Redefinition of viewing angle image quality in LCDs

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Keywords : viewing angle, contrast ratio, color shift, luminance, gamma shift

Abstract

We analyzed the problem of the typical definition of the viewing angle, where the contrast ratio is higher than 1:10 and suggest the new definition of the viewing angle by considering the contrast ratio, color shift, luminance and gamma shift in the viewing direction all together.

1. Introduction

At the early stage of mass production in LCDs, most LCDs were made by TN modes which have characteristics of a rapid decrease in the contrast ratio and gray inversion at the viewing direction. Therefore, the viewing angle in LCD has been defined as the range of angle, which satisfies both the minimum contrast ratio of 10:1 and no gray inversion. After the initial introduction of IPS and VA mode for LCD TV around late nineties, the viewing angle image quality of LCDs has dramatically improved especially in terms of the contrast ratio and gray inversion.[1-4] However, the specification of the LCD's viewing angle as the angle, within which the contrast ratio is larger than 10:1, is still commonly used without any justification that this is relevant specification from the user's point of view [5]. According to this specification, there is no difference among LCD TVs while the actual image qualities are quite different in the viewing direction. Thus it is needed to improve the definition of the viewing angle in LCDs, which can reflects on the actual image quality of the viewing direction well.

2. New definition of the viewing angle

Here we suggested that the viewing angle will be redefined as the range of the viewing angle, within which the contrast ratio is larger than 10:1 and the color shift value is smaller than 0.025. Furthermore, to entirely asses and include each acceptable viewing angle for all specific images on which the contrast ratio, luminance and gray scale information can be also critically important, we also suggest the more restricted viewing angle specification by considering two additional conditions, where the luminance is larger than 80 nit and 1/3 of the value at the normal direction and the gamma shift value is smaller than 10%.

The limit that human can perceive color difference is known to be less than 0.02 or 0.025 of △u'v' and we chose 0.025 of the average △u'v' for all colors as the allowable maximum color shift value at the viewing direction.

In order to define the average color shift value for "all colors", we measured the color shift values of a 40-inch LCD for about 1000 color patches which are uniformly distributed in RGB spaces and Macbeth color checker 24 patches and compared the average color shift values at the horizontal viewing directions as shown figure 1. The result shows that the average color shift value of Macbeth color checker 24 patches can be representative that of almost all colors especially within ±60-degree horizontal viewing direction.

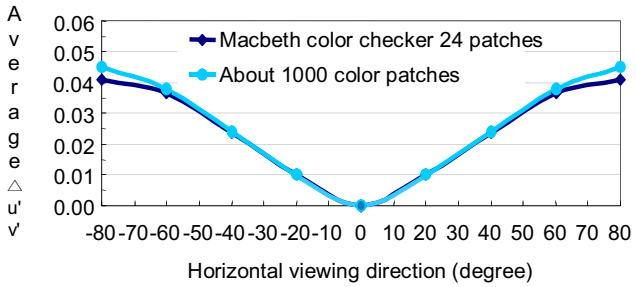

Fig. 1. The average △u'v' as the number of color patches in the horizontal viewing direction

The first additional condition for the more restricted viewing angle is luminance. According to viewing angle specification of China Quality Certification Center (:CQC), the viewing angle is defined as the range of angle, which satisfies both the minimum contrast ratio of 10:1 and the minimum luminance which is 1/3 value of normal direction. Moreover, the luminance has to be larger than 80 nit in order to realize the sRGB image. Therefore, we chose both of them as the precondition for the restricted viewing angle.

The second additional condition is the maximum gamma shift value of 10%. The gamma shift value (:GSV) is calculated by the equation 1 and the maximum value 10% was chosen considering the results of another gamma experiment.[6]

$$GSV(\%) = \frac{|Gv - Gn|}{Gn} \times 100 \quad (1)$$

Gv : gamma value at the viewing direction
Gn : gamma value at the normal direction

3. Viewing angle by new definition

We measured the contrast ratio, the color shift value, the luminance and the gamma shift value in all for two LCD TVs available in the market and calculated the horizontal viewing angle and horizontal special viewing angle specification according to the new definition.

Table 1 shows the measuring results and the viewing angle by the new definition. According to current viewing angle specification, which is the minimum contrast ratio 1/10, there are no difference in the viewing direction between sample A and B- two different LCD TVs. However, color shift, luminance and the gamma shift values show big difference between two LCDs.

TABLE 1. Horizontal viewing angle and horizontal restricted viewing angle by new definition

	Sample A	Sample B
Contrast ratio	> 170	> 170
Color shift	165	76
Viewing angle	**165**	**76**
Luminance	131	101
Gamma shift	> 170	~ 40
Restricted viewing angle	**131**	**~ 40**

Especially, the difference between two samples is critically dependent on the color shift value and Fig.2 shows the average color shift value (△u' v') of 24 colors of Macbeth color checker of two samples in the viewing direction. As shown, the viewing angle by the new definition of sample A is about 165 degrees and that of sample B is only about 76 degrees. The restricted viewing angle for specific image of sample A is about 131 degrees and that of sample B is about 40 degrees.

