Motion artifacts observed in 3-D LCDs that use shutter glasses (SG 3D)

HyungKi Hong
KyongHo Lim
JaeHong Kim
SunHee Park
HongSeop Shin
DonGyou Lee
Hyunho Shin

Abstract — Motion artifacts observed in 3-D LCDs using shutter glasses (SG 3D) has been investigated. A ghost-like artifact has been observed for static images due to incomplete image separation between the left and right views. The observed motion artifacts are different for the left and right views. And they occur even for images with zero binocular disparity. In this respect, the phenomena of observed artifacts in 3-D moving images are different from those of 3-D static images. 3-D motion artifacts were analyzed and are related to the moving speed of the images and the amount of binocular disparity.

Keywords — *3-D display, liquid-crystal display (LCD), motion artifact, shutter glasses, 3-D cross-talk.*

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1 Introduction

Today, 3-D technology is gaining more interest and is being applied to various applications. 3-D TV using shutter glasses (SG 3D) was introduced to the mass market.[1–3] Hence, the moving-image performance of SG 3D technology is important for TV application.

For LCDs, motion artifacts have been analyzed to be caused by the finite response time of LCDs and the hold-time effect. For example, as the image pattern scrolls constantly over the active area of an LCD, the position of the image in each frame is fixed, but the eyes track the image pattern at a constant speed, causing the motion artifact such as motion blur which is not observed in a static image.[4–6]

SG 3D is based on the temporal exchange between the left and right images. The duration of the period of non-zero luminance of an SG 3D LCD for each eye is about one-fourth of one frame. Therefore, the luminance profile of an SG 3D LCD is similar to the pulse shape, and the motion blur caused by the hold-time effect is not significant. Yet, motion artifacts of different profiles are observed for the left and right views in SG 3D LCD TV.

In this paper, the 3-D motion artifact of SG 3D was investigated. The phenomena of 3-D moving artifacts are newly characterized. Furthermore, the mechanisms of the 3-D motion artifact were analyzed as well.

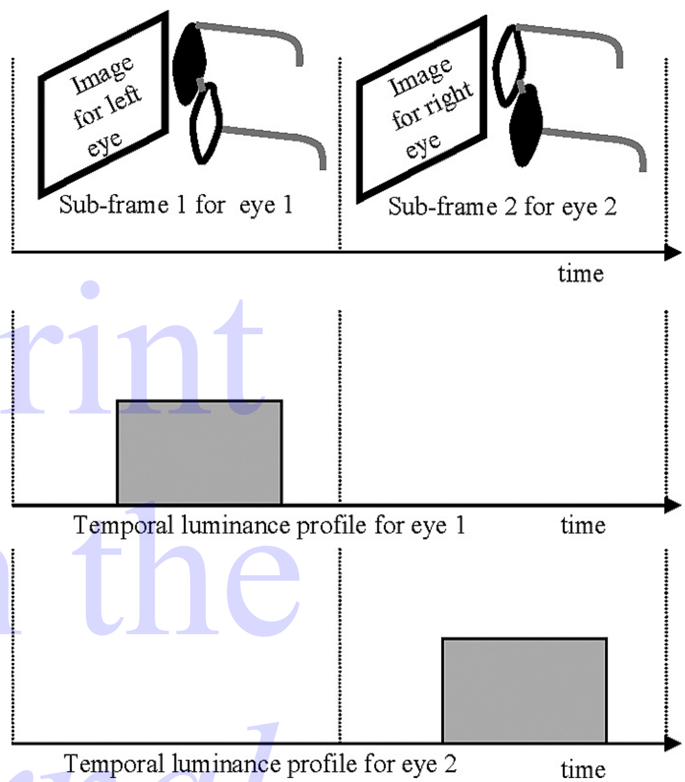

FIGURE 1 — Principle of stereoscopic 3-D using shutter glasses (SG 3D). Images for the left and right eye are displayed respectively during each subframe. One frame consists of two subframes.

2 Phenomena

The working principle of SG 3D is illustrated in Fig. 1. Each frame consists of two subframes. At subframe 1, the image for eye 1 is displayed on the imaging display, and one side of shutter glasses becomes transparent while the other side of the shutter glasses becomes non-transparent. At subframe 2, the image for eye 2 is displayed and the transparency and non-transparency for each side of the shutter glasses are interchanged.

