裸眼立体ディスプレイの立体視域と測定方法

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概要

ISO-PC159国内対策委員会では、裸眼立体ディスプレイの評価方法として、立体視の可能なユーザーの観察位置である立体視域を二つのレベル、即ち、立体画像による疲労を受けない立体視域QBVS (Qualified Binocular Viewing Space)と良好な立体画質の立体視域QSVS (Qualified Stereoscopic Viewing Space)に分けて、それぞれの広さを計測することを提案している。

立体ディスプレイは、ユーザーが実際に物体を見る場合と同様に左右の眼の視認角度で異なる視差画像を左右の眼にそれぞれ見せることにより立体感を誘引するディスプレイである。２眼式の裸眼立体ディスプレイは表示画面の前方の空間にそれぞれ左右の視差画像の光が集まる視認空間を形成しており、ユーザーは左右の目をそれぞれの対応した視認空間に置くことにより立体視を行う。この時、QBVS とQSVS の境界を決める重要な物理的要因として、①それぞれの視認空間から見える画像における左右視差画像の混在の程度を示す３Dクロストーク（３D　Crosstalk ）と、②それぞれの視認空間から見える視差画像の画質の差（Interocular difference of image quality）が考えられる。そこで、われわれは、これらの要因がその大きさにより立体画像の画質に対しどのような影響を及ぼすかについて把握するための検討を開始した。

ここでは、画像データ処理により擬似的に作成した３Dクロストークと両眼輝度差のある視差画像を実際に２眼式の裸眼立体ディスプレイに表示し、その強さにより立体画像の画質に対しどのような影響を及ぼすかについて主観評価実験により検討し、見出された以下の事柄を紹介する。[6)]

(１)両眼輝度差３０％以下までは大部分の観察者が気づかない。ただし、７０ % を超えると違和感を感じる観察者が増加する。QBVSとQSVSの境界はこの間にあると推察される。.

(２) 左右の視差画像に同時に3D クロストークの2重像がある場合、ゴースト画像間の立体視による逆視状態が発生し立体画像の知覚位置が不安定になる現象が発生する。この時のリーク光の比率は２０～40%程度であるが、画像の階調により異なる。

なお、今回は少人数の被験者による実験でありデータのバラツキも大きい。QBVSとQSVSの境界値の決定にはさらに詳細で大規模な実験データが必要である。

1. INTRODUCTION

Stereoscopic (3D) displays have been expected for long time to spread as the advanced display which gives us the more realistic visual information. Many kinds of autostereoscopic display have been developed and some of them were tried to use for consumer electronics such as mobile phone. However, autostereoscopic displays have not widely spread yet. Reasons are not obvious, but some of them may be the inadequate performances of the display, higher cost due to expensive optical parts, small number of contents and services of stereoscopic images and/or visual fatigue caused by 3D images.

ISO/TC 159/SC 4/WG 2 has decided that a Technical Report on 3D displays will be prepared as the first step of standardization. In Japan, 3D experts of companies, research institutes and academies are participating in JENC, and discussing the Technical Report in order to make it technical guideline for autostereoscopic displays.

2. VIEWING ZONES AND CHARACTERISTICS

As shown in Fig.1, two-view and multi-view autostereoscopic displays are designed to form single eye viewing spaces by use of lenticular lens or parallax barrier, where light lays of a view from all over the display solely exist without light rays of another views, so that the eye in the eye viewing space can watch the clear single view on all over the display. Observers at design viewing point against the display can watch 3D image by setting their left and right eyes in the eye viewing space for left parallax image and right eye viewing space for right parallax image, respectively.

Locations of these eye viewing spaces are usually fixed against the display surface direction. Thus the observer may watch pseudoscopic images and/or ghost images instead of 3D images according to their standing position. Those images are supposed to be discomfort and worried to be cause of visual fatigue.

