Chapter 4

Psychophysical Evaluation

4.1 Introduction

CBU can be quantified in physical parameters such as eye moving velocity, viewing distance, and target width. However, the spatiotemporal properties of the human visual system's coding mechanism are restricted. The goal of this psychophysical experiment was to determine indistinguishable CBUA in actual perception conditions.

4.2 Psychophysical Evaluation

Method of adjustment is the main technique designed to determine the just perceptible change in a stimulus. The threshold techniques are used to measure the observer's sensitivity to changes in a given stimulus. Absolute thresholds are defined as the just perceptible difference under a changing stimulus, while thresholds represent the just perceptible difference from a particular stimulus level greater than zero. Thresholds are reported in terms of physical units used to measure the stimulus.

For the determination of the absolute threshold, start with a sequence of closely spaced stimuli exhibiting a signal with a known value. Stimuli of random values are sequentially presented to the observer. As described above, upon presentation of the stimulus, the observer is asked whether he or she perceives the CBU. If CBU is not detected, the next stimulus in the sequence is presented and the question is repeated. This process of presenting the sample and asking the question is repeated until the observer responds perceived. During this experiment, the observer controls the stimulus magnitude and adjusts it when CBU is just perceptible or just perceptibly different from a starting level. The threshold is taken to be the average setting across a number trails by one or more observers. The schematic of psychophysical experiment apparatus is shown in Fig. 4-1.