The 3-D performance of a 3-D display is generally characterized by 3-D cross-talk, which represents the amount of image separation between the observed left and right views.[7] For SG 3D, where the left and right images are displayed on separate subframes, 3-D cross-talk is related to the effect of the previous subframes on the current subframe as the input signal for each subframe changes successively. When a static 3-D image is displayed on the imaging display, the left eye sees the left image as well as a weak overlapped right image when 3-D cross-talk is not zero. For

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H. Hong is with Seoul National University of Science and Technology, Visual Optics, Nowon-gu, Seoul 139-743, Korea; telephone +82-01-970-6232, e-mail: hyungki.hong@snut.ac.kr.
K. Lim, J. Kim, S. Park, H. Shin, D. Lee, and H. Shin are with the LG Display Co., Ltd., Paju-shi, Kyongki-do, Korea.

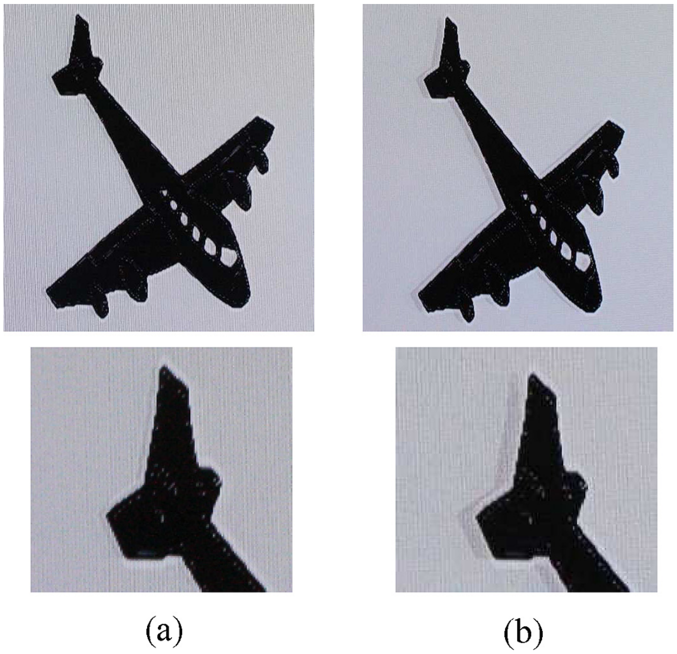

FIGURE 2 — Photos of ghost-like artifact observed for the static 3-D image for a binocular disparity of (a) two pixels and (b) 10 pixels. Photo is taken through one side of the shutter glasses.

the right eye, a ghost-like artifact of the left image is similarly observed overlapped with the right image.

The spatial difference between source images for the left and right eyes is typically called the binocular disparity.

FIGURE 3 — Photos of ghost-like artifact observed through each side of the shutter glasses where the image of zero binocular disparity is scrolled horizontally with a speed of 8 pixels/frame. Photos are taken, moving the camera horizontally.

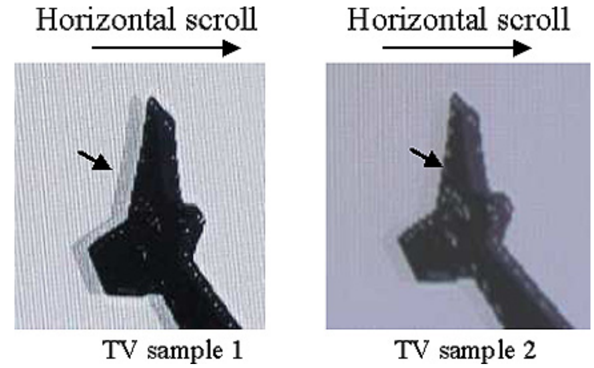

FIGURE 4 — Photo of 3-D motion artifact observed for one side of the shutter glasses in two samples of an SG 3D LCD with different 3-D cross-talk. The image of zero binocular disparity is scrolled horizontally with a speed of 8 pixels/frame. Each photo corresponds to the case of eye 1 where a ghost-like artifact is observed. The photos are taken by moving the camera horizontally.

Larger binocular disparity induces the perception of larger depth of the 3-D object. Figure 2 shows the photos of a ghost-like artifact when the static 3-D images of different binocular disparity are displayed on the imaging display. As the amount of binocular disparity becomes smaller, the distance of the ghost-like artifact from the intended image becomes smaller.

When the binocular disparity is zero, the images for the left and right eyes are the same. Therefore, the overlapped image is the same as the other image and the ghost-like artifacts are not observed in the static image even when the 3-D cross-talk of a 3-D display is not zero. However, when a image of zero disparity is scrolled horizontally, a ghost-like artifact is observed for one eye, while no artifact is observed for the other eye. This motion-artifact phenomenon observed for a moving image of zero binocular disparity is shown in Fig. 3. Because the phenomena of 3-D artifacts observed in a static image and a moving image are not the same, the mechanism of the 3-D motion artifact needs to be investigated.