We have proposed the new terms which express the characteristics of viewing zones in front of the autostereoscopic displays; QSVS (Qualified Stereoscopic Viewing Space) from where users can watch 3D images on all over the display and QBVS (Qualified Binocular Viewing Space) from where observers can watch images without visual fatigue caused by stereoscopic displays. It is supposed that QSVS and QBVS are determined by ghost images (double images) due to 3D crosstalk, pseudoscopy, 3D moiré, and/or interocular image difference such as luminance, chromaticity and contrast.[1),2)] But there aren't sufficient data on them.

In this paper, we discuss about the influence of the interocular luminance difference and the ghost images due to 3D crosstalk on QSVS and QBVS in case of two-view autostereoscopic displays with subjective experiments as the first step.

3. MEASUREMENT METHOD OF VIEWING ZONE

Figure 2 shows the schematic luminance profile along the design 3D viewing distance in case of a two-view autostereoscopic display measured with goniometric or conoscopic luminance meters at the center position of the display.

The yellow line is the luminance (*Yw)* profile for both left and right image are white. Red line is that (*Yl*) for left image of white and right image of black. Blue line (*Yr*) is that for left image of black and right image of white.

The interocular luminance difference (ILD) can be estimated by use of the profile of *Yw* in Fig.2 and Interpupillary distance (IPD).

3D crosstalk (*Xi*) profile in *i*-th eye viewing spaces is calculated by equation (1),

$$xi = \sum_{j \neq i} (Yj - Yb)/Yw \qquad (1)$$

where *Yj* is the luminance for white image of *j*-th view and black image of another views.

Equation (1) means that the 3D crosstalk profile in an eye viewing space is the summation of relative luminance profile of views for another eye viewing spaces. As shown in Fig.2(b), 3D crosstalk at the boundary between eye viewing spaces is 50% in case of two-view autostereoscopic display.

4. SETUP OF SUBJECTIVE EXPERIMENTS

The auotosteroscopic display used is the 15" Sharp notebook RD3D, which is two-view auotosteroscopic display with a native resolution of 1024x768. The original 3D crosstalk, *xo*, is about 4% and the original interocular luminance difference, ILDo, is smaller than 5% at the 3D viewing point of the center.

In order to evaluate the influence of large interocular luminance difference and distinct double image due to 3D crosstalk, the original image for left and right image are modified.

In case of the experiment for Interocular luminance difference (ILD), the modified luminance of right and left view, *Lrm* and *Llm*, are calculated by following equations, and the gray level of each pixel (0-255) is changed to display the modified luminance. Here, ILDo is ignored.

$$Lrm = (1 - ILD) \times Lr \qquad (2)$$

$$Llm = Ll \qquad (3)$$

In case of the experiment for double image due to 3D crosstalk, the modified luminance of Left view, *Llm,* is calculated by equation (4),

$$\begin{aligned} Llm &= Llo \times (1 - xl + xo) + Lro \times (xl - xo) \\ &= Llo + (xl - xo) \times (Lro - Llo) \qquad (4) \end{aligned}$$

where *Lro* and *Llo* are original luminance of right and left view.

Subjective experiments were carried out in a bright office room. The head position of the observer is fixed at the 3D viewing position during the experiment.

5.ON INTEROCULAR LUMINANCE DIFFERENCE

Interocular Luminance difference (ILD) is said to be cause of visual fatigue, and ILD within 10% is required in some papers.[3)4)] However, in case of the stereoscopic display with eye glasses, it is reported that ILD of 50 % is evaluated "perceptible but not annoying" by subjective evaluation.[5)]

Figure 3 shows the test chart which is a stereoscopic image of a photograph. Its resolution is 640x480 that corresponds to 9.4 inch in diagonal on the 15" 3D display. Observers are ten engineers of LCD. They answered the minimum value of ILD for "perceptible but not annoying", "slightly annoying", and "very annoying".