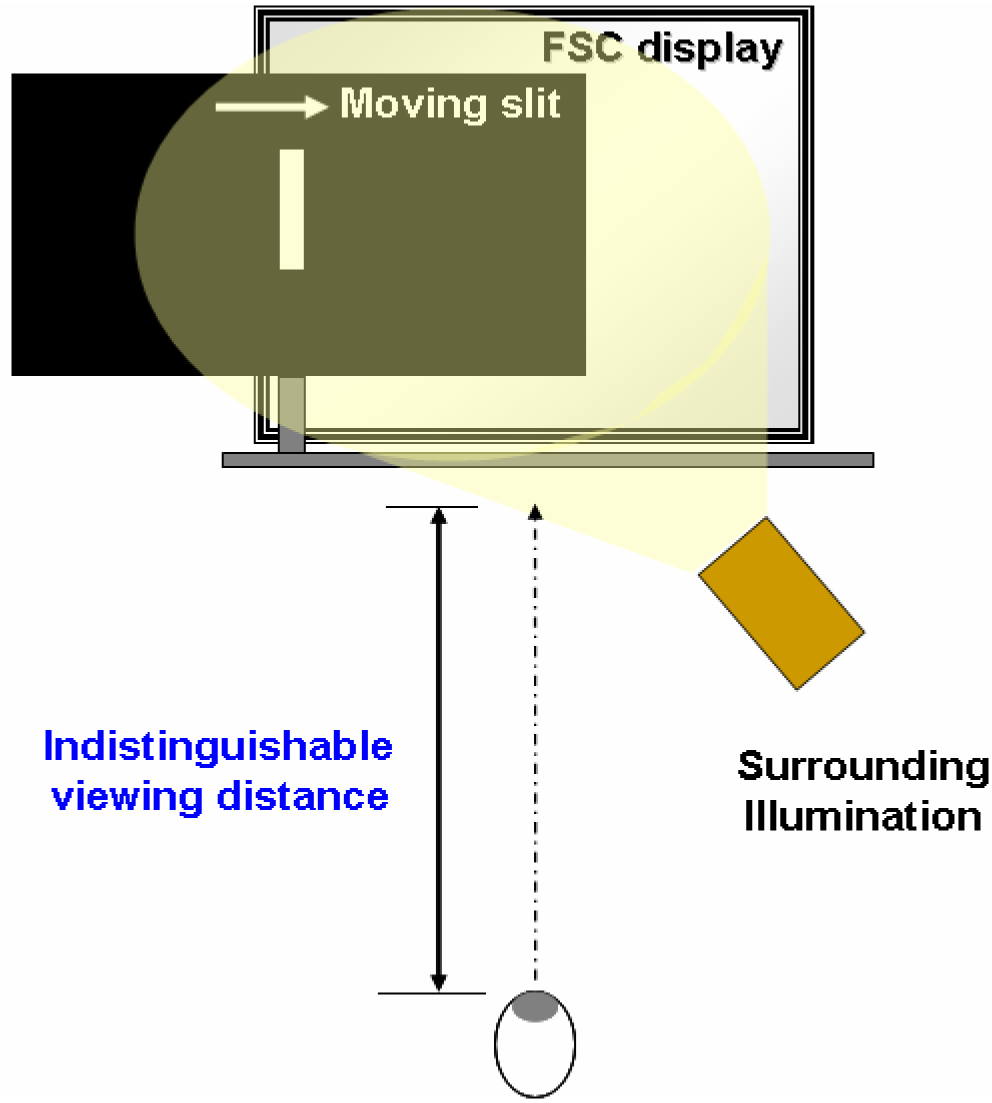


Fig. 4-1. Schematic of the psychophysical experiment apparatus.

In this psychophysical experiment, the white strip was utilized as the stimulus with the width of 21mm and 17mm for the light source of DLP projection system and FSC LCD, respectively. Furthermore, we choose several critical viewing conditions such as target luminance (20, 38, 69, 115, 327, 527 nits in DLP, and 18, 28, 42, 56 nits in FSC LCD), moving velocity (100, 200, 300, 400, 500, 600, 700, and 800 mm/s) and surrounding luminance (0, 30, 320 lux in DLP and 0, 27, 195 in FSC LCD) to minimize or maximize CBU perception.

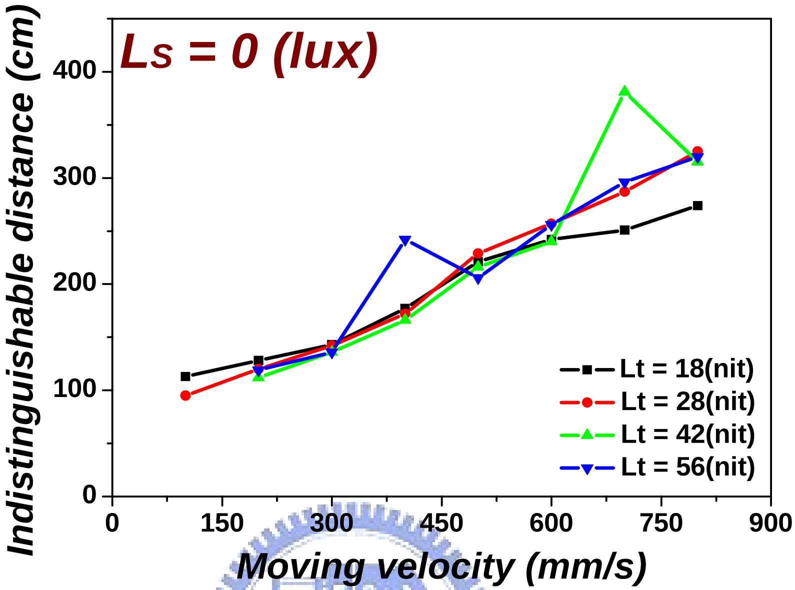
Finally, several viewing conditions were processed by eleven different observers and the threshold distances were averaged over them. They were undergraduate and graduate students. Their ages range form 23 to 36 years. They were screened for standard definition of normal visual acuity 20/20 on Snellen acuity pattern and normal color vision on Ishihara Test. The observers served in experimental studies before data collection began and stable criteria for judging the result of CBU. The data of observers are summarized in Tab. 4-1.

Tab. 4-1. Characteristics for each subject.

