# Human Visual Contrast Model for Display Devices

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## ABSTRACT

A new human visual contrast model, HVCR (human visual contrast ratio), was developed for the display devices used in this study. A psychophysical experiment was performed to find the minimum distinguishable luminance difference at each luminance level. In the experiment, a 19-inch SIPS (Super In Plane Switch) mode LCD was used. The PLCC (piecewise linear interpolation assuming constant chromaticity) method was used to characterise the display with a great accuracy. After characterisation, a transfer function was developed between the JND steps and luminance based upon the psychophysical experiment results. This function is a key element of the HVCR model. To evaluate HVCR, it was compared with other conventional contrast models. The results from this study show that HVCR reproduces the behaviour of the human visual system for contrast analysis. Furthermore, this model can be used not only in defect analysis, such as MURA and image sticking, but also for studying image quality.

## 1. INTRODUCTION

Contrast has a significant influence on the perceived image quality in display devices. The human eye is relatively less sensitive to the dark areas of an image than in the bright areas. This variation in sensitivity makes it much easier to see small relative changes in luminance in the bright areas of the image than in the dark regions. Barten[3] proposed a human contrast sensitivity model to explain the minimum contrast that is required to be detectable at a particular luminance level. This was represented as a non-linear model of the human visual system. Later, DICOM [4] (digital imaging and communications in medicine) derived the grey scale standard display function from Barten's model[4]. The function expresses luminance as a function of the JND (just noticeable difference). As a result, many industries have used the grey scale standard function to aid in designing their displays-, however, - display devices are evaluated by linear characteristic contrast ratio formulae. Most international standards (such as IEC, ISO and VESA) define the contrast ratio(CR) and contrast modulation(CM) as given in equations (1) and (2):

$$CR = L_{\max} / L_{\min} \tag{1}$$

$$CM = (L_{\max} - L_{\min}) / (L_{\max} + L_{\min}) \tag{2}$$

Unfortunately, these formulae disagree with the human visual system in that they cannot explain its non-linear behaviour. These linear formulae cause problems when they are applied to evaluate display characteristics such as viewing angle and image. Lee et al[1,2] suggested a new model derived from the psychophysical experiments and called HVC (human visual contrast) to overcome this problem. It explains well the non-linear properties of the human visual system and out-performs conventional contrast formulae. This model is given in equation (3).

$$HVC = 10^{T_i} \tag{3}$$

$$\Delta HVC = 10^{T_2} - 10^{T_1}$$

where, $T_i = 1.858 + 0.546 \times \log(L_i) - 0.0685 \times (\log(L_j))^2$

In the model, ΔHVC is a JND step between the two-luminance values tested, and HVC is the number of distinguishable luminance steps from an ideal black to the measured luminance. Thus

ΔHVC represents the absolute distinguishable luminance difference of the human visual systems. It predicts well the non-linear nature of the human visual system. The ΔHVC model has a drawback, however, in contrast evaluation tasks such as in viewing angle analysis: it is not a relative contrast model. Consequently, the first aim of this study was to improve the model and compare it with the other existing contrast models.

## 2. METHOD

An LG.Philips 19-inch SIPS (Super In Plane Switch) mode LCD panel was selected to measure JND luminance. This LCD had a good additive characteristics and a good white balance when compared with other types of LCDs. Before the test, characterisation was performed using the PLCC model. After characterisation, 25 colour patches were selected to transform from $L^*$ values with $a^*=b^*=0$ to RGB values. Equations (4) to (6) show the calculation method from $L^*a^*b^*$ to XYZ. After these calculations, the RGB values can be found by inverting PLCC.

$$X = X_n\{(a^*/500)+[(L^*+16)/116]\}^3 \tag{4}$$

$$Y = Y_n[(L^*+16)/116]^3 \tag{5}$$

$$Z = Z_n\{[(L^*+16)/116]-(b^*/200)\}^3 \tag{6}$$

Five observers participated in the experiment to find 5 JND luminance steps in the selected 25 neutral colour patches. In order to find the JND luminance steps, pair comparison was performed in a dark room. Observers were shown two squares, each 2-cm in size, against a neutral background as shown in Figure 1. Experimental software developed using Visual Basic 6.0 was used to control one of the samples in a pair in terms of RGB. Each observer was asked whether they could distinguish the difference between the two colours or not. The experiments were performed in two directions: increasing from a dark luminance level and decreasing from a high luminance level. After a colour was produced, a PR-650 tele-spectroradiometer (TSR), measured the resulting stimulus. The Human Visual Contrast model was developed from that JND experimental data. Using this data, a transfer function between the JND luminance steps and luminance was found. From this transfer function, the Human Visual Contrast model was derived. After developing the model, it was then compared with the ΔHVC, ΔL* and conventional contrast ratio formulae.