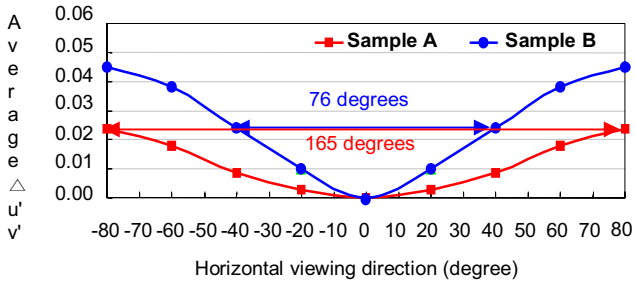

Fig. 2. Average △u'v' of 24 colors of Macbeth color checker in the horizontal viewing direction

4. Perceived viewing angle

In order to confirm that the viewing angle specification by the new definition is well matched to the perceived viewing angle in LCDs, we designed the perception experiment referring to the other similar research and compared the results of perceived viewing angles with that of new definition.[7-9]

Table 2 shows the condition of the subjective evaluation. We used 4 images for the subjective experiment and each image represents 4 kinds of the viewing angle image quality, which are the contrast ratio, the color shift, the luminance and the gamma shift as shown in figure 3.

TABLE 2. The condition of subjective evaluation

Evaluated panel	A and A' : 42-inch LCD TVs, B and B' : 40-inch LCD TVs
Evaluated images	4 images (1) night view (contrast ratio) (2) fruits (color shift) (3) people (luminance) (4) gray bar (gamma shift)
Subjects	8 females and 8 males
Viewing distance	3 H
Luminance	500 nit

Illuminance	~ 4 lx
Viewing direction	Horizontally 0, ±20, ±40, ±60, ±80 degrees
Experimental method	5 point scale method by comparing with the reference image quality

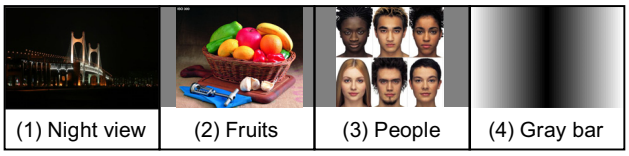

Fig. 3. 4 kinds of test image respectively represent contrast ratio, color shift, luminance and gamma shift image quality in the viewing angle.

In choosing the subjects, we tried to mix the various kinds of people considering their sex distinction, age and expertise as shown in table 3.

TABLE 3. The configuration of the subjects

Age	Female		Male	
	Expert	Non	Expert	Non
20s	1	1	1	1
30s	2	2	2	2
40s	1	1	1	1

Figure 4 shows the diagram of the experimental environment and total 4 panels are simultaneously set up. The specification of the 2 sample A panels and that of the 2 sample B panels are exactly the same. Sample A and B are set up for the reference panel in the normal direction and sample A' and B' are for the test panel in the viewing direction.

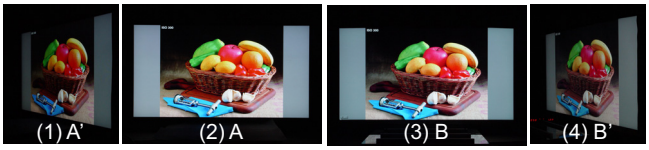

Fig. 4. Example of the experimental environment.

In the first experiment for finding the actual viewing angle range, subjects were asked to scale the degraded extent of the image quality in the each viewing direction comparing with that of the normal direction. Additionally, to obtain the individual viewing angle for the specific images, we informed subjects what kind of the image quality the each test image represents and we asked subjects to answer the degraded extent of the representative image quality in the next experiment

1: very annoying
2: annoying
3: slightly annoying
4: perceptible, but not annoying
5: imperceptible

Figure 5 represents the results of the first experiment, where the average of impairment extents of the sample for 4 images is shown.

Using the 3.5 limit of the acceptability threshold, the acceptable viewing angles are 160 degrees for sample A, and 79 degrees for B. This result shows that the new definition of the viewing angle reflects on the actual image quality in the viewing direction well.

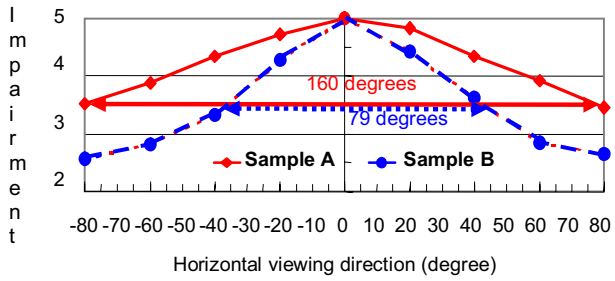

Fig. 5. Perceived viewing angle for two test samples

The results of the second subjective experiment are shown in table 4. Using the 3.5 limit of the acceptability threshold again, the acceptable contrast ratio, color shift, luminance and gamma shift viewing angles were calculated. It shows a very interesting result because the restricted viewing angle range for the specific color shift image is very similar to the perceived viewing angle range for the all 4 images. Therefore, we can infer that subjects feel most important for the color shift of the image and that's also the same we assume when we designed the new definition of the viewing angle at first. Moreover, this result also meets the calculated restricted viewing angle by the new definition.

TABLE 4. Acceptable viewing angles for the specific images by the subjective experiment

	Sample A	Sample B
Contrast ratio	131	76
Color shift	> 160	73
Luminance	> 160	82
Gamma shift	128	45
Restricted viewing angle	**128**	**45**

5. Summary

In this study, we suggest the new definition of the viewing angle in LCDs by considering the contrast ratio, the color shift, the luminance and gamma shift all together. The viewing angle range by this new definition is very similar to the acceptable viewing angle range by perception tests. Thus, these new specification will help the consumer to compare the image quality of the viewing angle among LCDs and the LCD maker to qualify their image quality in the viewing angle.

6. References

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