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Improved Angle-of-View Measurement Method for Display Devices

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Abstract

With the increasing demand for a better FPD image quality, better evaluation metrics and advanced display quality measurement methods are required to meet these needs. There are many measurement methods for evaluating the viewing angle of various display devices, but these methods, which include luminance drop, color shift, and contrast ratio decrease, are imperfect considering that human perception does not completely correlate to them. In this paper, a new method of measuring the perceptual angle of FPDs is proposed, considering human visual perception, which uses the color space of the color appearance model.

Keywords: perceptual angle, CIECAM02, viewing angle

1. Introduction

The display industry is currently characterized by intense competition. A greater variety of display devices are available from an increasing number of display makers, resulting in the efforts of companies to try to outsurvive one another. To satisfy their customers, companies are developing new technologies for image quality improvement and cost reduction. In this challenging situation, the use of specifications that best represent the display performance has become an important factor when buying TVs and monitors. The viewing angle is one such specification. LCD displays, which are now regarded as the most popular display type, are considered to have a wide viewing angle if their angle of view is 170° or more. The angle of view of LCDs is measured at the point when the contrast ratio drops to 10:1. This criterion, however, is actually a legacy specification as the current-day consumers would not consider a contrast ratio of only over 10:1 acceptable. Therefore, appropriate new criteria for evaluating angle-dependent quality are required. The recently proposed methods consider the change in the contrast ratio, luminance, and color. In this paper, a method is proposed involving the comparison of the perceptual angles based on the change in brightness and colorfulness.

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2. Experiments

To find a new method for angle-of-view measurement, four different displays were tested, as shown in Table 1. These displays were randomly chosen and were not specifically representatives of the OLED, LCD, and PDP displays. The measurements were taken in a dark room using a PR-705 spectroradiometer. The distance from the screen to the PR-705 was 2.5 times the vertical dimension. The measurement points were the center of each screen, and the colors that were measured were red, green, blue, and black. The measurement range was from -70 to 70° off the normal at 10° intervals.

The factors that humans perceive as having an impact on display image quality include brightness drop, weakened sharpness, and color deterioration [1, 2]. The existing widely used method of measuring the viewing angle uses a criterion of contrast ratio drop to 10:1. This criterion is actually

Table 1. Displays used for measurement analysis

Display	Diagonal Size	Remarks
OLED TV	14”	Panel under development
LCD TV	22”	
LCD TV	46”	LED BLU
PDP TV	50”	

incomplete as it includes only the brightness and sharpness factors but does not consider the color shift. Additionally, 10:1 is not an angle-of-view characteristic but an absolute value. To address these problems, the optical performance of each test display was measured. Using these data, the angle-of-view characteristics of the displays were also analyzed by considering the volume change in the 3D perceptual coordinates. The 3D perceptual coordinates in the CIECAM02 standard account for the human visual characteristics [3]. They consist of three components: brightness, colorfulness (saturation), and hue. Each axis refers to the absolute levels of perception, an attribute of visual sensation according to which the perceived color is more or less chromatic, and a particular shade of a color [4]. In this coordinate system, the volume data can represent how bright, clear, and vivid the images are. Using this system, a volume ratio can be established by comparing the off-axis data relative to the on-axis data. This volume ratio can provide the basis for a new standard of angle-of-view measurement for displays.

3. Results and Discussion

Fig. 1 shows the contrast ratio of the four displays that were measured from -70 to 70°. Only the data for 0-70° are shown as the left and right characteristics were nearly symmetrical at the normal viewing position.

As shown in Fig. 1, all the four displays had a contrast ratio of above 10:1 over the measured range of -70 to +70°. The 10:1 CR, however, is not an adequate standard for TVs as there were clear differences in the perceived quality of these displays. Table 2 shows the luminance and color of the displays as measured from the front viewing position. The luminance ratio shown in Fig. 2 is relative to the white-

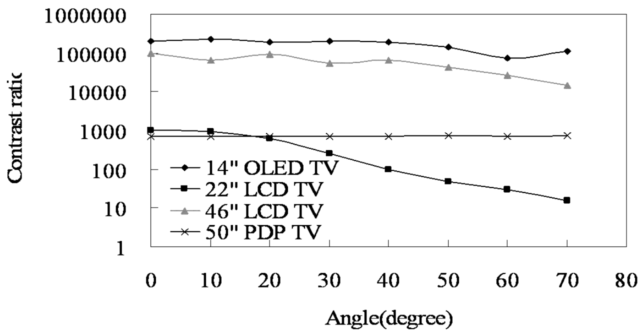

Fig. 1. Contrast ratio data of the four displays.