**Figure 1.** Presented colour patches example for the paired comparison test

Finally, the viewing angle characteristics of the LCD were measured for the new model and conventional Contrast Ratio. This was done to illustrate how the method used by most people use the contrast ratio when evaluating viewing angles differences.

## 3. RESULTS

### 3.1 Characterisation for the test display devices

An LG.Philips 19-inch SIPS LCD panel was used in this experiment. The additivity error of this sample is within ±1.0%. The formula is applied to detect additivity error as given in equation (7).

$$Additivity\quad error\ (\%) = [\{(Y_R + Y_G + Y_B - 2Y_{black}) - Y_{grey}\}/Y_{grey}] \tag{7}$$

In this formula, $Y_R$, $Y_G$, $Y_B$, $Y_{Black}$, and $Y_{grey}$ are the luminance values Y for the full red, green, blue, black and grey colours. Prior to the psychophysical experiment, the characterisation of the display was performed using the PLCC and GOG (gain-offset-gamma) models. A regression method was not considered because it is difficult to perform in the reverse calculation. The characterisation results are shown in Table 1. In these results, the PLCC method performs satisfactorily for this experiment with a mean $\Delta E^*ab$ of about 1.0. In case of the PLCC method, 8 neutral colours were used for training and 140 mixed colours were used to evaluate its performance.

**Table 1.** Basic statistical results for colour difference ($\Delta E^*ab$) between the predicted and measured XYZ values after characterisation of the test display device

| Model | Average of $\Delta E^*ab$ | Maximum of $\Delta E^*ab$ | Median of $\Delta E^*ab$ |
|---|---|---|---|
| PLCC | 0.96 | 7.85 | 0.64 |
| GOG | 2.6 | 3.7 | 2.7 |

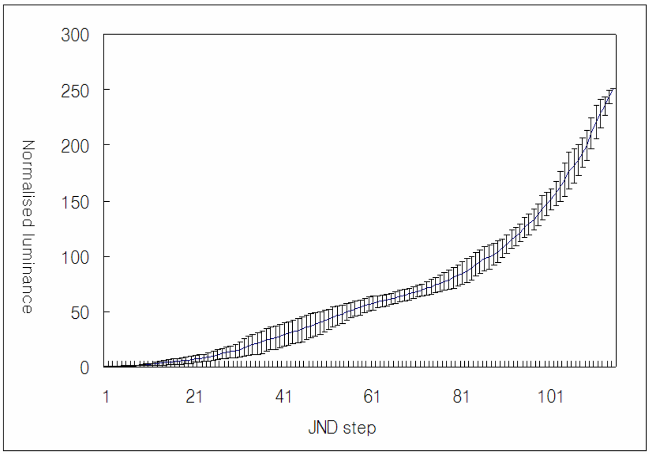
### 3.2 Development of the Human Visual Contrast model

The aim of the psychophysical experiment was to find the JND steps for each selected colour. Figure 2(a) shows the plot of the detected JND steps and luminance. Figure 2(b) shows that a log-log plot between JND steps and luminance, and shows the visual results and their predicted results by a model. For the first time, 25 colour patches were selected by characterisation of the test sample and then 5 JND step were found in each selected colour patch. Therefore 125 data were accumulated in this experiment.

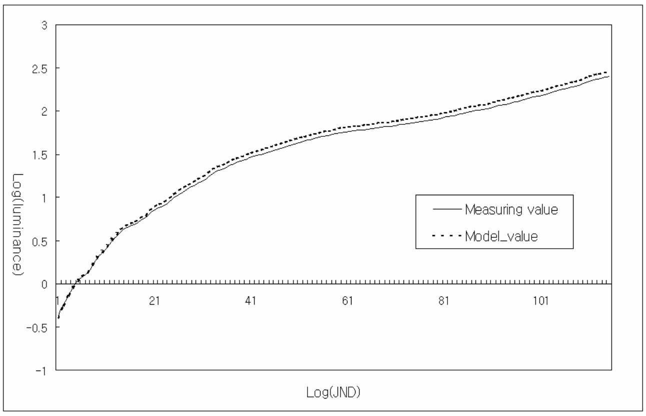
In order to make a transfer function between JND step and luminance, a polynomial regression method was used to fit the data in the log-log plot Fig 2(b). The results show that human vision is sensitive to low luminance levels. A transfer function can be developed from this data.

The R-squared value of this transfer function is 0.988. It indicates that the function can successfully account for the relationship between measured luminance and the JND luminance. HVCR (human visual contrast ratio) was developed based on this transfer function as shown in equation (8).