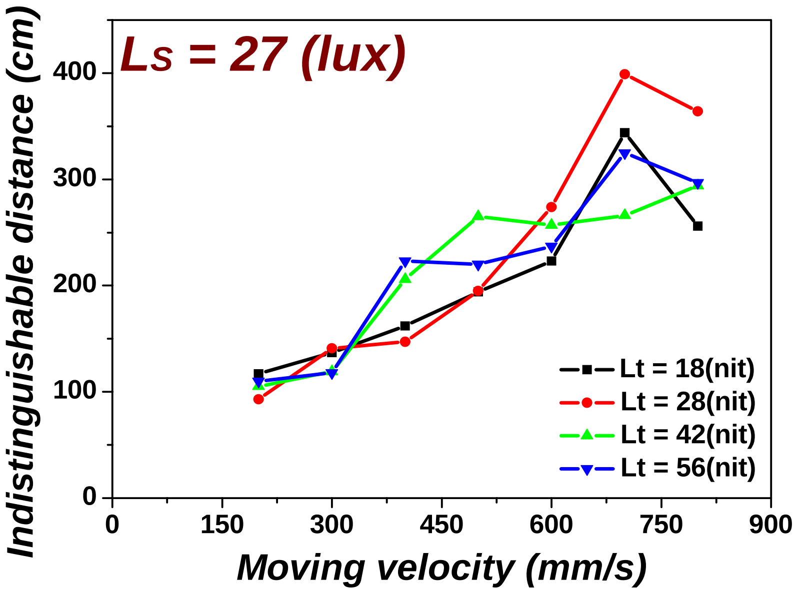
Observer	Age	Male/Female	Vision acuity	Color vision
WJ	23	Female	20/20	Normal
FC	29	Male	20/20	Normal
YB	28	Male	20/20	Normal
WJ	32	Male	20/20	Normal
ZB	32	Male	20/20	Normal
SC	23	Male	20/20	Normal
JH	31	Male	20/20	Normal
ML	36	Male	20/20	Normal
JW	27	Male	20/20	Normal
HJ	28	Female	20/20	Normal
YP	25	Female	20/20	Normal

4.3 Experiment Results

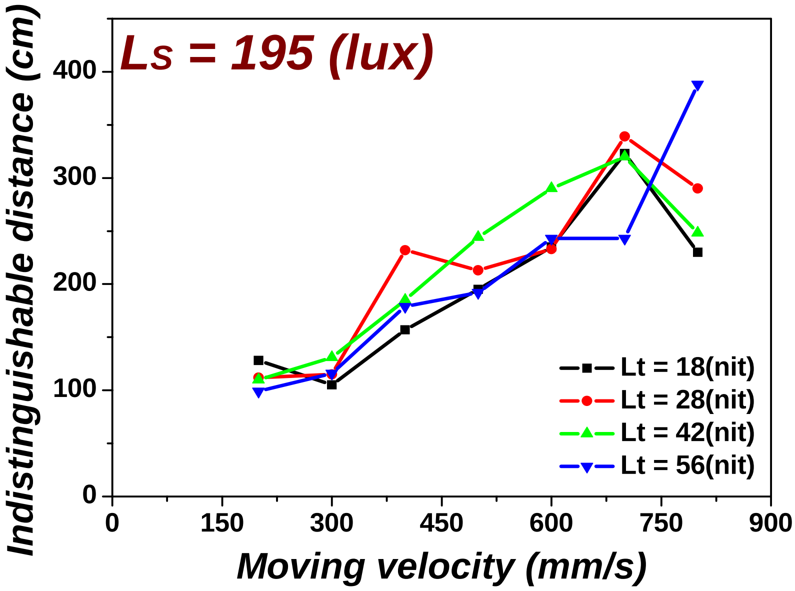
The averaged threshold distance of psychophysical evaluation under FSC LCD and DLP projector are shown in Figs. 4-2 and 4-3.



(a)

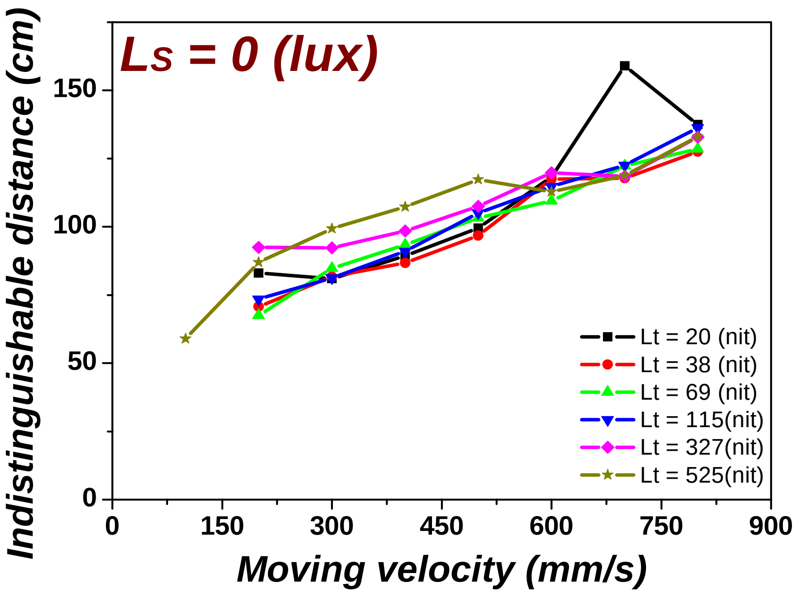


(b)

