Crosstalk issue in Stereo/autostereoscopic display
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Abstract
3D display image quality issues are getting more and more important with growing 3D display markets and also Display Measurement Standards (DMS) are. 3D image quality issues, such as crosstalk, viewing angle and 3D luminance, are much different from 2D display.

In this paper, we focus on stereo/autostereoscopic 2-view 3D display crosstalk issue and claim system crosstalk (SCT), viewer crosstalk(VCT) and co-location image contrast (CIC)(1, 2), and using a crosstalk model to identify the crosstalk issue from different points of view.

1. Introduction
3D Display Measurement Standards (3D-DMS) are developing in ICDM, Semi-Taiwan and IEC. Before discussing the measurement procedure, we have to define the wording and definition first at all. Ghost image phenomenon in stereo/autostereoscopic display have discussed in different point of view (3-6), the researchers want to know not only indicate the quality of the 3D display but also how the perception of human eye. The reports call the ghost image “3D crosstalk”, “stereo crosstalk ” or just “crosstalk” , and different wording and definition should be clearly defined first.

The elementary cues of stereovision from a stereoscopic display system are from a serious of images with lateral disparity. When two of the images with proper disparity are fed into a viewer's two eyes, the viewer obtains his first cue of 3D perception - binocular vision.

The ghost-image problem induced by crosstalk in stereoscopic, especially autostereoscopic, display systems has been believed to be the major factor to jeopardize stereopsis, as been widely discussed in previous research. In autostereoscopic display, image quality indicators like “System crosstalk” (or somebody call stereo crosstalk) is the most important issue for display makers.

System-Crosstalk results in ghost-image or “Viewer crosstalk”. The definition and relationship of the image contrast and viewer crosstalk are reviewed and clarified. From the contrast point of view, high-quality three-dimensional perception results from a combination of high image contrast and low crosstalk. Same as a conventional two-dimensional display, high image contrast is also required for a 3D display to present a satisfactory image to either eye of the viewer. Yet, there is an extra requirement for a 3D display. The viewer crosstalk must be low enough for the viewer's one eye to neglect the ghost image from the neighboring viewing zone of the other eye.

As a characteristic of the display system, the system crosstalk will confine a content provider within a certain range of image contrast to present satisfactory 3D pictures or videos to the viewer.

2. Pervious study of crosstalk issue
2.1 The 2-views crosstalk issue and a crosstalk model
Crosstalk issue (1, 2) can be expressed as below in the context of co-location image contrast ratio pixel by pixel

\[ \text{Viewer crosstalk} = \text{co-location image contrast} \times \text{system crosstalk} \]  

Table. 1. Different viewpoint of crosstalk issue.

<table>
<thead>
<tr>
<th>Crosstalk problem consideration</th>
<th>Hardware problem</th>
<th>Software problem</th>
<th>Macroscopic point of view</th>
<th>Subjective evaluation</th>
<th>Objective evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microscopic point of view</td>
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</tbody>
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Viewers crosstalk is the total amount of light leakage for the viewer at one pixel. Co-location point is the pixel where the ghost image appears on the image for the other eye (as shown in Figure 1). The co-location image contrast is the ratio of ghost and image luminance at the co-location point. System crosstalk indicates overall system light leakage due to the nature of the hardware of the optical work. System crosstalk (SCT), an index indicating the optical quality of a 3D display, can be called “3D crosstalk” or “stereo crosstalk”.
Figure 1. Typical image of ghost-image phenomenon induced by system crosstalk. The top two images are left eye image and left eye image respectively. The bottom image is fused image, you’ll see the ghost image in the double lightning.

Figure 2. Diagram for the parameters for the definitions.

The definition and characteristics of the SCT, VCT and CIC are:

**Viewer Crosstalk (VCT):** defined by the unwanted image/wanted image or incorrect image/correct image ($\beta_2/\alpha_1$)

- The quality of VCT or ghost image can be verified by human factor study.
- This is a perception grade human factor.

**System Crosstalk (SCT):** defined by light leakage from display system which can be measured by optical instruments ($\beta_2/\alpha_1$)

- Depends on the quality of viewing zone forming optics of a 3D display system.
- This is a measurable quantity which can be measured by optical instruments (e.g., luminance meter or conoscope).

**Co-location Image Contrast (CIC):** defined by image displayed on the display: $\text{CIC} = B/A$

- The image contrast shown on the image display
- This quantity can be given by a conventional 2D display measurement.

For a 2D display, the higher the image contrast, the better the visual quality, but this is not necessarily correct for a stereoscopic display. According to Equation (1), the viewer’s crosstalk is proportional to the co-location contrast. It indicates that as the co-location contrast gets higher, the ghost image phenomenon becomes worse.

