Enhancement of Perceived Sharpness by Chroma Contrast

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Abstract

We have investigated the image quality attribute due to the wide color gamut by comparing it with the conventional sRGB color gamut. The results from the comparison between the two displays showed that 93% of the selected images appeared to have more 'Sharpness' when displayed on the wide gamut display. Previous studies on wide gamut displays were mainly focused on how natural it looked with the color gamut covering the real object color gamut. However we found that the prior image quality attribute for wider color gamut is sharpness caused by chroma contrast. Therefore Sharpness is the main image quality attribute for wide color gamut displays and could be the main factor in image quality improvement.

Background on Image Quality

The image quality enhancement by lightness contrast is highly related to sharpness. However due to standardization of display maximum luminance and gamma curve of conventional TV displays these recent years, the interest in improvement of sharpness has decreased. Also studies on wide gamut displays have decreased for similar reasons. Yet, new technology on displays such as wide color and effort in image quality improvement is an ongoing issue.

The next phase for image quality studies are based on the contents and the results show that they are highly related to image quality. Heynderickx et. al.(2013) mentioned that humans do not always prefer the original and that when color contrast was varied, participants showed a clear preference for more colorful, yet slightly unnatural images[1]. Most of the results show that colorfulness increase has a positive effect on image quality due to memory color for natural images [2]. According to Tremeau and Charrier(2000), the colorfulness and the naturalness attributes which are known to be highly related may not necessarily closed, sometimes they are exclusive, sometimes they are complementary, which depends on judgment criteria [3]. This concludes that colorfulness attribute takes a large part in judging image quality but not so directly or independent.

Among the several wide color gamuts, one of the proposed wide color gamut is DCI-P3 [4] which has primaries adopted for digital cinema. We have used this wide gamut for our experiment. When the stimulus is a single flat color, the wide color gamut would act as an advantage in reproducing the real object color. However, the advantage is less effective when reproducing a complex image containing several colors. There are previous studies by Sakurai et al. (2008) in image preference showing that the area of color gamut contributes up to 46% in preference [5].

Other than the fact that it is large enough to cover the real object colors, we have investigated the image quality attribute due to the wide color gamut by comparing it with the conventional normal (sRGB) color gamut. Images were carefully selected to cover most of the contents that had mentioned to affect the image quality in previous studies as mentioned above. Also the images were rendered to improve the image quality within the two different gamut areas. The purpose of our study is to find out the main factor judging the image quality for wider gamut displays and its advantages.

Method

Experiment setup

Fourteen stimulus images were selected with various contents which contained emotional elements of natural, human, artificial and animation scenes (Figure 1). The image size was 1920 X 1080. The image numbers are labeled from 1 to 14 in Figure 1. It is difficult to completely divide the contents of the images; however it can be grouped in to five categories. There are six natural images that are numbered 1, 2, 6, 8, 10, and 11 with different color distribution. Image 3, 9, and 13 are scenes containing artificial contents. A human skin image is numbered 4. Two multicolored liquid and solid object image is number 5 and 7 respectively. For last, two animation images numbered 1 and 14. The psychophysical experiment data showed similarity within the five content groups. The comparison were done especially for natural and artificial/animation image categories.

Figure 1: Selected images for psychophysical experiment

The still images were rendered by Photoshop S/W in terms of brightness and lightness contrast. The brightness was rendered lighter (+10%) and darker (-10%) from the original. The lightness contrast was rendered in two steps of medium (+10%) and strong (+15%). Note that the saturation was not rendered. The saturation was not varied due to two displays having different color primaries (gamut). The examples for rendered images are shown in Figure 2. There are nine rendered methods for each image and therefore

14x9=126 images in total. The 126 rendered images were shown randomly for both pair and categorical judgment experiment.