3 Analysis

Commercial SG 3D LCD TVs 46 and 47 in. on the diagonal are used in the measurement. When the same scrolling image is displayed on two SG 3D samples, the intensities of the ghost-like artifact are observed to be smaller for one SG 3D sample whose 3-D cross-talk is smaller compared to that of the other SG 3D sample. This implies that this 3-D motion artifact is still related to 3-D cross-talk.

In a SG 3D LCD where each side of the shutter glasses has a time period of 1/60 sec, two subframes are separately used for the image generation of the left and right eyes. In each subframe, a signal for the image is applied for a time duration of 1/240 sec, and the black signal as the reset signal is applied for a time duration of 1/240 sec as illustrated in Fig. 5(a). The purpose of applying the black signal as the reset signal is to reduce the coupling effect between the adjacent subframes, *i.e.*, to reduce 3-D cross-talk. Fig-

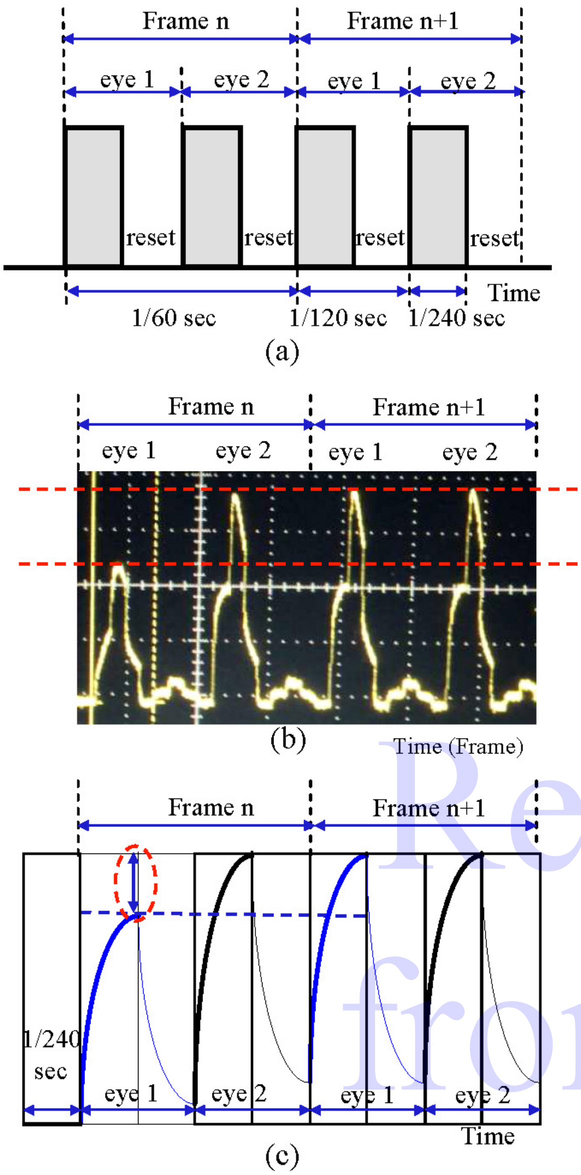

FIGURE 5 — (a) Input signal for a SG 3D LCD where the shutter glasses has a period of 1/60 sec. (b) Profile of temporal luminance measured without shutter glasses. (c) Schematic of temporal transmittance of LC cell for each subframe.

