Crosstalk Characterization of Stereoscopic 3D Display

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Abstract

Most of the stereoscopic displays suffer from crosstalk causing serious fatigue, headache, eyestrain etc. The key issue for the success of stereoscopic 3D display is overcoming the crosstalk. In this study, the degree of crosstalk of stereoscopic 3D display using shutter glasses is measured and the characterization models to predict the output tristimulus values by crosstalk are designed and evaluated. There is more than 90% luminance loss for the 3D viewing condition compared to 2D mode though there is little color gamut change. Because of the crosstalk, the measured color from one view is affected by the colors from other view. Based on the analysis of measurement data, three different crosstalk characterization models are designed. The Model I assumes that the same portion of the light from one view is leaked into the other view applying the same degree of crosstalk for all the measured data. The Model II assumes the different degree of crosstalk between Red, Green and Blue channels. The Model III applies different degree of crosstalk between red, green and blue primary channels and tristimulus values. The crosstalk characterization models are tested with the primary and secondary color combinations between left and right eye views. The result shows dramatic performance improvement for Model II and Model III compared to Model I.

1. Introduction

Nowadays the market share for stereoscopic 3D display is expected to grow fast as the 3D movies achieve the huge commercial success lately. The stereoscopic display techniques are based on the principle that left image is only seen to left eye and right eye sees the right image only. The stereoscopic 3-D displays can be categorized as anaglyph display, polarization display, time multiplexed display and Time-sequentially controlled polarization, depending on the methods to present left and right eye images to each eye respectively [1].

Most of the stereoscopic displays suffer from crosstalk, which means the phenomenon that the right image is leaked to left eye slightly and vice versa. The crosstalk produces double contours on the perceived image causing serious fatigue, headache, eyestrain etc [2-7]. The key issue for the success of stereoscopic 3D display is overcoming the crosstalk.

In this study, the degree of crosstalk of stereoscopic 3D display using shutter glasses is measured and the characterization models to predict the output tristimulus values by crosstalk are designed and evaluated.

2. Experimental set-up

The 50-inch Samsung plasma (PDP) TV (PN50A450) with 3D display function is used to generate stereoscopic image. The shutter glasses are needed to experience 3D image. The refresh rate for 3D mode is 120 Hz resulting in 60 Hz for each eye.

2.2 Measurement Geometry

The color measurement is done by simulating the 3D viewing condition as shown in Fig1. The shutter glasses are attached in front of the lens of spectroradiometer, CS-2000 and the distance from display to spectrometer is set to 2m. All the measurements are conducted in the dark room.

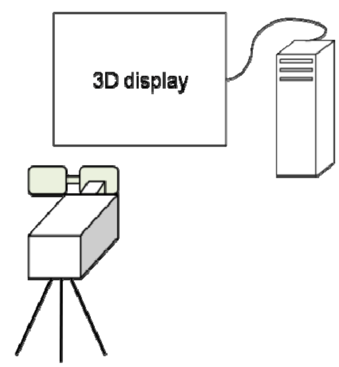

Figure 1. *Color Measurement Geometry*

2.3 Test color patches

For the color measurement, 6cm x6cm size color patch are shown in center of the screen with the black background. The original left and right images are generated first and then combined into one BMP file using horizontal interlaced method as shown in Figure 2.

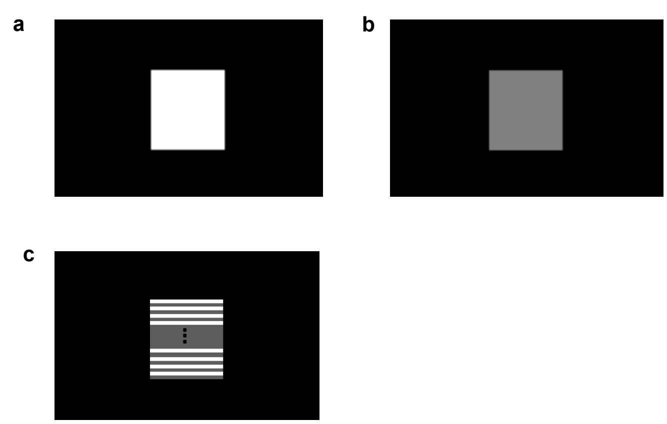

Figure 2. *Horizontal interlaced method, (a) left image, (b) right image, (c) horizontal interlaced image*

