Chapter 5

CBU Suppression

5.1 Introduction

CBU artifacts and visibility evaluation of FS display have been investigated. These efforts were used as the foundation if CBU can be eliminated using compensation. In this chapter, the CBU suppression can be divided into two methods: minimum frame rate prediction and image compensation. Each method will be presented in this section.

5.2 Minimum Frame Rate Prediction

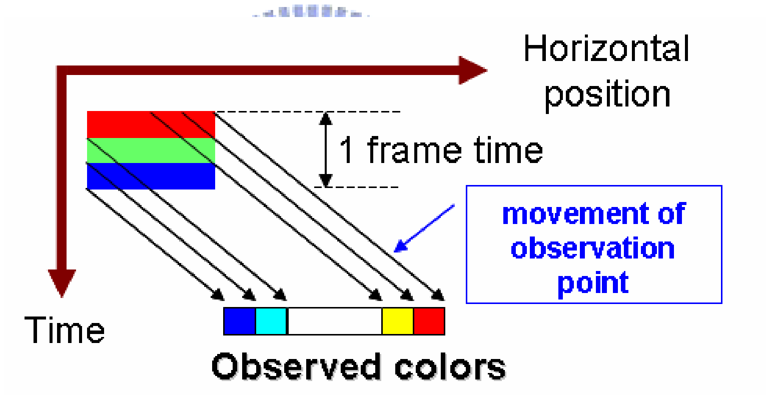
According to the result of indistinguishable CBUA, the frame rate of this 32” FSC-LCD TV can be derived for suppression of CBU. From eqs. (3-1) and (4-1), if an observer watches the FSC-LCD with distance of $D_{observe}$ under $CBUA_{observe} \leqq CBUA_{indistiguishable}$ condition, the observer may not perceive CBU. From eqs. (1) and (2), the above inequality can be rewritten as

$$\tan^{-1}\left(\frac{T}{2D_{observe}}+\frac{V}{FD_{observe}}\right)-\tan^{-1}\left(\frac{T}{2D_{observe}}\right) \le \tan^{-1}\left(\frac{T}{2D_{indistinguishable}}+\frac{V}{60D_{indistinguishable}}\right)-\tan^{-1}\left(\frac{T}{2D_{indistinguishable}}\right) \qquad (5\text{-}1)$$

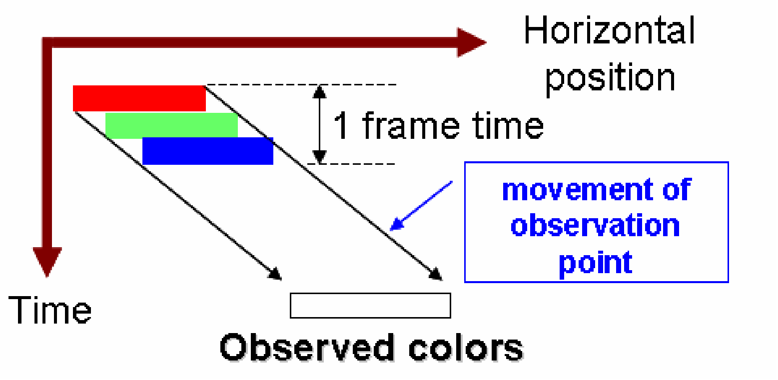
Therefore, the minimum frame rate (F) of a FSC LCD TV for CBU elimination can be calculated once T, $D_{observe}$ and V were known. For example, if an observer watches a 32” FSC-LCD TV at distance of 250 cm which is around three times of the diagonal length. Under the environmental condition of Ls=0 lux, $L_{T=}$56 nits, V=800 mm/sec, and T=17 mm, the $D_{indistinguishable}$ can be derived as 330 cm by eq.(3-1). From eq. (5-1), the minimum frame rate of the 32” FSC-LCD TV for eliminating CBU is at least 90 Hz. Although the assumption for getting this result is when the observer watches the screen without relative head moving, the formula provides a basic requirement for designing FSC-LCD.