Figure 4 shows the result of the subjective experiment about the relation between ILD and subjective evaluation of the image appearance. It is shown in Fig.4 that the ILD smaller than 50% is "imperceptible" and ILD smaller that 70% is "not annoying" for 50% of the response. This result is in good agreement with the result in case of 3D display with eye glasses.[5] Therefore, it is confirmed that ILD is one of the important characteristics that decide the boundary of QSVS and QBVS. But the influence of ILD seems weaker than that have been supposed. So it needs more researches to determine the limits of QBVS and Q3DVS.

6. ON GHOST IMAGES DUE TO 3D CROSSTALK

As shown in Fig. 5, test charts of 3D crosstalk are images of the ring suspended at 30 mm from the grid pattern on the display surface. Its resolution is 450x338, that corresponds to size of 6.6 inch in diagonal. The gray level of the background is 245 (90% in luminance) and that of the ring is 90 (10% in luminance) or 145 (30% in luminance). The ghost image due to higher 3D crosstalk is simulated by data image modification by use of equation (4). Observers are nine engineers of LCD. They answered the maximum value of 3D crosstalk for acceptable quality of 3D image and that for stable depth perception.

Figure 6 shows the result of the subjective experiment about the relations between 3D crosstalk and the depth perception. Here, 3D crosstalk of the left image is equal to that of right image. It simulates the condition of two-view autosteroscopic display that has eye viewing spaces of the width of around Interpupillary Distance (IPD).

In the case of the ring of 90 gray level, 50% of observers answered that the image quality of 3D crosstalk less than 10% is good, and that the images of 3D crosstalk around 20% are very annoying. In the latter case, some observers seem to be confused by pseudoscopy of ghost images. It suggests that 3D crosstalk is one of the important factors which determine not only QSVS but also QBVS in case of two-view autostereoscopic displays those have eye viewing spaces of the width around Interpupillary Distance (IPD).

Figure 6 also shows that influence of 3D crosstalk is weaker in case of the ring of 145 gray level than that of 90 gray level. It is because that the contrast of the ghost is lower for the ring of 145 gray level as expected by equation (4).

7. ON 3D CROSSTALK OF GRAY LEVEL IMAGE

Evaluation of ghost images due to 3D crosstalk between view-images of middle range of gray level is more important. Because, almost of all images are composed of 50^{th} – 200^{th} gray level pixels.

The real performance of 3D autostereoscopic displays depends on both it's optical characteristics and it's digital image data processing technique. The 3D crosstalk profile obtained from luminance profile by use of black & white images shown in Fig.2 cannot evaluate the digital image data processing technique. that is effective for gray level 3D crosstalk canceling.

Figure 7 shows schematic picture of views taken by a CCD camera for a two-view auto-stereoscopic display. The ghost image of gray bar appears in left view due to 3D crosstalk from the right view, where original left image is plain and original right image is gray bar.

In Figure 8, the differences of luminance between ghost area and surroundings area are expressed by CIE1976 ΔL*. The effect of ghost canceling by image data processing is well expressed by ΔL* map as shown in Fig. 8(a) without date processing and (b)with data processing. Those data is useful for content creators in order to display clear 3D images on autostereoscopic displays.

8. SUMMARY

(1)We have proposed the new terms of Q3DVS (Qualified 3D Viewing Space) and QBVS (Qualified Binocular Viewing Space) in order to express the characteristics of viewing zones for two-view auto-stereoscopic displays.

(2) Interocular Luminance Difference of 30 - 50 % seems to be the limit for Q3DVS and QBVS.

(3) Ghost images due to 3D crosstalk induce pseudoscopy in some case of two-view auto-stereoscopic display.

(4) Measurement of ghost image due to 3D crosstalk between views of inter gray level is useful to evaluate the actual performance of the two-view auto-stereoscopic display.