We summarize the crosstalk issue as the following:

1. Crosstalk occurs at co-location points.
2. System crosstalk is an indicator of the performance of a stereoscopic display. Viewer crosstalk is equal to the product of image contrast and system crosstalk. For a system designer, one wants to find out the maximum tolerable system crosstalk.
3. For constant system crosstalk, it is not always better to have higher image contrasts.
4. Viewer crosstalk is a local issue. It is more likely for ghost image to occur where the image contrast is higher.
2.2. Visibility threshold and fusion limit

One other issue commonly discussed regarding Viewer crosstalk (VCT) is the visibility threshold. According to Weber’s law, within the range of luminance of normal daily life (1~300 cd/m²) and large enough binocular disparity, the Weber ratio is 0.02. Therefore, for image contrast ratio at 300, the system crosstalk can be calculated by:

\[
\text{Weber ratio} = \text{contrast ratio} \times \text{system crosstalk}; \\
0.02 = 300 \times \alpha; \quad \text{system crosstalk } \alpha \text{ approaches } 1\times10^{-4}
\]

1\times10^{-4} may not be a practical target for system crosstalk for (auto)stereoscopic systems, but the Weber ratio provides an ideal benchmark where there is no perceivable crosstalk in the system. The visibility threshold and the crosstalk cancellation under the crosstalk model, however, are pixel by pixel or from a microscopic point of view to study the crosstalk issue.

![Visibility threshold](image)

Figure. 5 Criteria of system crosstalk from different viewpoint, which is depend on maximum CIC, image disparity and monocular cues of content.

3. Measurement of System crosstalk (SCT)

3.1 Procedure of measurement:

I. Point O is the center of the display in a three-dimensional Cartesian coordinate system: \(O(0, 0, 0)\), \(D_{IP}\) is the designated eye position, and \(D_{IPD}\) is the interpupillary distance.

II. Put the luminance meter at the position of left eye (\(P_L\)), which is at \((-D_{IP}/2, 0, D_{IP})\).

III. Measure the luminance of the display center when test patterns for left and right eyes (respectively) are (a) Black/White (b) White/Black (c) Black/Black (\(L_{KW.L}, L_{WK.L}, L_{KK.L}\)).

IV. Put the luminance meter at the position of right eye (\(P_R\)), which is at \((D_{IP}/2, 0, D_{IP})\).

V. Measure the luminance of the display center when test patterns for left and right eyes (respectively) are (a) White/Black (b) Black/White (c) Black/Black (\(L_{WRK}, L_{RWK}, L_{KKK}\)).

3.2 Analysis of SCT:

Calculate 3D system crosstalk \(SCT_L\) and \(SCT_R\) with the maximum values of luminance for each eye, for a 2-view display you can use the following equations:

\[
SCT_L = \frac{L_{KW.L} - L_{WK.L}}{L_{WWL} - L_{KKL}} \quad (1)
\]

\[
SCT_R = \frac{L_{WRK} - L_{RK.K}}{L_{WKR} - L_{KKR}} \quad (2)
\]

3.3 Verify measurement procedure using crosstalk model:

We can verify the measure pattern and test procedures using crosstalk model. The right side are the test pattern for the left eye crosstalk \(SCT_L\) measurement, and the luminance which should left eye perceive is shown on the left side equations.

The first test pattern: KW

\[BwB_1 + Ab_2 = L_{KW.L}\]

The second test pattern: WK

\[BbB_2 + AW_1 = L_{KW.L}\]

The final test pattern: KK

\[BbB_1 + Ab_1 = L_{KKK}\]

Where

\[
L_{KW.L} - L_{WK.L} = (BwB_1 + Ab_2) - (BbB_1 + Ab_1)
\]

\[
L_{WK.L} - L_{KKK} = (BbB_2 + AW_1) - (BbB_1 + Ab_1)
\]

\[
\beta = \frac{(Bw - Bb)}{B_1} = \frac{(Bw - Bb)}{(Aw - Ab)}
\]

In most case \((Bw - Bb) \sim (Aw - Ab)\)

\[
L_{KW.L} - L_{WK.L} = SCT_L
\]

4 Measurement of 3D stereo contrast ratio

4.1 Procedure of measurement:

I. Put the luminance meter at the position of left eye (\(P_L\)), which is at \((-D_{IP}/2, 0, D_{IP})\).

II. Measure the luminance at the display center (\(L_{WWL}\)) for both displays white.

III. Measure the luminance at the display center (\(L_{KKK}\)) for both displays black.

IV. Put the luminance meter at the position of right eye...
In 3D contrast ratio measurement procedure, we can’t verify the procedure due to we don’t have the benchmark. The metric of this test should need further human factor study.

5. Conclusions
Crosstalk issue in stereo/autostereoscopic display can be considered from different point of view. In this paper, we claim system crosstalk (SCT), viewer crosstalk (VCT) and co-location image contrast (CIC) using a crosstalk model to identify the crosstalk issue from different point of view. The advantages of claiming SCT, VCT and CIC are:

I. Clarify hardware optical property and stereoscopic content contrast issue
II. Specify local and global issue
III. Indicate that it is more likely for ghost image to occur where the image contrast is higher.
IV. The model can be applied for psychology experiment
V. The model can be applied for crosstalk cancellation

6. Acknowledgements
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7. References