5.3 Image Compensation

CBU can be simulated by the proposed model; it means the shift position of each primary color fields of a single frame can be calculated in physical stimuli analyses. By individually updating the R, G, and B color fields at the correct spatio-temporal coordinates, the compensation algorithm capable of generating such compensated images without CBU. The mechanism of CBU suppression is illustrated in Fig. 5-1. The observed CBU image can be quantified when viewing conditions were known such as Fig. 5-1 (a). This effort shown in Fig. 5-1 (a) was used to determine the component images of each color fields if this artifact can be suppressed by using this compensation mechanism. Thus, we may not sense CBU in the observed color such as Fig. 5-1 (b) in the relative motion between the image and the observer.



(a)



(b)

Fig. 5-1. The schematic of the a) CBU and b) image compensation mechanism.

Method we used for image quality evaluation was subjective measure, where viewers perceived images directly to determine the compensated quality. In general, viewer's focus on the difference between compensated image and original image, they notice such details when CBU becomes unacceptable.

In this section, an impairment category scale is used instead of number to label each suppression results in the compensation experiment. The scale starts from high level and, because of various viewing factors, the quality is degraded. The levels of impairment comprise a five-category qualitative scale with the following categories of impairment descriptor. A score of 5 is no CBU (Imperceptible), score of 4 represents a little CBU, which can be ignored (Perceptible, but not annoying), score of 3 shows CBU which can be seen evidently but be accepted (Slightly annoying), score of 2 shows a lot of CBU, which cannot be accepted (Annoying) and finally score of 1 shows too much CBU, therefore cannot be tolerated (Very annoying). These examples are shown in Tab. 5-1.

Tab. 5-1 The impairment category scale method sued for subjective evaluation.

Absolute score	Evaluation result
5	Imperceptible
4	Perceptible, but not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Experiments were performed in several experimental orders according to the viewing conditions in phase II. First, subjects sat in front of the FSC displays at an original distance and fix his eye ball in a fixation point which laser point projection in the screen center. Before performing compensation, if the $D_{observe}$ is less than $D_{indistinguishable}$, it means the observer may not sense CBU, therefore, we do not need to compensate the image signal. In contrast, the image should be compensated to suppress CBU in viewing processing. The criteria of compensations can be shown in Tab. 5-2.

Tab. 5-2. Psychophysical evaluation in CBU.

Equation	Evaluation Result
$D_{observe} > D_{indistinguishable}$	Imperceptible
$D_{observe} < D_{indistinguishable}$	Perceptible

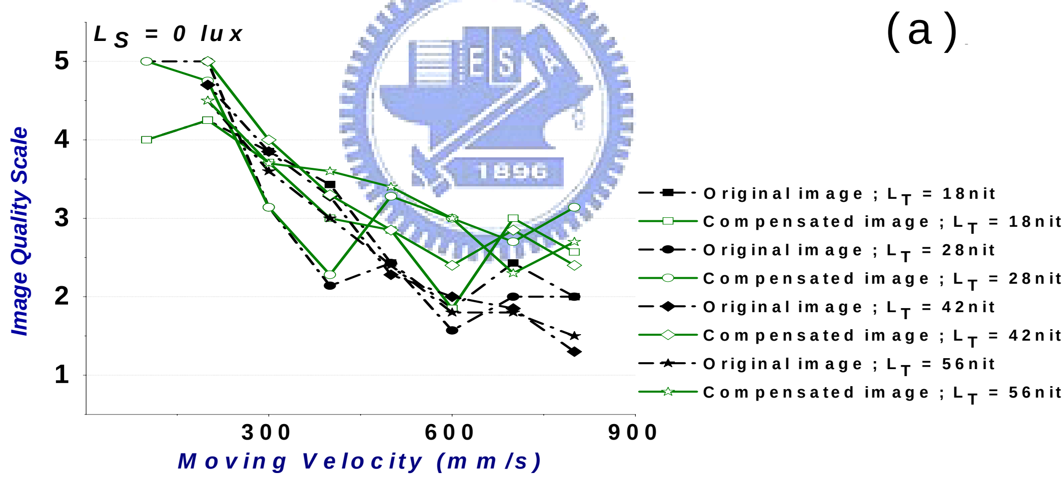
After evaluation, the original image, a vertical white bar, was displayed before, immediately following, the compensated one, which individually updating three color fields to correct positions by MATLAB, was be perceived for demonstration after stimulation. The schematic for clear explanation compensation mechanism was shown in Fig. 5-3. After that, eye movement was induced by a moving target, which a black object combined with the x-y table, close to the target image to evaluate the image qualities when the eye ball moving pass through left to the right in the moment. Finally, five scales for discrimination diagnosis to evaluate the image performance were responded by observers in the perceived moment and were recorded it for demonstration.