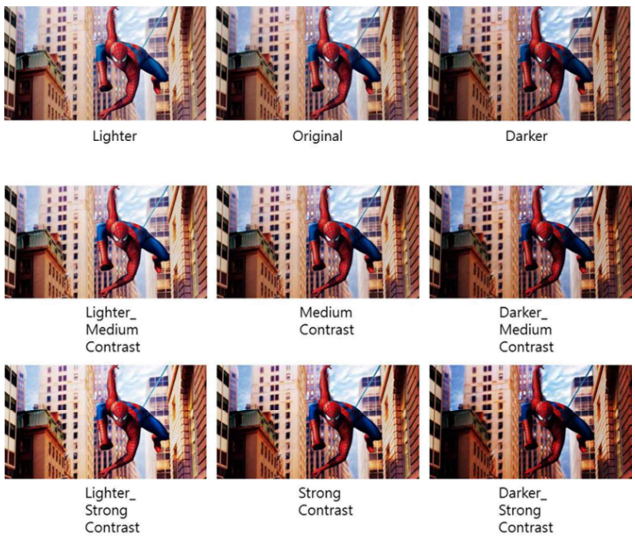


Figure 2: Rendering procedure

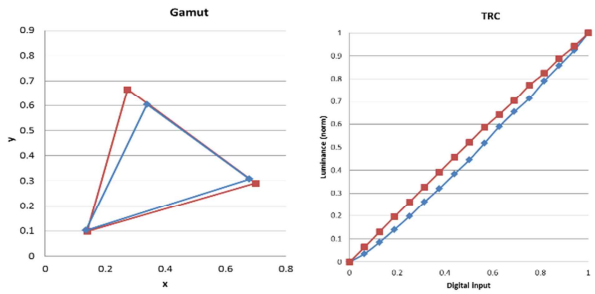


Figure 3: The display gamut and tone-reproduction-curve for wide gamut (square) and normal gamut (diamond).

These images were shown on HP DreamColor Z27x Professional Display which has 99% coverage of DCI-P3 gamut along with Samsung LS27D390 LCD monitor with sRGB color gamut. The two displays had the same size of 27" and similar white luminance of 236cd/m^2 and 263cd/m^2 respectively. The gamut of the HP monitor had 126% larger color gamut in CIExy color space than the Samsung LCD monitor. The gamut and tone-reproduction-curve are shown in Figure 3.

Psychophysical Procedure

Subjective image quality evaluation was performed by 51 participates with normal vision under normal office lighting. The demographic information was 10 males and 11 females in their 20s', 6 males and 9 females in their 30s', and 15 females in their 40s'. The result of the experiment shows no significant difference among the gender and age group. Therefore the results were averaged for all participants.

The rendered images were shown on the two different displays which were side by side for pair comparison. The wide gamut display was a LCD display (**A**) and other was also a LCD display with normal gamut (**B**). The experiment setup is shown in Figure 4. The left is showing the pair comparison experiment and right is categorical judgement. The categorical judgment experiment is conducted using only the wide gamut display.

Figure 4: Selected images for psychophysical experiment (left: pair comparison, right: categorical judgment experiment)

For the pair comparison experiment, the participants were asked to choose one among the two images for having better image quality attribute of 'Naturalness', 'Sharpness', 'Deepness', 'Clearness', and 'Image Quality'. There were five image quality attributes to judge and asked one by one for all rendered images. Technical variables such as contrast and lightness were excluded from the questionnaire. 'Naturalness' and 'Image Quality' are expected as common questionnaires. 'Sharpness' was asked as a perceptional technical attribute variable. 'Deepness' and 'Clearness' are iso-clearness and iso-depth respectively which are secondary attributes of NCS (Natural Color System) [6]. 'Deepness' is a perception term when lightness decrease with increase of chromaticness. 'Clearness' is a perception term when both chromaticness and lightness increase at the same time.

The categorical judgment experiment was conducted by showing the images only on the wide gamut display to scale the five image quality attributes in a 7 point category scale; 1: Least imaginable "ness", 2: Mildly "ness", 3: Moderately "ness", 4: "ness", 5: Moderately highly "ness", 6: Highly "ness", 7: Highest imaginable "ness".

