 (1952)

Biography

Youngshin Kwak received her BSc (major: physics, minor: computer science, 1995) and MSc (physics, 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. Her main research topics for PhD are device characterisation and modelling colour appearance of projection media.