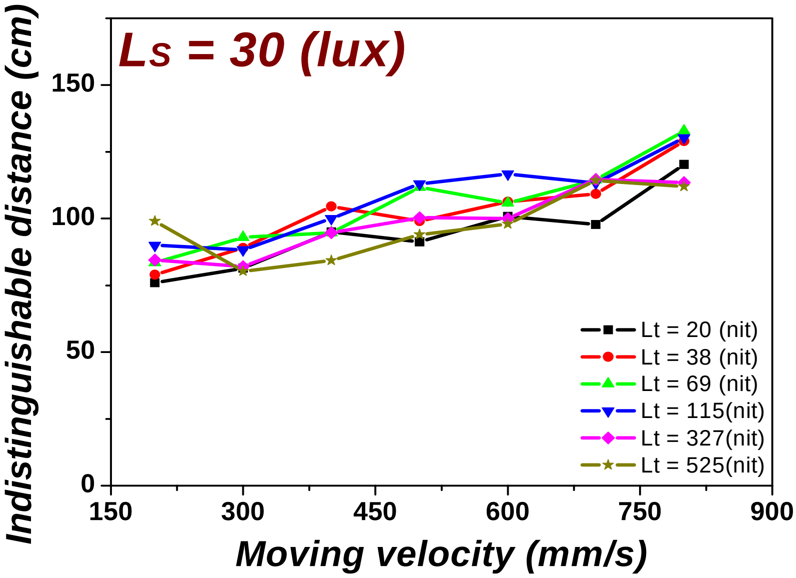


(c)

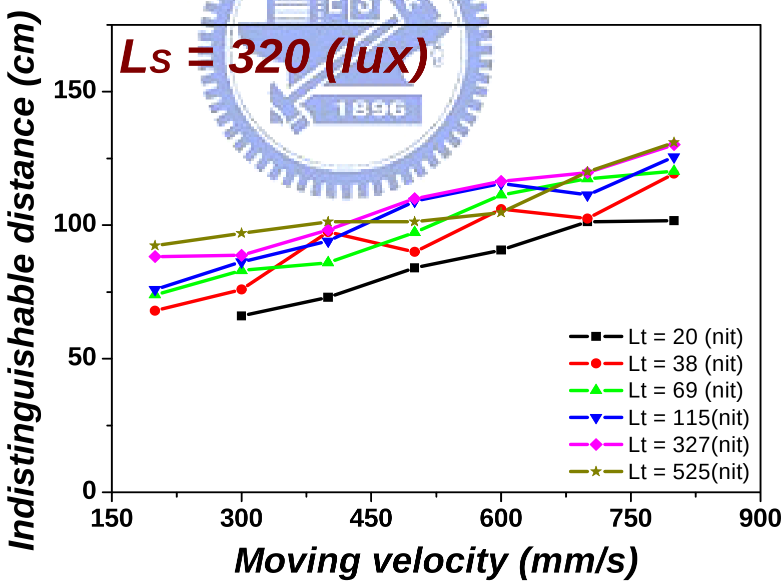
Fig. 4-2. Threshold distance of psychophysical evaluation with a) dark surrounding, b) surrounding illumination with 27 lux, and c) surrounding illumination with 195 lux in seven observers under FSC LCD.



(a)



(b)



(c)

Fig. 4-3. Threshold distance of psychophysical evaluation with a) dark surrounding, b) surrounding illumination with 30 lux, and c) surrounding illumination with 320 lux in four observers under DLP projection system.

To develop a model for the experiment data, we used a formula to describe it. Since there are three variables in those experiment data, each mathematical form of the variables can be obtained when we regard two other parameters as a constant. After that, a nonlinear regression model for CBU predictors can be written as

