Improved Method for Angle-of-View Measurement of Display Devices

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Abstract

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

1. Introduction

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

2. Experimental

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

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”	

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 measurement method of viewing angle uses a criterion of contrast ratio drop to 10:1. This criterion is actually incomplete as it only includes brightness and sharpness factor but it does not consider color shift. Additionally, 10:1 is not an

angle-of-view characteristic; it is an absolute value. To solve these problems, measurements of optical performance were taken on the test displays. Using these data, the angle-of-view characteristics of the displays were also analyzed by considering volume change in 3-D perceptual coordinates. 3-D perceptual coordinates in the CIECAM02 standard account for human visual characteristics [3]. The 3-D perceptual coordinates consist of three components: brightness, colorfulness (saturation), and hue. Each axis refers to 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, volume data can represent how bright, clear, and vivid the images are. Using this system, a volume ratio can be established by comparing off-axis data relative to 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 contrast ratio of four displays that were measured from -70° to 70°. Data are shown only for 0° to 70° as the left and right characteristics were nearly symmetrical about the normal viewing position.

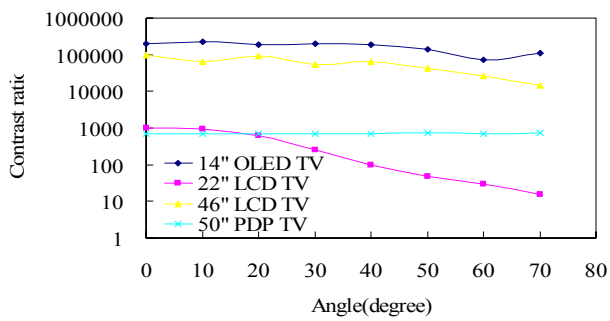

Fig. 1. Contrast ratio data of the four displays

Table 2. Luminance and color of displays

	Luminance cd/㎡		Color coordinates	
	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

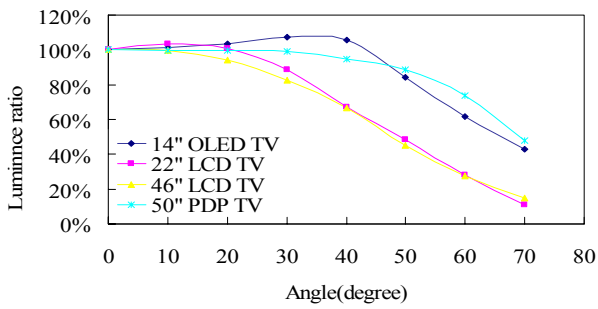

Fig. 2. Luminance ratio of four displays

As shown in fig. 1, all four displays have contrast ratio above 10:1 over the measured range of -70° to +70°. However, 10:1 CR is not an adequate standard for TV, as there were clear differences in the perceived quality of these displays. Table 2 shows 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 luminance values of table 2. These values offer a more discriminating standard than an arbitrary (e.g. 10:1) value of absolute contrast ratio. However, neither of these criteria can detect loss of color fidelity.

Color shift as measured in 1976 CIE coordinates, Δ(u'v'), provides a useful criterion for assessing color performance of a display. The numerical formula for Δ(u'v') is shown in equation (1):

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

Fig.3 shows color differences of the test displays as a function of viewing angle. However, planar color coordinates such as CIE1976 (u',v') or CIE1931 (x,y) coordinates are not adequate to fully represent chromatic characteristics, as they do not include a brightness factor [5]. These planar systems measure changes in color coordinates, but not necessarily how much perceived color changes due to the absence of a brightness factor. In fig. 3, using (u',v') coordinates, off-axis color difference of the test 14" OLED TV is significantly greater than the color difference of the other displays. However, visual assessments of the off-axis display quality would not indicate such a large perceptual performance difference. Our findings are therefore consistent with those of the CIECAM02 committee, which is that Δu'v' measurements are insufficient for describing off-axis color deterioration of displays in human perceptual terms.

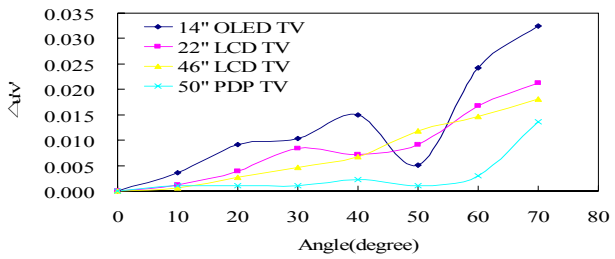

Fig. 3. $\Delta(u'v')_\theta$ **of four displays**

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, surrounding (ambient) conditions, luminance of the adapting field and the luminance of the background. The color space has not only perceptual correlates for lightness, chroma and 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 angle-of-view characteristics, absolute values at each angle should be compared with that of other angles. This is the reason brightness, colorfulness, and hue are used for angle-of-view measurement of displays from among color appearance predictors. The 3-D 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 existing, less perceptually-based methods of determining viewing angle.