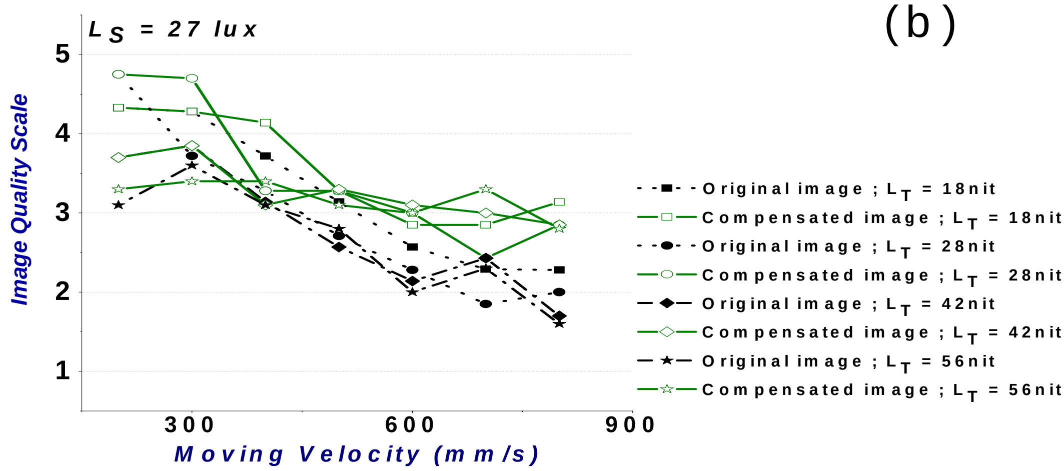
5.4 Experiment Result

The performances of image quality are summarized in Figs. 5-2 and 5-3 for the eye moving view with stationary image. For comparison, the image performances of original and compensated images were demonstrated in the psychophysical experiment. In the Figs. 5-2 and 5-3, the blach dash dot line indicates the image quality of original test pattern, and the solid line shows the image quality of compensated image under different viewing conditions.

From the result, the compensated image was adequate for CBU eliminating in 74% and 66% of the experimental results with FSC LCD and DLP projection system, respectively.

When CBU occurs, each color field is often perceived in the original image edge separately. Therefore, the perceptual quality always gets lower score especially in larger eye moving velocity as shown in Figs. 5-1 and 5-2. On the other hand, CBU suppressed due to the color fields were overlapped on the same position in the moment on the retina by using image compensation. Hence, the visibility of this artifact can be decreased than the original one. Yet, not all of the CBU artifact can be suppressed by using image compensation. Possible explanation could be the sequence of the color fields. During the experiment, we assumed the observers started sensation from R to B color fields. In fact, we had a chance to perceive component image of CBU in sequence as G, B, and R or B, R, and G. Thus, CBU might become more noticeable with compensated image than original one. However, as the result, image compensation is a feasible method for eliminating CBU in FS displays.