Table 2. Luminance and color of the displays

	Luminance		Color Coordinates	
	cd/㎡			
	White	Black	u'	v'
14" OLED TV	200.6	0.001	0.187	0.440
22" LCD TV	142.5	0.146	0.196	0.467
46" LCD TV	192.8	0.002	0.195	0.441
50" PDP TV	57.2	0.083	0.192	0.431

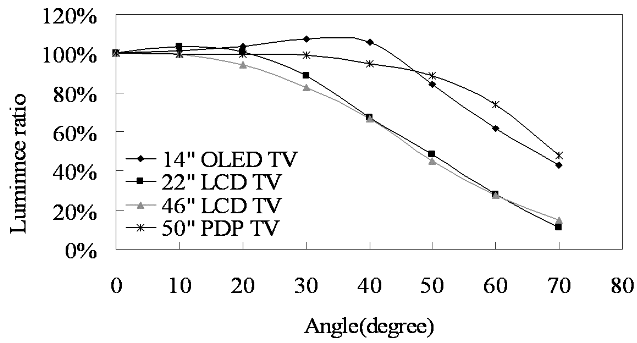

Fig. 2. Luminance ratio of the four displays.

luminance values in Table 2. These values offer a more discriminating standard than an arbitrary (e.g., 10:1) absolute-contrast-ratio value. Neither of these criteria, however, can detect the loss of color fidelity.

Color shift, as measured through the CIE1976 coordinates Δ(u'v'), provides a useful criterion for assessing the color performance of a display. The numerical formula for Δ(u'v') is shown in equation (1):

$$\Delta\left(u',v'\right)_\theta = \sqrt{(u_0' - u_\theta')^2 + (v_0' - v_\theta')^2} \qquad (1)$$

Fig. 3 shows the color differences of the test displays as a function of the viewing angle. Planar color coordinates such as the CIE1976 (u',v') or CIE1931 (x,y) coordinates, however, cannot fully represent the chromatic characteristics as they do not include a brightness factor [5]. These planar systems measure the changes in the color coordinates but not necessarily how much the perceived color changes, due to the absence of a brightness factor. In Fig. 3, using the (u',v') coordinates, the off-axis color difference of the test 14" OLED TV is shown to be significantly greater than the color difference of the other displays. The visual assess-

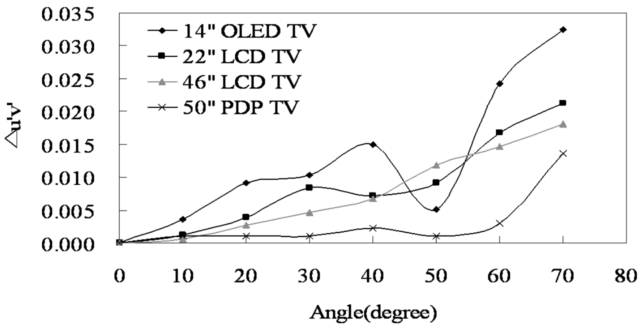

Fig. 3. △(u'v')θ of the four displays.

ments of the off-axis display quality, however, would not indicate such a large perceptual performance difference. The findings obtained in this study are therefore consistent with those obtained by the CIECAM02 Committee, which is that Δu'v' measurements are insufficient for describing the off-axis color deterioration of displays in human perceptual terms.

CIECAM02 is a color appearance model that maps the color space according to human perceptual characteristics. It uses sample tristimulus values as input parameters and has several additional input parameters, including the white-tristimulus value, the surrounding (ambient) conditions, the luminance of the adapting field, and the luminance of the background. The color space has not only perceptual correlates for lightness, chroma, and the hue angle but also the perceptual attributes of brightness and colorfulness [6]. Lightness, saturation, and chroma are normalized values; on the other hand, brightness and colorfulness are absolute values. For evaluating the angle-of-view characteristics, the absolute values at each angle should be compared with those of the other angles. This explains why brightness, colorfulness, and hue are used for the angle-of-view measurement of displays from among the color appearance predictors. The 3D perceptual coordinate, which consists of brightness, colorfulness, and hue, is the QMh coordinate. A volume ratio based on the QMh coordinate provides the basis for a new standard that can replace the existing less-perceptually-based methods of determining the viewing angle.

Table 3 and Fig. 4 show the QMh volumetric data of the four test displays. As a test control, these data were taken in a dark ambient. The volumes at 0, 30, and 60° were overlaid for comparison. Table 3 shows the values of the volume that was normalized to the sRGB volume, which was 100 on the QMh coordinate system. Fig. 4 represents

Table 3. QMh volumes of the displays at 0, 30, and 60°

QMh volume (vs. SRGB) [%]			
Angle	0°	30°	60°
14" OLED TV	303.1	391.8	282.2
22" LCD TV	120.2	115.3	65.6
46" LCD TV	237.6	198.8	111.3
50" PDP TV	206.1	206	181.7

