The Influence of the Relative Luminance of the Surround on the Perceived Quality of an Image on a Large Display

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Abstract

The purpose of this study is to investigate the influences of surround relative luminance on the appearance of colour images presented on a large display. Psychophysical experiments were conducted under four surround conditions, i.e. dark, dim and bright surrounds excluding flare, as well as a typical office surround. Fourteen observers were asked to assess image quality and the three perceptual appearances, colourfulness, naturalness and contrast, using the categorical judgment method. Five colour images were manipulated to produce variations by rendering lightness, chroma and sharpness. These manipulated images were used as the stimuli in the assessment. The experimental results show that there were significant differences between the four surround conditions for dark images in terms of image quality and the three perceptual appearances, in particular colourfulness. In addition, naturalness was found to be the critical factor affecting image quality for all surrounds.

Introduction

The most important goal of imaging reproduction systems is arguably to produce pictures having an equal appearance to the original scene. In attempts to achieve this goal, it has been necessary to understand perceptual effects such as the psychophysical response of human observers towards physical luminance. In addition, measuring perceptual effects influenced by the change of viewing condition has also been an important theme for satisfactory cross-media reproduction [1]. To name a few, the Stevens effect [2,3] and the Bartleson-Breneman effect [4] well summarize the perceived brightness change affected by physical luminance and the variation of surround luminance. Hunt [5], Pitt and Winter [6], and Breneman [7] investigated the surround effect on perceived colourfulness and their results showed an apparent colourfulness decrease for a dark surround. However, their experimental conditions and scaling techniques were quite different such as colour patches matched using a monocular matching technique in Hunt's experiment, a colour mosaic setup matched using a binocular matching technique by Pitt and Winter, and colour patches against an achromatic mosaic using a binocular matching technique by Breneman. Furthermore, it is important to find out whether the same surround effects can be applied to colour images. Recently, Liu [8] and Laird [9] used colour images seen on self-luminous displays to examine the change of perceived contrast and image preference as influenced by different surround conditions.

Although much effort has been put into studying the surround effect on colour and image appearance, the question still unresolved is 'How different does a complex image appear under various surround conditions?' The comprehensive answer to this question needs to include the variations of image quality and its perceptual appearances such as naturalness and colourfulness etc. caused by a change of the surround condition. In a practical situation, the surround can be defined as the rest of the room in which the viewing is taking place. Describing the surround accurately, however, needs attention because an ordinary viewing condition includes a complex spatial configuration, viewing flare, a large range of luminances, and a diversity of image sizes [10]. According to CIE [11], a surround can be defined by the surround ratio (S_R), which is calculated by dividing the luminance of a white in the surround area by the luminance of a reference white shown in the display area.

This study concentrates on the change of perceptual appearances related to image quality affected by surround relative luminance. In advance of this study, a pilot psychophysical experiment was conducted for a dark surround [12]. This was designed to determine the test images, methods for manipulating images, and perceptual appearances related to image quality. From the results of the pilot study, 5 original test images, 15 methods for manipulating the original images and 3 perceptual image appearances (colourfulness, naturalness and contrast) with image quality were chosen for the current study. Furthermore, as mentioned previously, the practical surround condition where a display is viewed is complex. Hence, the surround conditions used for this study were divided into two groups. For Group 1, the illumination was located behind the display, so that the illumination provided little viewing flare to the displayed image but observers could perceive a surround of varying brightness. For Group 2, a typical office environment where fluorescent lamps were in the ceiling was used, so that viewing flare was added to the displayed image.

Figure 1. *Five test images selected for this study. Their names are 'Seashore', 'Pier', 'Park', 'Fruits' and 'Kids' from left to right.*

Experimental

Image Manipulation

The influence of surround relative luminance on image quality and its three perceived appearances (colourfulness, contrast and naturalness) were investigated using 5 test images as shown in Figure 1. These 5 original images were manipulated to provide wide range of variations to observers, but realistic appearance, along the dimensions of CIECAM02 lightness (J) and chroma (C) [11]. Table 1 describes 15 manipulation methods that can be separated into three groups: lightness, chroma and sharpness. The latter was achieved by manipulating the J values in the frequency domain. Each manipulation method has a three-part name corresponding to the image parameter controlled, the type of the manipulating function and the amount of variation given to the original image. For example, SHFE1/5 is a sharpness manipulation (S) by high frequency emphasis filter (HFE) with 1/5 of cut-off frequency parameter.