Results

Pair comparison

The pair comparison results showed that 93% of the selected images appeared to have more 'Sharpness' on the wide gamut display. The other image quality attributes selected for the wide gamut display were followed after 'Sharpness'. Most of the images on wide gamut was selected to have more 'Sharpness' except for darker strong contrast rendered images of test image 2, 4, 6, and 11; these are skin and natural images.

The unexpected result was that the Naturalness was selected more for images on normal color gamut display. There were exception of selecting wide gamut for skin, high detail artificial, animation, graphic images with the 10% increased lightness preferred for 'Naturalness'. 'Naturalness' was the main attribute for judging image quality in most of the previous studies mentioned above.

Wide gamut display was selected to have more 'Deepness' for all test images. Most of the rendered images of test image 5 and 7 the wide gamut was preferred for 'Clearness'. The rendered attributes are not important in judging 'Clearness' for wide gamut displays.

Table 1: Pair comparison experiment results of selected display (A: wide gamut, B: normal gamut) for better image quality

Image	Original	Lighter	L_mC	L_sC	Darker	D_mC	D_sC	mC	sC
1	B	A	A	A	B	B	B	A	B
2	A	A	A	B	A	B	B	B	B
3	B	A	B	B	B	B	B	B	B
4	A	A	A	A	B	B	B	B	B
5	A	A	A	A	A	A	A	A	A
6	A	A	A	B	B	B	B	B	B
7	A	A	A	A	A	A	A	A	A
8	B	A	A	B	B	B	B	B	B
9	A	A	A	A	B	B	B	A	B
10	B	B	B	B	B	B	B	B	B
11	A	A	B	B	B	B	B	B	B
12	A	A	A	A	A	A	A	A	A
13	B	A	B	B	B	B	B	B	B
14	A	A	A	A	B	B	B	B	B

Table 1 shows the results for 'Image Quality' pair comparison experiment. "A" is wide gamut and "B" is normal gamut selected for better "Image Quality". Original test image 1, 3, 8, 10, 13 selected normal gamut for better "Image Quality" which are mostly natural images. Previous studies on image quality have hypothesis that images with natural contents seem to have more naturalness due to wide gamut covering real object colors. However, normal gamut was preferred more for natural images and thought that it is due to relation with familiarity. Those images are preferred on wide gamut displays when lightness is increased by 10% except for image 10, containing relatively darker contents. Therefore most of the test images were preferred on wide gamut display when lightness is increased

Adjusting the lightness of an image can be confused with contrast increase. However the results were completely different. This is shown by comparing the results of lighter (Lighter) and medium contrast (mC) rendered test image preference display results (Table 1). The normal gamut display was preferred more for the medium contrast (mC) rendered test images.

Table 2: 'Image Quality' selection rate for artificial/animation images and natural image on wide gamut display against normal gamut display

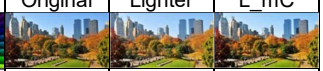
Artificial/Animation Image			Natural Image		
L_mC	Lighter	Original	Original	L_mC	mC
					
76.5%	86.3%	76.5%	45.1%	62.7%	54.9%
Darker	Lighter	Original	Original	Lighter	L_mC
					
72.5%	74.5%	66.7%	52.9%	70.6%	60.8%
mC	Lighter	Original	Original	Lighter	L_mC
					
82.4%	90.2%	72.5%	35.3%	43.1%	43.1%
L_sC	Lighter	Original	Original	Lighter	
					
64.7%	74.5%	64.7%	56.9%	60.8%	

Table 2 shows comparison of image quality selection rate for artificial/animation images and natural image on wide gamut display. It is shown that 'Image quality' decreases when the contrast is adjusted more than medium contrast except for few artificial images. 'Image quality' was higher on wide gamut display for artificial/animation images than natural images. When lightness is darkened, 'Image quality' of natural images on wide gamut was very low and on the contrary, artificial/animation images were higher when showed on normal color gamut. Also, the darkened rendered image of artificial/animation was judged to have better 'Image quality' than the original image on wide gamut display.