In the equation, the JND step is the minimum luminance distinguishable by human observers. $T_i$ is a transfer function, *a is an offset value* for the test display device and $L_i$ is the measured luminance.




(a) Raw data from the JND experiment




(b) Log-log plot of JND steps against luminance between measured and anticipated results

**Figure 2.** Relationship between detected JND step and luminance

$$HVCR = (10^{T_{\max}} / 10^{T_{\min}})$$

$$JNDs = 10^{T_i}$$

$$\text{where, } T_i = a + 0.4548 \times \log(L_i) - 0.0115 \times (\log(L_i))^2 \quad (8)$$

$T_{max}$ and $T_{min}$ are stand for white and black colours.

Where the offset value varies according to the minimum luminance value of the display device tested. In this experiment, *a* was set to 0.6277. *JNDs* means the distinguishable luminance steps between the minimum luminance and the measured luminance. As to the concept of JNDs, HVCR can be recommended for describing the contrast characteristics.

The HVCR model was compared with the other conventional contrast models. Figure 3 shows the functions of four contrast models: CR (equation (1)), $\Delta L^*$ Ratio, old HVC (equation (2)) and new HVCR (equation (8)). As it can be seen, all models have same tendency except the conventional contrast ratio. The conventional contrast ratio (CR) has linear characteristics across full data step range. Also the HVC showed a high contrast in low luminance level. These high contrasts can overestimate the low contrast colours. In the other hand, the HVCR model shows the similar tendency with $L^*$ ratio.

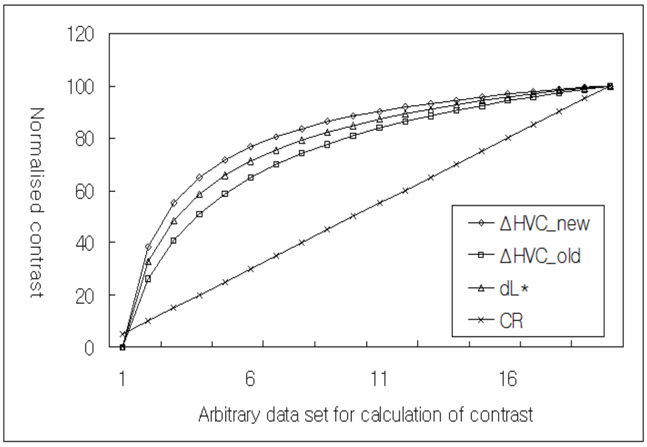



**Figure 3.** Comparison the new contrast model with other conventional contrast models.

Viewing angle characteristics is the most important factor for evaluating the image quality of LCD. An LCD display was measured to reveal the trends of the contrast models at different viewing angles. The contrast ratios calculated in each angle. As it was mentioned, the contrast ratio should be considered the human visual system. In this study, the new HVC model was calculated in each test angle with white and black colours. Figure 4 is an example of viewing angle analysis. All data were normalised for comparison on the same scale. In these results, the HVC model was shown to the over-estimate the viewing angle of display. In addition, the relationship between $\Delta L^*$ and the HVCR has a similar tendency.

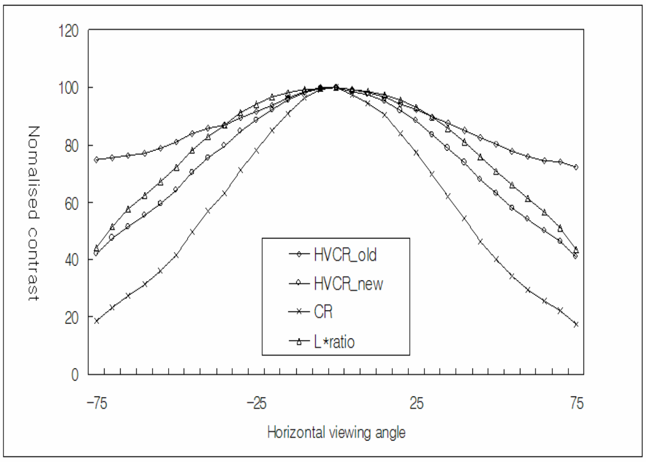



**Figure 4.** Viewing angle evaluation with contrast models for SIPS mode LCD

## 4. CONCLUSIONS

A new contrast ratio model, HVCR, was developed in this study. It gave reasonable prediction to the visual results and viewing angle test for an LCD display. This model can be applied to all display devices by optimising the model's offset (minimum luminance). Also this model can be used for evaluating image quality for display devices. Furthermore, it can perform a defect analysis such as MURA phenomena and image sticking analysis for display devices in future research.

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