Psychophysical Experimental Setting

A 42-inch Samsung Plasma Display Panel (model PPM42H3), with a resolution of 1024×768 pixels, was characterized by a 3D-LUT with tetrahedral interpolation. The average errors were 1.25 and 1.74 ΔE^*_{ab} units for the forward and reverse models. The reference white of the display was set at 174 $cd \cdot m^{-2}$ with a correlated colour temperature of 8940 K. The 5 test images designated 'seashore', 'pier', 'park', 'fruits' and 'kids' (Figure 1). A total of 14 observers completed over 50,000 observations. The categorical judgment method with a 9-point category scale was applied to access 4 attributes: image quality, colourfulness, contrast and naturalness. Thurston's law of Comparative Judgment, Case V, was used to convert the observers' category data into Z-scores.

Surround Condition

The details of the four surround conditions investigated are summarized in Table 2. The dark, dim and bright conditions belong to the Group 1 surround previously explained. Two tungsten lamps and 16 lamps of D65 were used for dim and bright surrounds, respectively. The wall behind the display was illuminated. Hence, there was no viewing flare on the displayed images, but observers perceived the surround with varying luminances. For the office condition belonging to the Group 2 surround, there were three fluorescent lamps in the ceiling but not directly on top of the display.

Table 2: Four surround conditions investigated for this study.

Name	Surround Ratio (S_R) [11]	Viewing Flare	Surround White
Dark	~ 0	-	-
Dim	0.17	0%	33 $cd \cdot m^{-2}$, 2610K
Bright	2.34	0.68%	448 $cd \cdot m^{-2}$, 6020K
Office	0.30	1.32%	57 $cd \cdot m^{-2}$, 3387K

Table 1: Summary of the image manipulation methods and their names in brackets.

Image Parameter	Transfer Function used (the name of each manipulation)
Lightness (L)	**Linear function (LL)** $J_{output} = 0.8 \cdot J_{input}$ (LL08) $J_{output} = 0.9 \cdot J_{input}$ (LL09)
	Sigmoid function (LS) $J_{output} = \frac{100}{A \cdot \{1 + [M/(0.01 \cdot J_{input})]^E\}}$ where A = $1/(1+M^E)$, M=1.23 and E=1.45 (LSS), and M=0.63 and E=2.35 (LSL). When M is smaller and E is larger, the image manipulated will have a bigger contrast.
	Inverse-Sigmoid function (LIS) $J_{output} = 100 \cdot M \cdot \left[\frac{1 - 0.01 \cdot A \cdot J_{input}}{0.01 \cdot A \cdot J_{input}}\right]^{-1/E}$ where M=1.23 and E=1.45 (LISS), and M=0.63 and E=2.35 (LISL).
	Local Color Correction Method (LLCC) The background luminance factor (Y_b) in CIECAM02 was computed from the absolute luminance value of each pixel [11,13]. This individual value of Y_b was used to compute a new lightness (J) value for each pixel.
Chroma (C)	**Linear function (CL)** $C_{output} = 0.6 \cdot C_{input}$ (CL06) $C_{output} = 0.8 \cdot C_{input}$ (CL08)
	Sigmoid function (CS) $C_{output} = \frac{100}{A \cdot \{1 + [M/(C_{input}/C_{max})]^E\}}$ where M=0.63 and E=2.35 and C_{max} is the maximum C in the image considered.
	Inverse-Sigmoid function (CIS) $C_{output} = 100 \cdot M \cdot \left[\frac{1 - A \cdot (C_{input}/C_{max})}{A \cdot (C_{input}/C_{max})}\right]^{-1/E}$ where M=0.63 and E=2.35.
Sharpness (S)	**Contrast Sensitivity Function (SCSF)** The Barten's contrast sensitivity function was used [14]. The two frequency ranges were enhanced: 0.6 – 9.3 cpd and 23.97 – 31.96 cpd corresponding to the areas whose lightness-variations are the best detectable and the edge area, respectively.
	High Frequency Emphasis Filter (SHFE) $Filter = 1 + 1.5 \cdot [1 - \exp(-frequency^2/(2 \cdot d^2))]$ where d = 1024 × 1/5 (SHFE1/5), d = 1024 × 1/11 (SHFE1/11), and the horizontal resolution of the display used was 1024 in this study. As the cut-off frequency parameter (d) is smaller, the image becomes sharpened due to the increase of the eliminated low-frequency information.