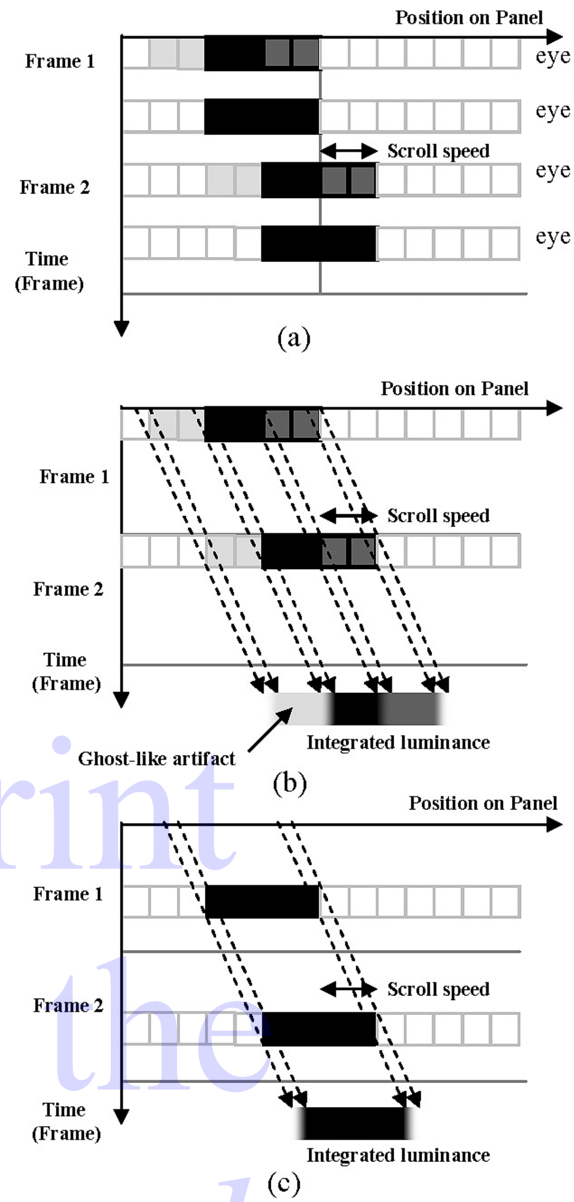

FIGURE 6 — (a) Illustration of the luminance change of a pixel for each frame when a pattern of four pixels scrolls with a speed of 2 pixels/frame. Two horizontal bars for each frame represent two subframes for eye 1 and eye 2, respectively. The gray level of each box represents the luminance for each pixel. (b) Schematic of motion artifact of subframe 1 observed by eye 1. (c) Schematic of motion artifact of subframe 2 observed by eye 2.

ure 5(b) shows the temporal luminance measured by a photodiode as the input signal changes from one gray level to other gray level at the start of frame *n*. It is measured without placing the shutter glasses in front of the photodiode, so the intensity peaks for eye 1 and eye 2 are measured. The peak intensity of the first subframe of frame *n* is measured to be smaller than those of other peaks. This measurement result indicates that the LC state does not reach the final state during 1/240 sec. Figure 5(c) illustrates the schematic, explaining the effect of the previous subframe. When input signals for eye 1 and eye 2 changes from 0 gray to 255 gray, the LC state does not reach the maximum transmittance at the first subframe of frame *n* and then does not decrease to the lowest transmittance by the reset signal. It can only reach the maximum transmittance at the second subframe of frame *n* and the following frames.

Figure 6 shows a model of a 3-D motion artifact observed for the images with zero binocular disparity where the pattern of four pixels moves with a scroll speed of 2 pixels/frame. The luminance of each pixel reaches the target luminance, not at the first subframe but at the second subframe. So, a luminance deviation exists around the boundaries of the pattern of four pixels for the first subframe, but is not so for the second subframe as shown in Fig. 6(a). Generation of a motion artifact in an LCD had been explained such that as the eyeball tracks a moving object, the light stimulus along the track is integrated by the visual system, and this integrated value on the retina is different from that of a static image.[4] The effect of the integra-