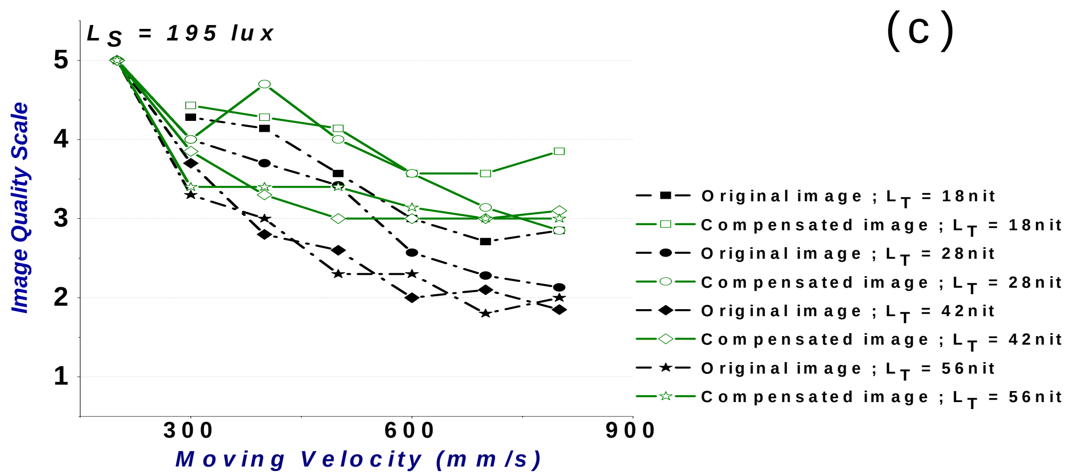
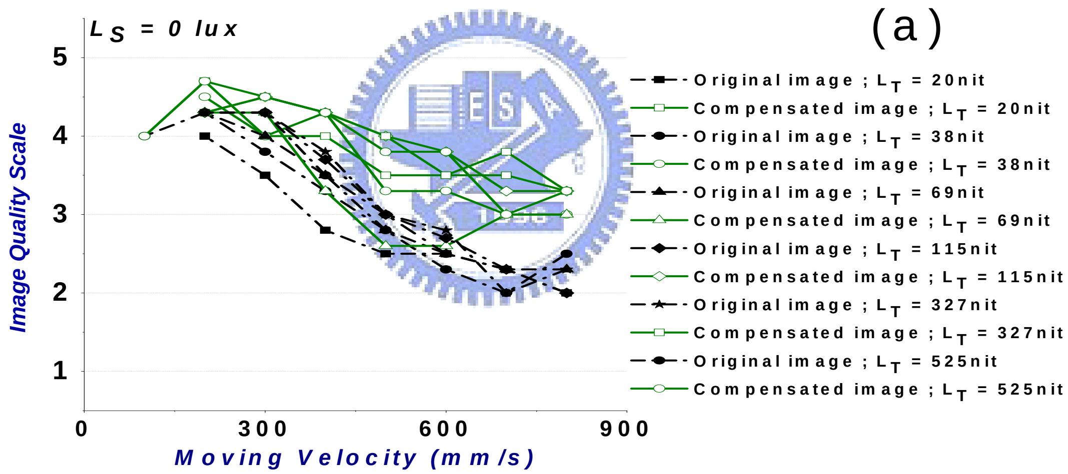
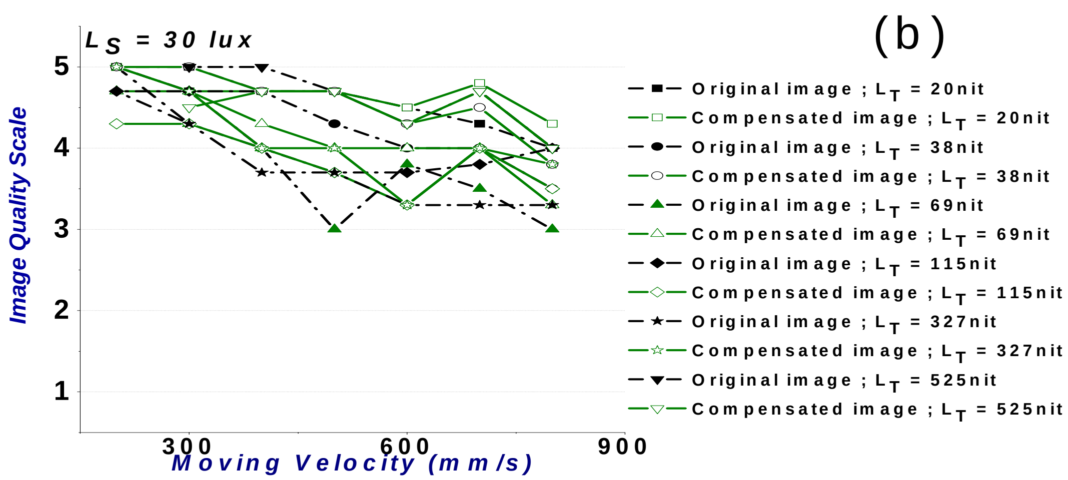


Fig. 5-2. Evaluating the image quality of original and compensation images with a) dark surrounding, b) surrounding illumination with 27 lux, and c) surrounding illumination with 195 lux in FSC LCD.