Results and Discussions

Only noticeable results are described with the graphs comparing Z-scores for each of the 4 attributes scaled for the dark, dim, bright and office surrounds. The paired t-test was utilized to investigate whether the same image appears different according to variation in the relative surround luminance. Only the effects with statistical significance according to the paired t-test will be reported here.

The Change of Image Colourfulness

Figure 2 shows that the perceived colourfulness appearance in terms of Z-scores for the bright surround is plotted with those for the dark surround. It can be seen that the bright surround makes images appear slightly more colourful than those viewed for the dark surround. This phenomenon agrees with those found by Hunt [5], Pitt and Winter [6], and Breneman [7]. Unlike the bright surround, the dim and office surrounds did not provide any significant perceived colourfulness change from the dark surround.

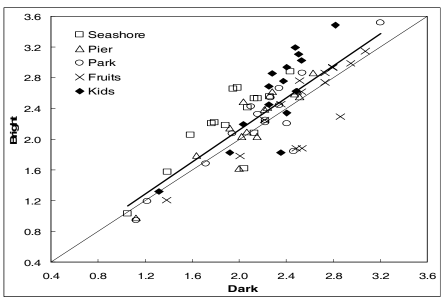


Figure 2. Image colorfulness comparison with Z-scores of all images manipulated by 15 methods, seen under the dark (X-axis) and bright surround (Y-axis). Also shown are a line at 45 degrees and a linear fitting line.

Figure 3 shows the change of perceived colourfulness appearance caused by lightness-decrement of the image for the dark, dim, bright and office surrounds. The comparison is made with the average and the spread of Z-scores of 5 test images for the original image and its darkened images by 10% and 20% lightness-reduction. For the dark surround, colourfulness is not affected by decreased-lightness manipulation (LL09 and LL08). However, a lowering of colourfulness with decreasing lightness can be viewed to be more apparent for the dim, bright and office surrounds. This tendency was also found for naturalness, contrast and image quality.

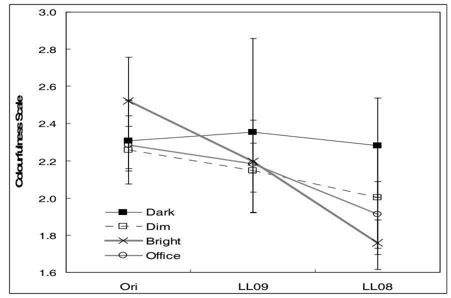


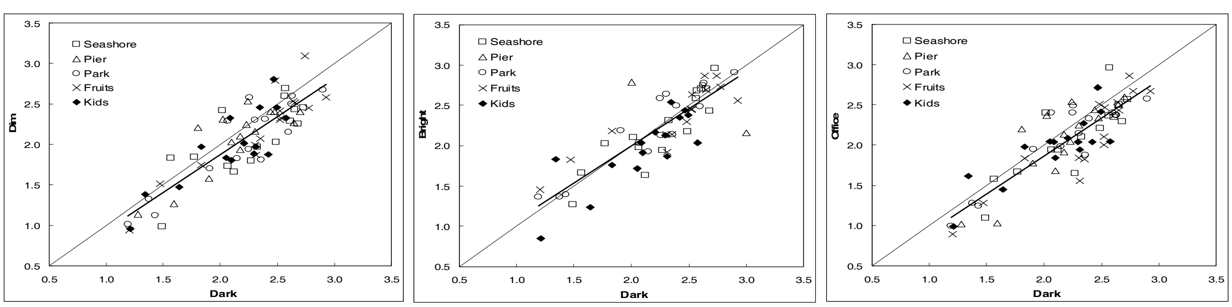
Figure 3. Image colorfulness comparison with the average Z-scores of 5 test images for dark, dim, bright and office surrounds. X-axis denotes the lightness manipulations: LL09 and LL08, also the original image.

The Change of Image Naturalness

Figures 4(a), (b) and (c) show the visual results of naturalness appearance in terms of Z-scores for dim, bright and office surrounds against those for dark surround, respectively. It can be seen that a higher naturalness is perceived for the dark surround than that for the dim and office surrounds, i.e. most data points are located below 45° lines in Figures 4(a) and (c). The reason observing less natural images for the dim surround can be caused by desaturating effect of the dim surround in which the plasma display was seen [15]. Due to this effect, the preferred skin colour on a television viewed in dim ambient tungsten light required higher purity than in a reflection print viewed in daylight [16]. However, hardly any difference is seen between the bright and dark surrounds in Figure 4(b). Why the image naturalness looks alike between the dark and bright surrounds may be due to an increase of the perceived colourfulness for the bright surround as found in the previous section.