TABLE 3. QMh volumes of displays at 0, 30, 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

Table 3 and fig. 4 show 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° are overlaid for comparison. Table 3 shows values of the volume based normalized to sRGB volume, which is 100 on the QMh coordinate system. Fig. 4 represents variation of volume on QMh coordinates as a function of the viewing angle. Larger volumes correspond to 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 viewing position relative to the on-axis volume.

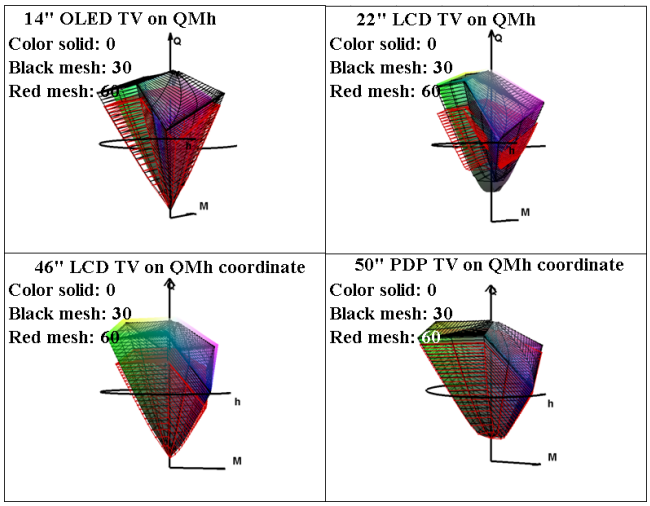

Fig. 4. Angle-of-view characteristics of four test displays mapped onto 3-D perceptual coordinates

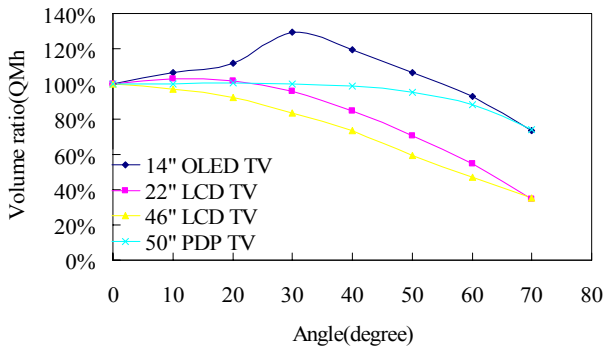

Fig. 5. Volume ratio of four test displays relative to on-axis volume

By observing the change in volume ratio of the 14” OLED TV in Fig. 5, the volume at 30° is actually greater than 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 fig. 3. As the luminance ratio at 30° increases as shown in fig. 2, perceived colorfulness increased together with the rise of luminance [7]. The color difference of the 14" OLED TV in fig. 3 is more than that of the other displays. In the 14" OLED TV, primary colors of the display in 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 of 0°. The volume ratio method using QMh perceptual coordinates predicts that perceived characteristics of the display are better off-axis, which would not be predicted by simple color difference values from prior color coordinate systems.

If the criterion of this new method is the angle where volume ratio on QMh coordinates drops to 50%, then viewing angle can be defined as perceptual angle. Perceptual angle is a new method which includes human perceptual characteristics and is much more accurate in correlating to human perception compared to prior viewing angle criteria. At low ambient conditions, perceptual angles of the 14" OLED TV and 50" PDP TV were over 140°, while the 22" LCD TV and 46" LCD TV were 100° by the criterion of the 50% volume ratio. Industry agreement is needed on the point at which to set the volume ratio (50%, or some other threshold), and on an appropriate ambient condition or conditions in which to make the measurement. Additional human recognition experiments should be performed to guide the selection of these values.

4. Summary

The 10:1 contrast ratio criterion as a means of determining viewing angle should no longer be used, as most viewers today would not consider 10:1 CR to be adequate, nor does this method provide any means of determining off-axis color performance or accuracy. Use of Δ (u'v') color difference is also insufficient as CIE 1976 coordinates lack brightness measures and therefore do not correlate well to human perception of color performance. An alternative evaluation method to evaluate angular dependence on display quality, CIECAM02, has been developed to address these deficiencies. CIECAM02 can be used for total image quality evaluation because it includes brightness, colorfulness, and hue factors. A new method of defining viewing angle, perceptual angle, can be defined using CIECAM02. For best correlation to viewer perception, the specification of 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. In order to develop the most accurate standard, one which has the best correlation to human perception, additional experiments are being conducted. This perceptual angle standardization work is in progress under the auspices of the international standards organization, SEMI.

5. References

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