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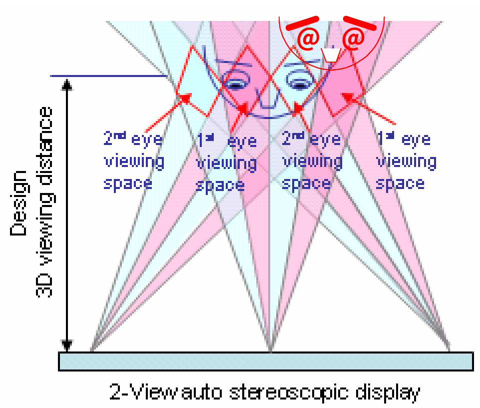


Figure 1 Schematic image of viewing zones.

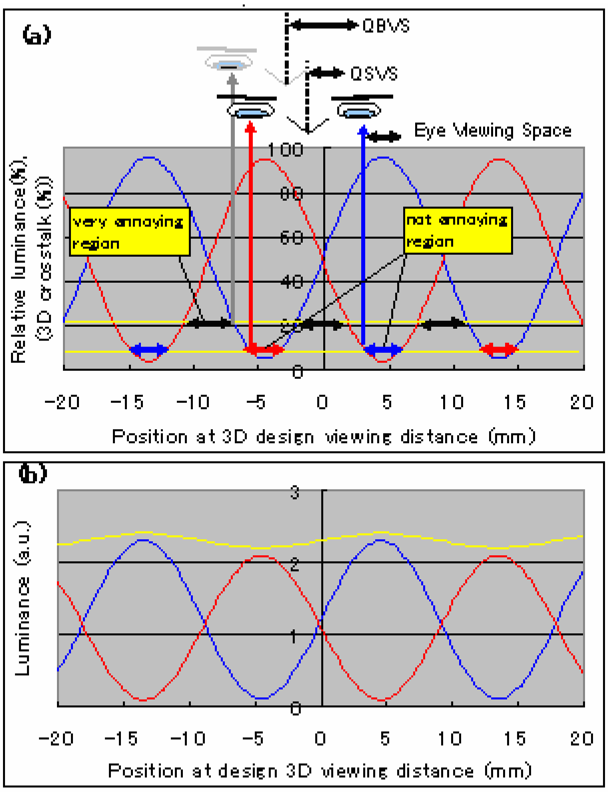
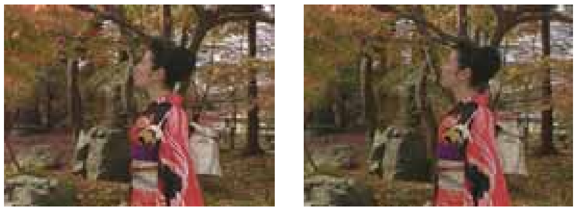


Figure 2 (a) Schematic image of relative luminance profiles (3D crosstalk profiles) of a two-views auto-stereoscopic display.

(b)Luminance profiles.

blue; right image is white and left image is black,

red; right image is black and left image is white, yellow; both right and left images are white.



(100% of luminance) (70% of luminance)

Figure 3 Test chart for experiment of for Interocular luminance difference (from ITU test chart)

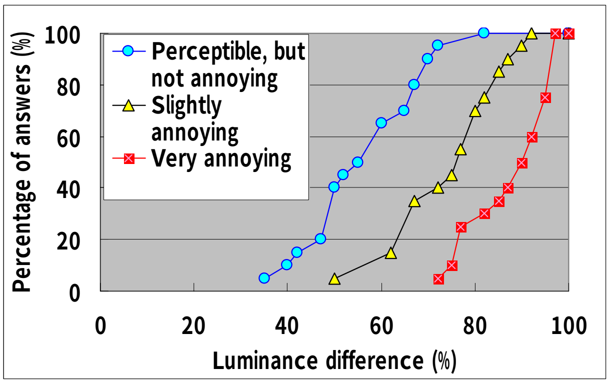


Figure 4 Experimental result on the relation between the interocular luminance difference and quality of 3D image.