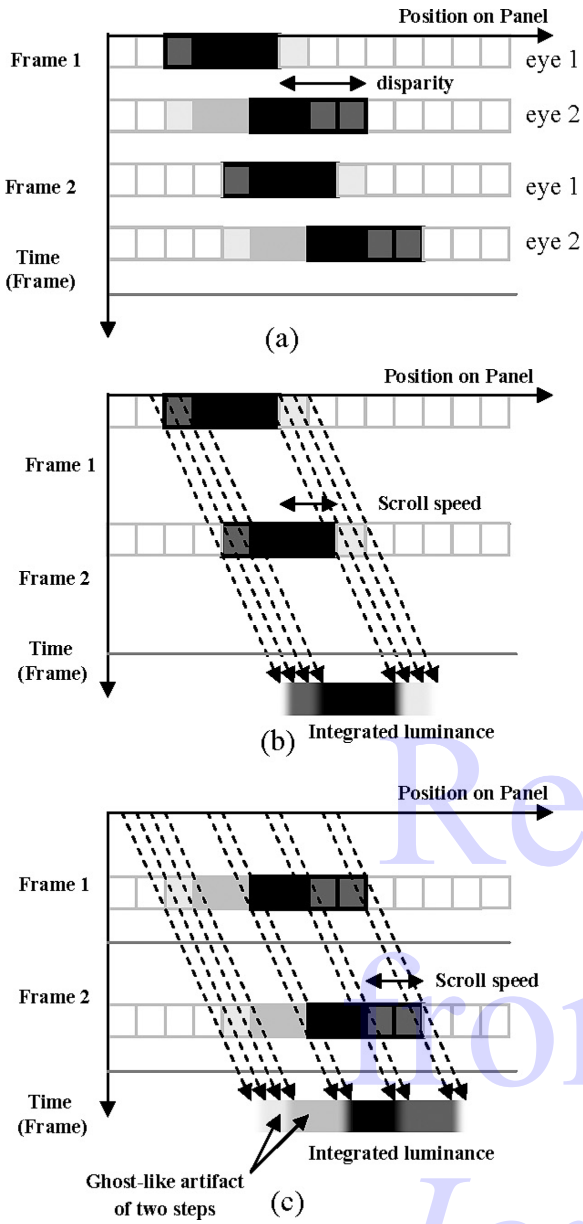

FIGURE 7 — (a) Illustration of luminance change of a pixel for each frame when pattern of four pixels scrolls with a speed of 2 pixels/frame. Two horizontal bars for each frame represent two subframes for eye 1 and eye 2, respectively. The image for the first and second subframes has a binocular disparity of three pixels. The gray level of each box represents the luminance for each pixel. (b) Schematic of motion artifact of subframe 1 observed by eye 1. (c) Schematic of motion artifact of subframe 2 observed by eye 2.

tion along the track of the eyeball is shown in Figs. 6(b) and 6(c) for each eye. In SG 3D, each eye sees only one of two subframes, respectively through the shutter glasses, so tracks of the pattern of each subframe should be considered separately. For the case of the first subframe, a luminance variation of two-pixel widths exists around the boundaries of the pattern. The integrated luminance along the track results in regions of flat luminance of about two-pixel widths. So those regions of the flat luminance will be observed as a ghost-like overlapped image, rather than a blurred image. For the second subframe, pixels adjacent to the moving patterns are at the same luminance level. As luminance along

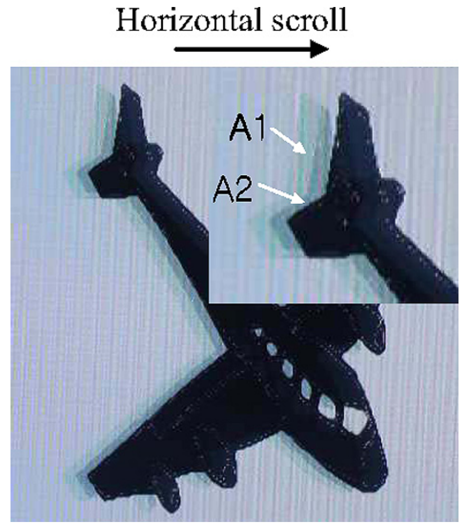

FIGURE 8 — Photo of 3-D motion artifact observed for one side of the shutter glasses where the left and right images with a binocular disparity of 10 pixels are scrolled horizontally with a speed of 8 pixels/frame. The photo is taken by moving the camera horizontally.

the track is integrated, only motion blur shorter than one-pixel width occurs for the other eye. Therefore, when 3-D cross-talk is not ignorable, the luminance difference between subframe n and $n + 1$ of eye 1 becomes noticeable, and this causes a motion artifact with a flat luminance profile. This model matches well with the observed phenomena shown in Fig. 4 where a ghost-like artifact is observed only for one eye and no ghost-like artifact is observed for the other eye.

When the binocular disparity is not zero, the profile of the motion artifact becomes more complicated. Depending on the values of the scroll speed and the binocular disparity, various luminance profiles of motion artifacts are possible. One example is shown in Fig. 7 where the binocular disparity is three pixels and the pattern moves with a scroll speed of 2 pixels/frame. The same schematics as shown in Fig. 6 are illustrated in Fig. 7. Due to the binocular disparity and the movement of each frame, the luminance variation occurs around a four-pixel pattern for the first and the second subframes, although it is different for each subframe. So the luminance deviation will cause a motion artifact with a flat luminance profile for each eye. The integrated luminance in Fig. 7(c) shows a profile of two flat regions for the left side of the observed image, and this will cause two ghost-like artifacts. Figure 8 shows an example where such an artifact is observed.

4 Conclusion

Motion artifacts observed in a SG 3D LCD can occur even for moving images with zero binocular disparity as the moving image in the 3-D mode affects the luminance of the adjacent subframes. Also, these motion artifacts are observed to be different for the left and right eyes. In this respect, the phenomena of motion artifacts observed in a SG 3D LCD is different from the artifacts observed in the moving images of a 2-D LCD or static images of a SG 3D LCD.

The mechanism of these motion artifacts and the relationship of their luminance profile to the scrolling speed and the binocular disparity of 3-D images are analyzed and compared with the observed ghost-like artifacts.

We expect that the analysis of these phenomena will contribute to a reduction in the motion artifact observed in SG 3D LCDs in the future.

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