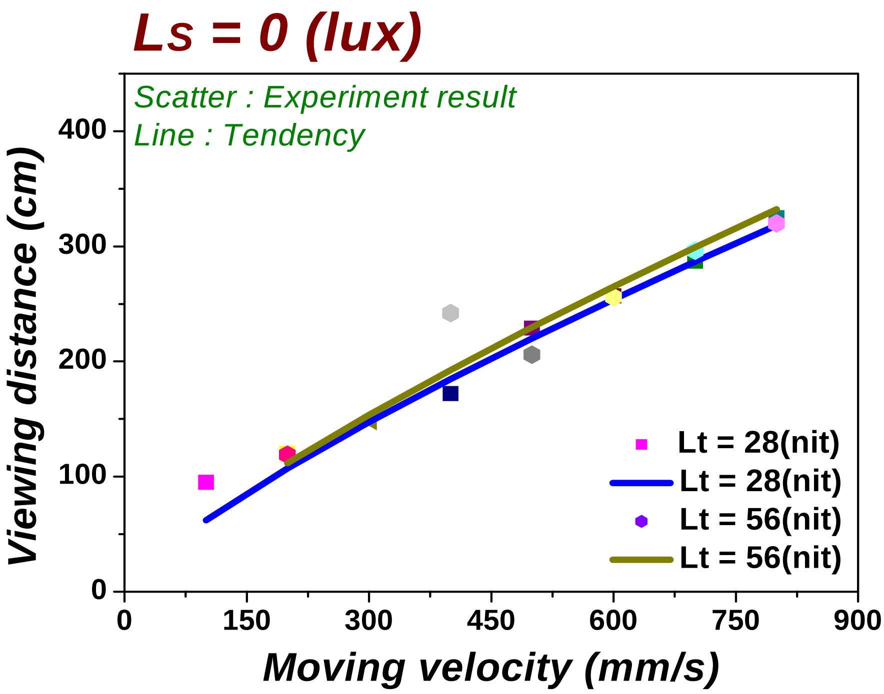
$$D_{indistinguishable} = kL_T{}^a V^b (cL_S + i) \qquad (4\text{-}1)$$

where k, a, b, c, i are unknown constant in this formula and Lt is the target luminance in cd/m², Ls is the surrounding luminance in lux, V is the moving velocity in mm/sec. For each FSC type display, the relations between the viewing distance and psychophysical evaluation in FSC LCD and DLP projection system can be described most of our data by following table.

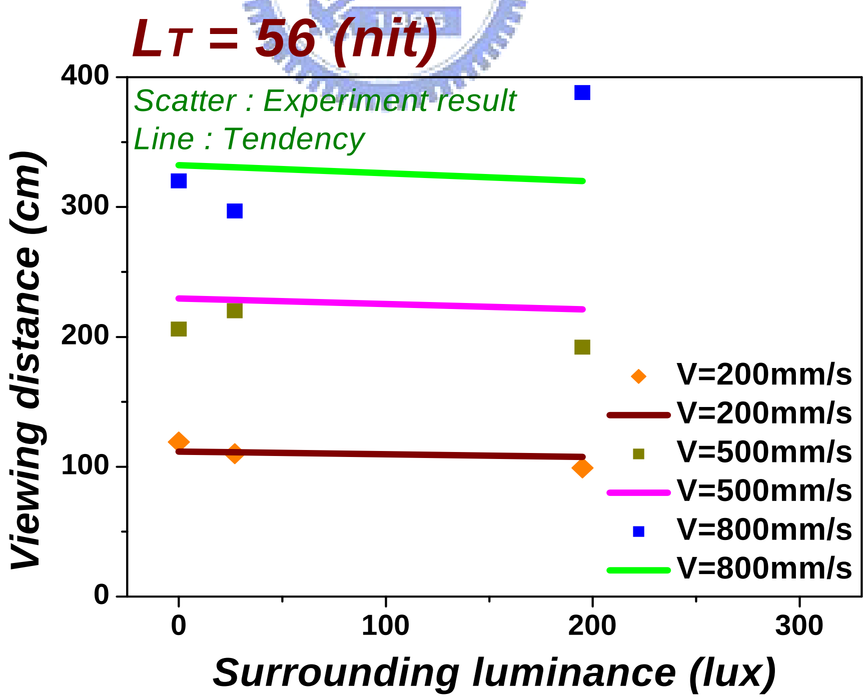
Tab. 4-2 The coefficients of the equation under two type displays.