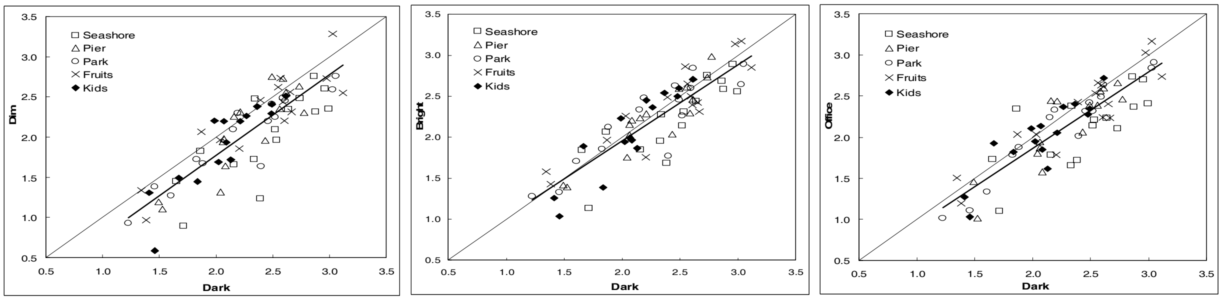
The Change of Image Contrast

It was found that image contrast results were the same as those of image naturalness, i.e. higher contrast was perceived for the dark surround than that for the dim and office surrounds. However, there was no significant difference between the dark and bright surrounds.



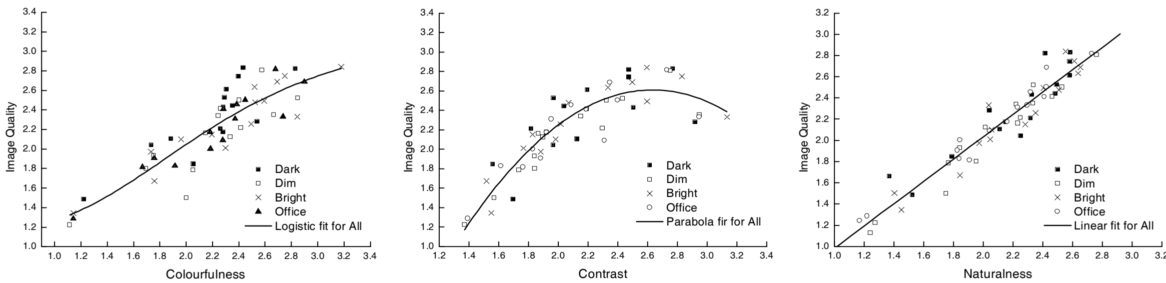
(a) (b) (c)

Figure 4. Image naturalness comparison with Z-scores of all images manipulated by 15 methods, seen under the dark and (a) the dim, (b) the bright, and (c) the office surrounds. X-axis denotes the dark surround. The data are viewed separately with respect to the individual 5 test images, and shown is a line at 45 degrees. Also shown is a linear fitting line to demonstrate a tendency being examined from data.



(a) **(b)** **(c)**

Figure 5. *Image quality comparison with Z-scores of all images manipulated by 15 methods, seen under the dark and (a) the dim, (b) the bright, and (c) the office surrounds. X-axis denotes the dark surround. The data are viewed separately with respect to the individual 5 test images, and shown is a line at 45 degrees. Also shown is a linear fitting line to demonstrate a tendency being examined from data.*



(a) **(b)** **(c)**

Figure 6. *Image quality scale versus (a) image colourfulness scale, (b) image contrast scale, and (c) image naturalness scale. The data are viewed separately with respect to each of the dark, dim, bright and office surrounds. Also shown are three fitting curves.*

As chroma decreased linearly by CL09 and CL08 manipulations, image contrast became lower. This can be explained by the Helmholtz-Kohlraush effect in which a less colourful colour looks darker, and by the Stevens effect in which brightness (or lightness) contrast decreases with decreasing luminance. However, this trend was found to be more apparent for all surrounds except the dark surround.