In this study, two sets of measurements are done. For the first set of measurement (SET1), Red, Green, Blue, White, Black, Cyan, Magenta, and Yellow colors are chosen. Then the colors are measured for all the possible left-right color combinations resulting in 64 measurements for each view.

Secondly (SET2), one of the views is chosen as a reference with white color patch in the center, while the color for the other view (test color) is changed from black (0,0,0) to white (255,255,255) with 32 step increment. The color measurement is done for the reference white color patch.

3. Color Characteristic of Display and shutter glasses

The color gamut of the display is measured in 2D and 3D modes. 2D mode means the measurement condition without shutter glasses. For 3D mode, primary colors shown behind the shutter glasses are measured for each view and the other view is set to black color. Figure 3 and Table 1 summarize the measurement results. It is notable that shutter glasses do not affect the chromaticities of the primary colors significantly. However luminance has been reduced significantly. In the case of White color, luminance measured in 3D mode is only 5.5% of that in 2D mode.

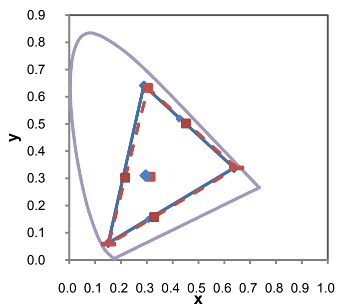

Figure 1. *comparison of color gamut for 2D and 3D mode*

Table1: Measured data of the primary colors

	2D			3D		
	Lv	x	y	Lv	x	y
R	43.37	0.65	0.34	3.19	0.64	0.34
G	154.74	0.30	0.63	9.46	0.29	0.64
B	11.21	0.15	0.06	1.16	0.15	0.06
W	216.61	0.31	0.31	11.96	0.30	0.31
K	0	0.29	0.28	0.07	0.28	0.30

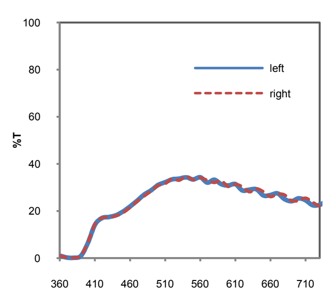

Figure 2. *Spectral Transmittance for left and right side of glasses*

The transmittances of the glasses are measured using X-Rite CE-7000A as shown in Figure4. Both lens show little difference and the average transmittance is 23.75 % and 23.79 % for left and right lens respectively.

Theoretically, the luminance for 3D mode can be calculated from the luminance in 2D mode and transmittance of the glasses. Firstly, compare to 2D mode, only half of the frames will be shown for each eye in 3D mode reducing the measured luminance to be halved. Then halved luminance will be reduced again by the glasses. The measured data in Table1, however, indicate that there are other factors affecting the final luminance entering the eye since the measured luminance in 3D model is much lower than the theoretically calculated luminance (216.61/2 x 23.7% = 25.7cd/m^2).

4. Chromaticity and luminance shifts by crosstalk

Data analysis for the measurement results clearly shows the chromaticity and luminance changes by crosstalk. As an example, Table2 summarizes the measured values of red colors on the left view with different colors on the right view. As illustrated in Figure 3, the measured chromaticities are shifted toward those of colors in the opposite views.