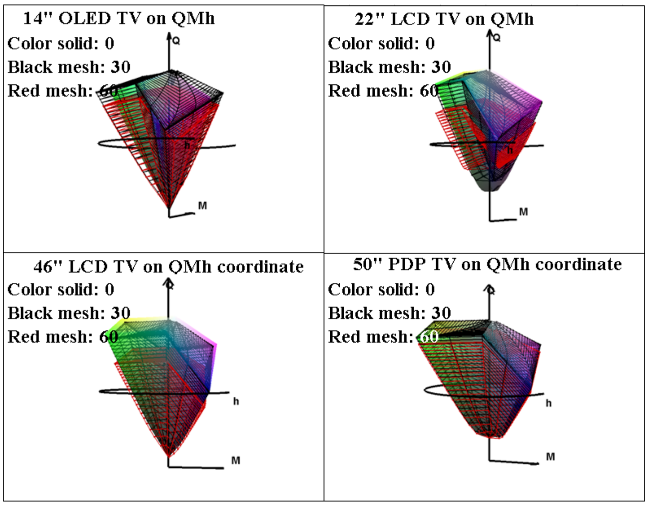

Fig. 4. Angle-of-view characteristics of the four test displays mapped onto the 3D perceptual coordinates.

the variation in volume on the QMh coordinates as a function of the viewing angle. The larger volumes correspond to a higher perceived display quality. In other words, if the volume is constant at any angle view, then the display has good angle-of-view characteristics. Fig. 5 shows the ratio of volume as a function of the viewing position relative to the on-axis volume.

The change in volume ratio of the 14" OLED TV in Fig. 5 shows that the volume at 30° was actually greater

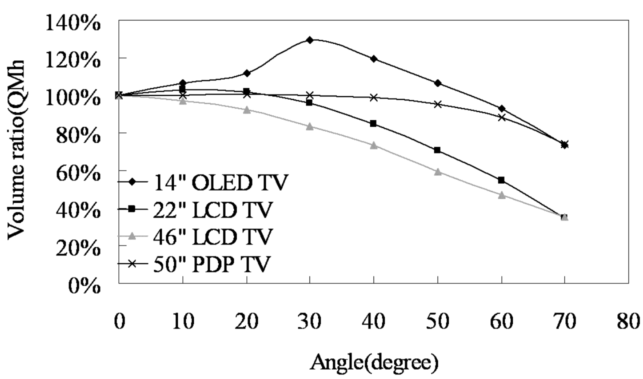

Fig. 5. Volume ratio of the four test displays relative to the on-axis volume.

than that at the on-axis view. This means that for this display, the image quality at 30° is better than the on-axis quality. This can be explained by Fig. 2 and 3. As the luminance ratio at 30° increased, as shown in Fig. 2, the perceived colorfulness increased along with the luminance [7]. The color difference of the 14" OLED TV indicated in Fig. 3 is more than that of the other displays. In the 14" OLED TV, the primary colors of the display in the planar color coordinates moved to deeper colors at 30°. These increased color characteristics mean that the display's ability to reproduce color at 30° is actually better than at the normal on-axis view. Therefore, the volume at 30° is larger than that at 0°. The volume ratio method using QMh perceptual coordinates predicts that the perceived characteristics of the display are better off-axis, which could not be predicted by the simple color difference values from the prior color coordinate systems.

If the criterion of this new method is the angle where the volume ratio on the QMh coordinates drops to 50%, then the viewing angle can be defined as the perceptual angle. A 50% volume refers to the point where the display assumes a half-perceptual quality. This criterion can be changed by the circumstances or applications. The perceptual-angle method, a new method that includes the human perceptual characteristics, much more accurately correlates to human perception compared to the prior viewing angle criterion. At low ambient conditions, the perceptual angles of the 14" OLED TV and 50" PDP TV were over 140° while those of the 22" and 46" LCD TVs were 100° based on the 50% volume ratio criterion. Industry agreement is needed on the point at which to set the volume ratio (50%, or some other threshold), and on the appropriate ambient condition or conditions under which the measurement should be made. Additional human-recognition experiments should be performed to guide the selection of these values.

4. Summary

The 10:1 contrast ratio criterion should no longer be used as a means of determining the viewing angle as most viewers today would not consider the 10:1 CR adequate and as such method does not provide any means of determining the off-axis color performance or accuracy.

The use of the Δ(u'v') color difference is also insufficient as the CIE1976 coordinates lack brightness measures and therefore do not correlate well to the human perception of color performance. An alternative method for evaluating the angular dependence on the display quality, CIECAM02, was developed to address these deficiencies. CIECAM02 can be used for total image quality evaluation because it includes the brightness, colorfulness, and hue factors. A new method of defining the viewing angle, based on the perceptual angle, can be established using CIECAM02. For the best correlation to viewer perception, the specification of the perceptual angle can be set as the angle at which the volume of the color space decreases to 50% of its on-axis value, or to some other industry-agreed value. To develop the most accurate standard, one that has the best correlation to human perception, additional experiments are being conducted under the auspices of the international standards organization SEMI.

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