The Change of Image Quality

Figures 5(a), (b) and (c) show the image quality results in terms of Z-scores for the dim, bright and office surrounds plotted against those for the dark surround, respectively. It can be seen that almost all data points are located below a 45° line for each of the three comparisons. This indicates higher image quality for the images viewed in the dark surround than those viewed in the dim, bright and office surrounds. The paired t-test also supported that the dark surround could provide better viewing condition for image quality than the other illuminated surrounds. The image quality results can be better understood when considering the results of colourfulness, naturalness and contrast described in the last three sections. For dim and office surrounds, image quality decreases due to the reduction of contrast and naturalness. For the bright surround, image quality degrades, despite the increment of colourfulness and similar contrast and naturalness compared with those for the dark surround. Therefore, increasing naturalness having a positive linear relationship with image quality, which will be explained in the next section, can improve image quality for the bright surround.

The relationship between image quality and its three perceptual appearances

Figures 6(a), (b) and (c) are intended to show how the variations of perceived colourfulness, contrast and naturalness affect image quality for each of the four surrounds investigated, by plotting image quality results against colourfulness, contrast and naturalness results, respectively. The mean Z-scores of 5 test images for each of the 15 manipulations were plotted. And suitable functions were fitted to the data points to demonstrate the relationship between image quality and each of its three perceptual appearances. It can be seen in Figure 6(a) that image quality increases with colourfulness until reaching the high colourfulness region. Figure 6(c) clearly shows that a positive correlation between image quality and naturalness, i.e. a higher natural image can have a higher image quality. For perceived contrast, the highest image quality has a medium perceived contrast as shown in Figure 6(b). This was also found by Calabria [17]. All the above trends were highly consistent regardless of which surround was used.

The comparison of empirical image quality models for dark, dim, bright and office surrounds

A multiple regression analysis was conducted to evaluate how well the three perceptual appearances studied (naturalness, contrast and colourfulness) can predict image quality for each surround condition. Table 3 gives the regression coefficients and those in bold font are significantly different from zero based on a statistical test. R denotes a multiple correlation coefficient. Table 3 shows

Table 3: The empirical image quality models for dark, dim, bright and office surrounds (Image Quality = a·Naturalness + b·Contrast + c·Colourfulness + d).

Surround	a	b	c	d	R
Dark	**0.705**	**0.282**	**0.226**	**- 0.424**	0.925
Dim	**0.992**	0.070	0.053	**- 0.257**	0.939
Bright	**0.792**	**0.164**	**0.177**	**- 0.424**	0.966
Office	**0.849**	-0.050	**0.214**	- 0.013	0.944

that for the dim surround, naturalness itself is enough to be able to predict image quality, and naturalness and colourfulness are required for the office surround. It can be concluded that naturalness is the most important perceptual appearance controlling image quality for all surround conditions. Besides naturalness, colourfulness is also a critical factor affecting image quality rather than contrast for a typical office viewing condition.

CONCLUSION

The influence of surround relative luminance on the appearance of complex colour images displayed on a 42-inch self-luminous display was investigated in terms of 4 attributes: image quality and its three perceived appearances, colourfulness, contrast and naturalness. The surround conditions were divided into two groups: for the Group 1, a varying-brightness surround was perceived by the observers but this surround did not affect the displayed image, and for the Group 2, a brighter surround was used, leading to more flare being added to the displayed image. The surround relative luminance was changed from dark to dim to bright for the Group 1. A typical office viewing condition was used for the Group 2.

The results clearly showed that the dark surround provided higher image quality than the dim, bright and office surrounds, demonstrating a darkened room may be the best viewing condition to achieve the highest image quality for images reproduced on a display. The most important perceptual appearance was naturalness, followed by colourfulness and contrast, for all surround conditions.

The other findings are summarized below:

- Image colourfulness could be improved by the bright surround that was consistent with the results of Breneman, Pitt and Winter, and Hunt.
- The change of surround condition did not alter the main relationships between image quality and each of its three perceived appearances.
- About the impact of surround relative luminance on the colour image appearance, there was one distinctive phenomenon. A darker image was perceived to be less colourful, less natural, and lower contrast for dim, bright and office surround than those viewed for dark surround, finally, resulting in a lower overall perceived image quality. The reason for this might be that the illuminated surround could enhance the perceived contrast when viewing the darkened image against the light surround, so the darkened image looked even darker. This indicates that the absolute luminance of a display should be above a certain level to provide constant image colour appearance for any viewing conditions.

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