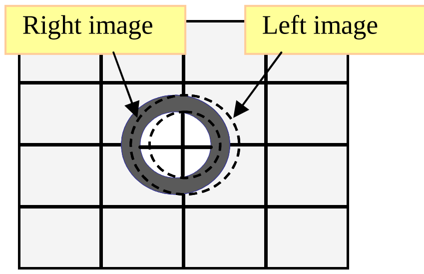


Figure 5 Test chart for 3D crosstalk experiment

The ring suspended at 30 mm from the grid pattern on the display surface. The resolution is 450x338 that corresponds to size of 6.6 inch in diagonal.

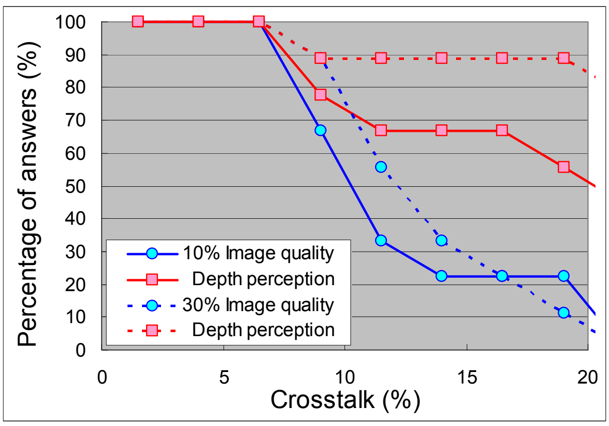


Figure 6 Experimental result on the relation between the 3D crosstalk and evaluation of 3D image quality.

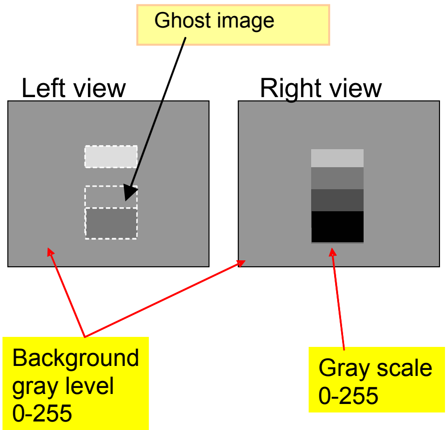


Figure 7 Schematic images of ghost images by 3D crosstalk taken with a CCD camera.

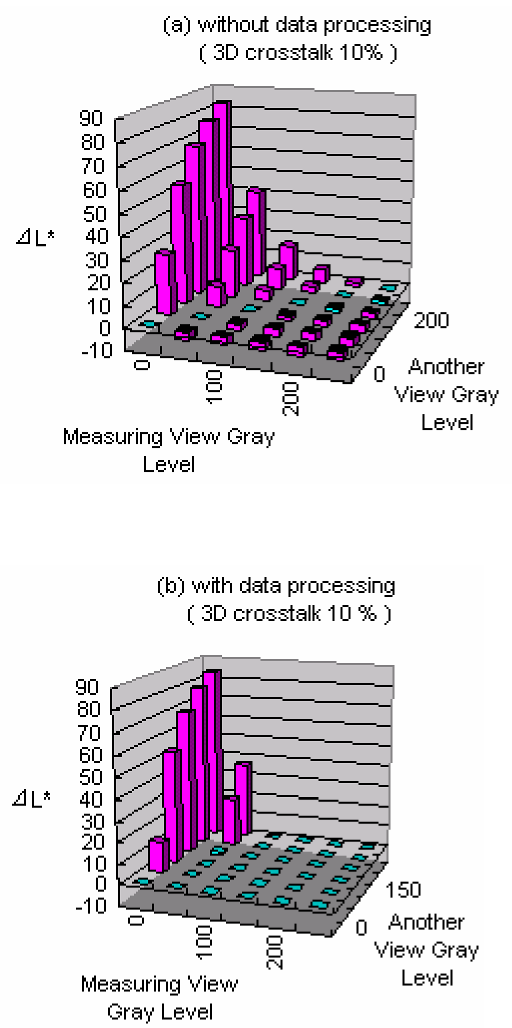


Figure 8 Ghost Intensity map due to 3D crosstalk between gray level images without and with ghost canceling data processing.