Categorical judgement

Table 3 shows the results of categorical judgment experiment for 'Image Quality' on wide gamut display. The shaded values are high scores over 4.90 out of 1 to 7 showing high image quality. The high scores for the original image are natural and skin color test images. This result is almost the opposite from the pair comparison experiment. This shows that the expectation for natural and skin images are higher for judging image quality. Also image quality is highly related to naturalness as many previous studies already proved. The scores are relatively low when the test images are rendered by strong contrast.

Table 3: Categorical judgement experiment results of wide gamut display image quality scores (shaded values over 4.90)

Image	Original	Lighter	L_mC	L_sC	Darker	D_mC	D_sC	mC	sC
1	5.20	4.88	5.00	5.12	4.65	4.37	4.49	4.94	5.25
2	4.61	4.53	4.94	4.78	4.27	4.51	4.12	4.57	4.22
3	5.20	4.92	5.02	5.18	5.02	4.82	4.63	5.24	4.96
4	5.08	5.04	5.14	4.84	4.53	4.08	3.92	4.76	4.57
5	4.76	4.76	4.59	4.98	5.02	4.51	4.71	4.71	5.02
6	5.00	4.48	5.14	4.31	4.39	4.60	3.29	3.29	4.20
7	4.76	5.18	5.06	4.90	4.76	5.20	4.25	4.25	4.69
8	4.45	4.50	4.43	4.22	4.31	4.39	4.16	4.16	4.35
9	4.49	5.08	5.45	4.69	4.78	4.86	4.67	4.67	4.88
10	5.12	4.86	5.00	4.65	4.47	4.12	3.94	3.94	4.12
11	5.02	5.33	5.06	4.92	4.69	4.04	3.49	3.49	4.49
12	4.61	4.12	4.51	4.57	4.63	4.57	4.22	4.22	4.59
13	4.24	3.78	4.04	4.06	3.90	4.41	3.94	3.94	4.02
14	4.57	4.88	4.76	4.41	4.53	3.75	3.98	3.98	4.55

The 'Image Quality' score increased for the entire test images which 'Sharpness' score was higher than the original. The natural image 2, 6, 8, and 11 'Image Quality' score increased when the lightness was rendered lighter. On the contrary, the 'Image Quality' score was lower than the original when the test image lightness was lowered and contrast risen. For artificial/animation images, other than the natural image, the 'Sharpness' and 'Image Quality" score increased when rendered lighter and with higher contrast.

Score of 'Sharpness', 'Clearness' and 'Image Quality' for natural image 10 decreased when it was rendered lighter and with high contrast. This indicates that high contrast for natural contents could be an unfamiliar experience to viewers.

Table 4: 'Image Quality' score for artificial/animation images and natural image on wide gamut display

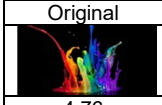
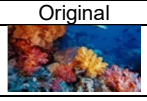
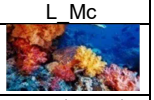
Artificial/Animation Image		Natural Image	
Original	Darker	Original	L_Mc
			
4.76	5.02 (+0.26)	4.61	4.94 (+0.33)
Original	D_Mc	Original	L_Mc
			
4.76	5.20 (+0.44)	5.00	5.14 (+0.14)
Original	Mc	Original	Lighter
			
4.61	4.65 (+0.04)	4.45	4.50 (+0.05)
Original	D_Mc	Original	Lighter
			
4.24	4.41 (+0.17)	5.02	5.33 (+0.31)

Table 4 shows the comparison of 'Image Quality' score for artificial/animation images and natural image on wide gamut display through categorical judgement experiment. 'Image Quality' score was high for natural image 8 and 11 which had higher 'Naturalness' than the original. Natural images were preferred when lightness was lighter. On the contrary, artificial and animation images were preferred when lightness was darkened.