Table2: Chromaticity and luminance shift by Crosstalk

Left side	Lv	x	y
red (red for right)	3.24	0.64	0.34
red (green for right)	3.69	0.61	0.37
red (blue for right)	3.17	0.63	0.33
red (white for right)	3.88	0.61	0.36
red (black for right)	3.19	0.64	0.34

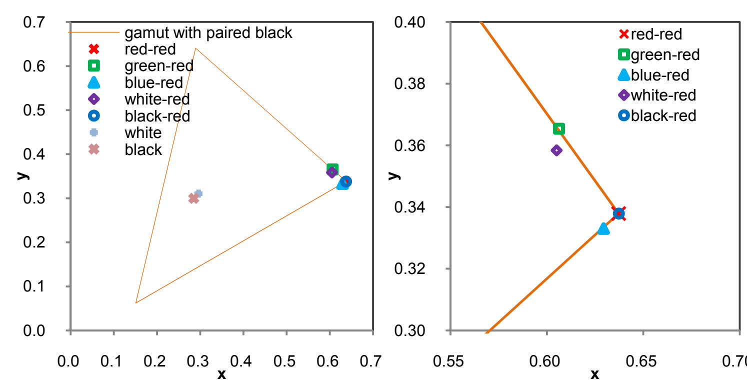

Figure 3. *Chromaticity shift by crosstalk*

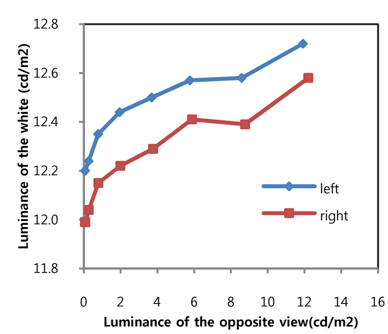

Figure 4. *Luminance shift by crosstalk*

Measurement result for Set2 patches, i.e. white patches with various gray colors on the opposite view, clearly explains the luminance change by the crosstalk as depicted in Figure6. The measured luminance increases along with the luminance increment of the opposite view.

5. Crosstalk Characterization

Three crosstalk characterization models are designed to predict the output tristimulus values considering the crosstalk effect. The performances of the models are tested.

5.1 Crosstalk Characterization Models

The first model, Model I, in Equation (1) is the most commonly used method for the previous researches to quantify crosstalk [8].

$$L = L1 + \alpha R1, \quad (1)$$
$$R = R1 + \alpha L1,$$

Where
R1, L1 : the original luminance for right-eye/left-eye image
R, L : the viewer perceived luminance for right-eye /left-eye image
α : degree of crosstalk.

The second model, Model II, is designed based on the assumption that degree of crosstalk for each channel, i.e. portion of the leaked light from the other side is different among Red, Green and Blue channel. This assumption implies that degree of crosstalk has channel dependency. Equation (2) is to predict the measured XYZ values for left-eye image. The same method can be applied for right-eye image.

$$X = X_L + \alpha X_{R,R} + \beta X_{R,G} + \gamma X_{R,B} \quad (2\text{-}1)$$

Where
X_L, X_R : the original measured data for left-eye/right-eye image
X : predicted X value for the left eye view

$$Y = Y_L + \alpha Y_{R,R} + \beta Y_{R,G} + \gamma Y_{R,B} \quad (2\text{-}2)$$
$$Z = Z_L + \alpha Z_{R,R} + \beta Z_{R,G} + \gamma Z_{R,B} \quad (2\text{-}3)$$

α, β, γ : degree of crosstalk for each channel

For more accurate prediction of the crosstalk, the third model, Model III, is designed by applying different degrees of crosstalk for red, green and blue channels. Equation (3) is for the left-eye color. Model III allows more channel dependency than Model II and possible luminance level dependency for the leaked light.

$$X = X_L + \alpha_R X_{R,R} + \alpha_G X_{R,G} + \alpha_B X_{R,B} \quad (3\text{-}1)$$