Coefficient / Type	k	a	b	c	i
FSC LCD	0.083	0.062	0.786	-0.03	16.274
DLP Projection System	0.063	0.023	0.341	-0.026	182.55

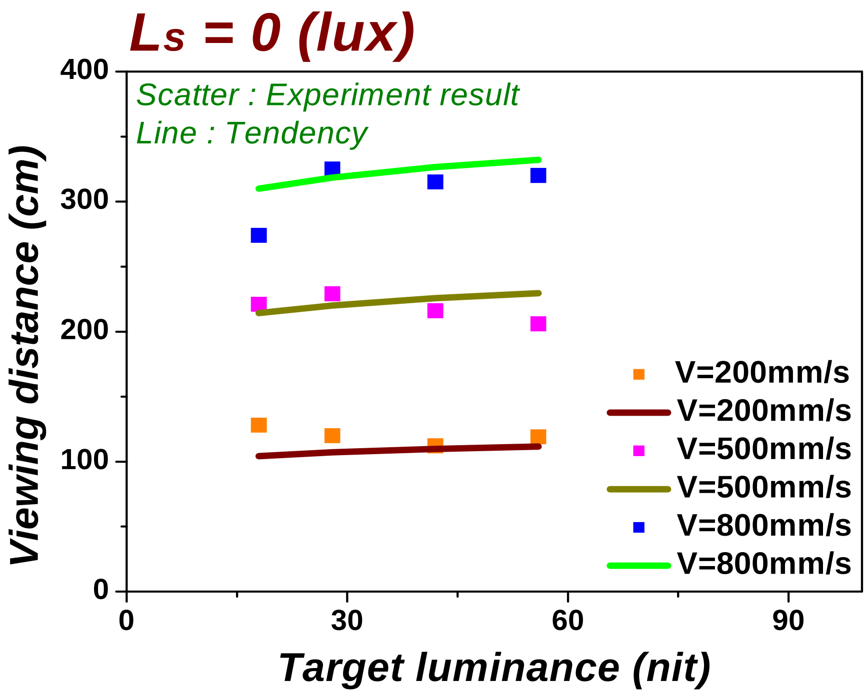
From this equation, CBU was be quantified for two tendencies. It is easier to be perceived with higher moving velocity and higher bright objects, but invisible with higher surrounding luminance. The examples of each tendency with various parameters were shown in Fig. 4-4.


Ls = 0 (lux)
Scatter : Experiment result
Line : Tendency
Lt = 28(nit)
Lt = 28(nit)
Lt = 56(nit)
Lt = 56(nit)
Viewing distance (cm)
Moving velocity (mm/s)
0
100
200
300
400
0
150
300
450
600
750
900

(a)


LT = 56 (nit)
Scatter : Experiment result
Line : Tendency
V=200mm/s
V=200mm/s
V=500mm/s
V=500mm/s
V=800mm/s
V=800mm/s
Viewing distance (cm)
Surrounding luminance (lux)
0
100
200
300
400
0
100
200
300

(b)



(c)

Fig. 4-4. The indistinguishable viewing distance of CBU with various, a)moving velocity, b)surrounding luminance, and c)target luminance in a 32” FSC LCD.

However, not all parameters here are the mainly factors caused CBU. Therefore, the results also indicate that, CBU is noticeable at higher moving velocity, but only slightly affected by the brightness of target and surrounding luminance. As the result, the moving velocity is still the mainly parameter causing CBU in human perceptual processing of psychophysical evaluation.

After that, the most important step is to derive the indistinguishable CBUA for designing FSC LCDs. In order to figure out the distinguishable CBUA of human eyes, from the threshold distance, the indistinguishable CBUA can be derived from eq. (3-1). The averaged indistinguishable CBUA in FSC LCD and DLP projection system were 0.22° (S.D.=0.04°) and 0.23° (S.D.=0.07°), the averaged indistinguishable CBUA under several conditions in

DLP projection system and FSC LCD were presented in Table 4-3. As we can see, the indistinguishable CBUA of DLP projection system is close to other one. Therefore, the indistinguishable CBUA may represent the angular resolution of human eyes on FSC displays.

Tab. 4-3. The indistinguishable CBUA of human eyes with these two displays.

Type	Indistinguishable CBUA	Standard deviation
FSC LCD	0.22°	0.04°
DLP Projection System	0.23°	0.07°

4.4 Summary

Using psychophysical experiment to quantify the visibility of CBU is a direct method. Eye moving velocity is the main parameter causeing CBU more noticeable in all viewing conditions. Subsequently, the indistinguishable CBUA can be derived from eq. (3-1) as 0.22° on a 32" FSC LCD. Hence, we have successfully established a model to evaluate CBU of FSC LCD by using a convenient experiment setup. Thus, the model will be used to design the suppression algorithm to improve image quality in current FSC displays.