Image quality attributes

Table 5: Correlation coefficient R^2 values of each image quality attributes ('Naturalness', 'Sharpness', 'Deepness', and 'Clearness') against 'Image Quality'

	Image	Naturalness	Sharpness	Deepness	Clearness
Image Quality	1	0.73	0.93	-0.28	0.89
	2	0.75	0.86	-0.05	0.92
	3	0.47	0.65	0.15	0.59
	4	0.92	0.98	-0.38	0.97
	5	0.72	0.77	0.30	0.65
	6	0.86	0.86	0.06	0.96
	7	0.02	0.88	0.13	0.63
	8	0.02	0.88	0.13	0.63
	9	0.06	0.96	-0.26	0.53
	10	0.91	0.96	-0.04	0.94
	11	0.99	0.98	0.15	0.95
	12	0.42	0.88	0.46	0.42
	13	0.36	0.78	0.49	0.50
	14	0.90	0.96	0.23	0.92

Table 5 lists the correlation coefficient R^2 values of each image quality attributes against 'Image Quality' for each image. The correlation coefficient R^2 was calculated using the entire rendered images and original images. The highest correlation with 'Naturalness' (0.99) was image 11 which is a typical natural scene. This is an obvious conclusion that 'Naturalness' is an image quality attribute depending on natural content of the image.

An interesting result was that 'Sharpness' and 'Naturalness' correlation against 'Image Quality' has similar pattern between natural and artificial/animation images. This shows that 'Sharpness' and 'Naturalness' is not an opposite attribute for image quality.

The 'Sharpness' shows high correlation with 'Image Quality'. In other words, 'Sharpness' is the most important image quality attribute for all kinds of image contents for wide gamut displays.

'Clearness' is another image quality attribute related to 'Image Quality' depending on the image contents. 'Clearness' is highly related to 'Image Quality' for natural images. Image 14 was an exception for most of the results which is actually an animation movie scene but featured to be natural as possible. 'Deepness' had the lowest relation among the rest of the image quality attributes.

The relationship between Image Quality and other attributes were fitted using the results of categorical judgment experiment (eq 1). The image quality attributes 'Naturalness', 'Sharpness', 'Deepness' and 'Clearness' were used as variables and assumed to have a linear relationship with 'Image Quality'.

$$\text{Image Quality} = a1*\text{Naturalness} + a2*\text{Sharpness} + a3*\text{Deepness} + a4*\text{Clearness} \quad (1)$$

The average weighting factors of the equation for every image is a1=0.21 ('Naturalness'), a2=0.53 ('Sharpness'), a3=0.08 ('Deepness'), and a4=0.17 ('Clearness').

The 'Image Quality' score was highly related to 'Sharpness' having the highest weighting factor for most of the images and especially high for images that contain chromatic colors. 'Naturalness' and 'Clearness' has similar weighting factor values. This is also shown from the correlation coefficient between 'Image Quality'.

The two displays had similar tone reproduction curve and maximum luminance which implicates that the perceived sharpness is not caused by lightness contrast. The difference between the two displays was the color gamut and it comes to a conclusion that chroma contrast is accrued by the larger volume color gamut and acts as a reason for the image to be perceived sharper.

Conclusion

Previous studies on wide gamut displays were mainly focused on how natural it looked with the color gamut covering the real object color gamut. We found that 'Naturalness' was poorer on wide gamut than on normal gamut displays. 'Image Quality' for natural images were lower on wide gamut displays than artificial/animation images. Also we have found that the prior image quality attribute for wider color gamut was 'Sharpness' which is caused by chroma contrast. Therefore 'Sharpness' is the main image quality attribute for wide color gamut displays and could be the main factor in image quality improvement.

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