Where
X_L, X_R: the original measured data for left-eye/right-eye image
X: the original X value for RGB channels of right image
X : predicted X value for perceived color
α_r, α_g, α_b: degree of crosstalk for R,G,B channels

$$Y = Y_L + \beta_R Y_{R,R} + \beta_G Y_{R,G} + \beta_B Y_{R,B} \quad (3\text{-}2)$$
$$Z = Z_L + \gamma_R Z_{R,R} + \gamma_G Z_{R,G} + \gamma_B Z_{R,B} \quad (3\text{-}3)$$

5.2 Model Parameters

To implement three models in Section 5.1, the original tristimulus values are needed. In this study, the measured data with black color on the opposite view is used as the original data since the leaked light from the black color is negligible because of the low luminance of the black. The model parameters (α, β, γ) are obtained by minimizing the CIELAB color difference $\triangle E^*_{ab}$ values between the measured and predicted data. For model parameter calculation, the measured data of red, green and blue colors are used with red, green, blue and black colors on the opposite view.

Table3: Parameters for crosstalk characterization models

		To predict Left Color			To predict Right Color		
		α	β	γ	α	β	γ
Model I		4.87 %	-	-	4.85 %	-	-
Model II		4.60%	5.71%	0.73%	4.60%	5.73%	0.73%
Model III	R	5.24%	5.41%	0.00%	5.12%	5.30%	0.00%
	G	5.11%	5.91%	5.44%	5.21%	6.11%	5.53%
	B	0.78%	1.00%	0.85%	0.73%	0.88%	0.84%

Table3 summarizes the calculated model parameters. Large difference between model parameters for each model implies that the light from one view leak into the other view in a complicated way.

5.3 Model Performances

The performance of the characterization models in Section 5.2 are tested using the measurement data SET1. Table 4 compares the color difference between the measured and the predicted for each model. 'Leaked Color' column means the color displayed on the opposite view of the measurement view.

Table4: Performances for crosstalk characterization models

$\triangle E^*_{ab}$	Left view prediction			Right view prediction		
leaked color	Model I	Model II	Model III	Model I	Model II	Model III
Red	1.42	1.62	1.22	1.10	1.62	0.40
Green	3.21	2.05	1.08	3.68	2.03	0.35
Blue	9.30	0.97	0.94	9.97	0.98	0.30
White	11.94	3.03	1.33	11.91	0.84	1.75
C, M, Y	7.73	3.05	1.29	8.16	3.04	1.25

The Model II shows the dramatic improvement when blue and secondary colors are leaked into the view from the other side. And the Model III predicts crosstalk gradually better than Model II. These results using Model II and III prove the channel dependency of the degree of crosstalk. But the results in Model II and Model III as $\triangle E^*_{ab}$ is quite similar even though Model III considers more parameters. That means the RGB channel dependency affects crosstalk rather than X, Y and Z tristimulus values dependency.

6. Conclusion

In this study, color characteristics of stereoscopic 3D display and the effect of the crosstalk are analyzed. It is found the significant luminance loss for the 3D viewing condition compared to 2D mode though there is little color gamut change. More than 90% of the luminance is lost by wearing shutter glasses and splitting left and right eye images.

Because of the crosstalk, the measured color from one view is affected by the colors from other view. The degree of crosstalk can be defined using crosstalk characterization models. Based on the measurement data, three different crosstalk characterization models are designed.

The Model I assumes that the same portion of the light from one view is leaked into the other view applying the same degree of crosstalk for all the measured data. The Model II assumes the different degree of crosstalk among Red, Green and Blue channels. The Model III applies different degree of crosstalk between red, green and blue primary channels.

The original colors, meaning not affected by the crosstalk, are determined by measuring the colors on one view with black color on the other view and used for the characterization models.

The crosstalk characterization models are tested with the primary and secondary color combinations between left and right eye views. The result shows dramatic performance improvement for Model II and Model III compared to Model I. It means that there is Channel dependency as the reason for crosstalk.

For further study the proposed three models need to be verified with more color combinations between two views.

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Author Biography

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