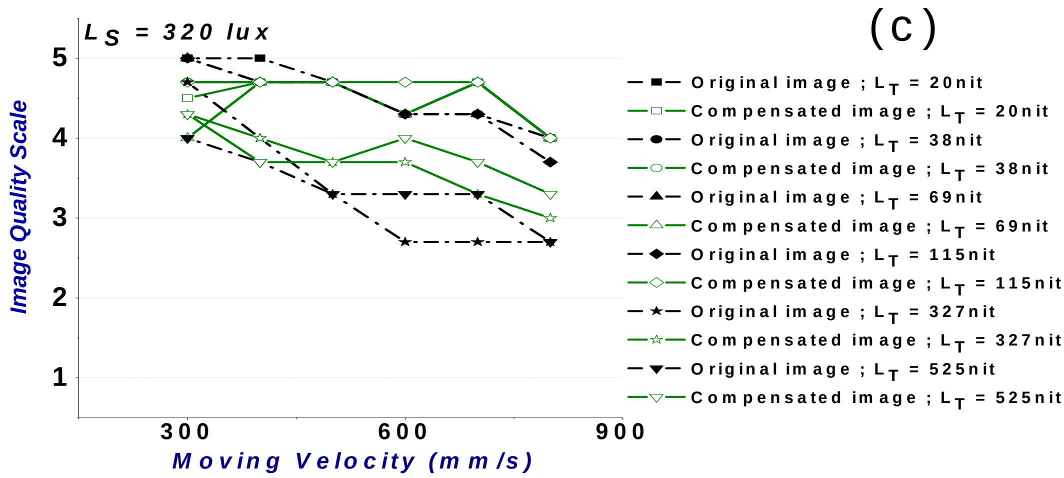


Fig. 5-3. Evaluating the image quality of original and compensation images with a) dark surrounding, b) surrounding illumination with 30 lux, and c) surrounding illumination with 320 lux in DLP projection system.

For example, in Fig. 5-2 (a) shows a photograph of image used in this psychophysical experiment, (b) is the image with CBU simulated by proposed model, (c) is the compensated one input this FSC displays, and the suppression result (c) captured by the DSC is similar to (a).

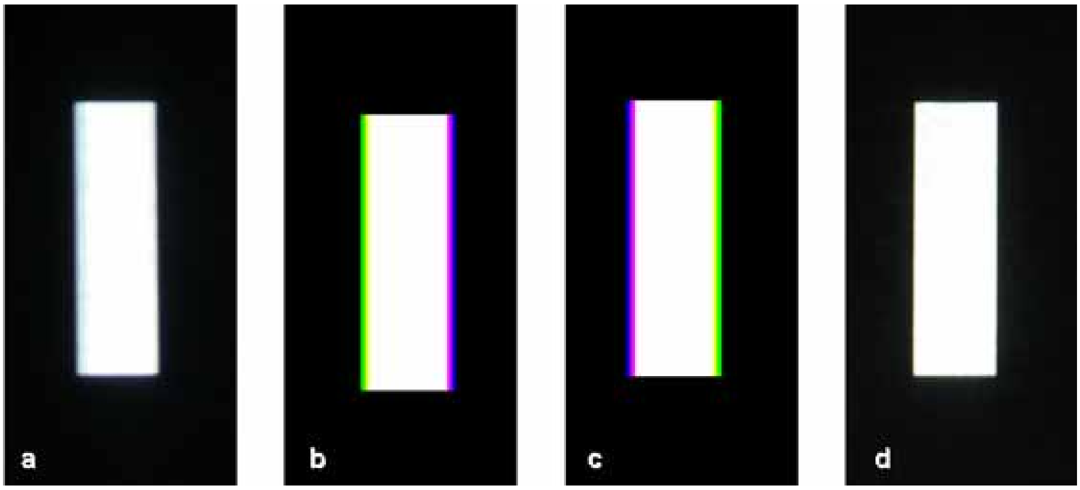


Fig. 5-4. CBU suppression result captured in DLP projection system.

5.5 Summary

The minimum frame rate of FSC LCD TV for CBU suppression can be calculated form the model once the test pattern width, viewing distance, and eye moving velocity were known. On the other hand, image compensation, used to enhance the image perceptual quality, was demonstrated acceptable by using psychophysical experiment. Thus, these two CBU suppression methods will be useful for all different size FSC LCDs.