19.3: Correlation between Perceived Motion Blur and MPRT Measurement

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Abstract
The MPRT has been studied as the method of measuring motion blur on LCD. Subjective evaluation was conducted using the method of adjustment for investigating perceived motion blur. As a result, a strong correlativity was found between the perceived motion blur and the measurements by MPRT. So the MPRT can indicate very well the degree of motion blur perceived by humans.

1. Introduction
In recent years, a number of studies have been reported on evaluation and alleviation of motion artifacts. Particularly for motion blur on LCD, which belongs to motion artifacts, several evaluation techniques have been proposed as commercialization of improvement technologies progresses. [1-3]

To expressly define a motion blur, it is necessary to consider the response time in intermediate gray level of liquid crystal and blur occurrence caused by hold type displaying method. However, the liquid crystal response time (LCRT), which is used generally, cannot express the LCD motion blur that we perceive because it does not contain those factors. It has been learned that motion blurs that arise on hold type display units are caused by the mismatch between the pursuit of human eyeballs and the motion of the displayed image. [4] To digitalize such motion blurs, we need a measuring method that takes eyeball motion into account.

Hence, a number of companies got together and started study how to evaluate motion blurs on LCD in 2001. As a result, they defined Moving Picture Response Time (MPRT) that allows us to quantify the motion blurs of liquid crystal using a pursuit camera. A method to measure MPRT has been established to date, and commercialization of a measuring device also has been started.

In our study, subjective evaluation experiment by the method of adjustment was conducted to verify the agreement between the measurements of MPRT and the motion blurs that humans feel. This paper reports the correlativity between the motion blur that test humans perceived and the result of MPRT measurement.

2. Overview of the definition of MPRT
2.1 Measuring device and units
The MPRT method was defined as a technique to quantify the motion blurs a humans feels when he/she views a moving picture displayed on an liquid crystal panel while he/she is in a condition of smooth pursuit eye tracking (SPET), or in other words, when his/her eye(s) is smoothly pursuing a moving object. This definition enables us to measure MPRT values using a common CCD camera. Several pursuit camera systems have already been proposed in which a camera chases a moving edge on a screen and takes photographs of images of motion blur, and some of the systems have entered in commercialization of measuring device. [5, 6]

Motion blur can be better understood if it is expressed by the width of displayed blur. However, the width of a blur displayed on the panel varies with the moving velocity and the hold time (vertical frequency) of the moving picture. In addition, the unit, "pixel/frame", used in the definition of moving velocity of a test pattern varies with the resolution of the panel, and further, the adequate viewing distance also varies with the panel size and the intended use. If a motion blur is digitalized by its width, it is not possible to evaluate the display performance of moving picture through direct comparison between results of measurement, and therefore, to express a motion blur by its width is not suitable for evaluation criterion. For this reason, the MPRT method uses “time (ms)” as the units of measurement results so that we can directly compare numerical values even when those conditions are different. In other words, the “time” used as the evaluation value of moving picture blur is a value normalized under all conditions, and if we give a speed and other conditions to the numerical value (time) obtained by measurement, it is possible even to determine the blur width on the panel

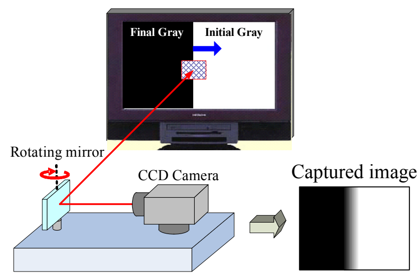

Fig. 1. Measurement system: A rotary mirror pursues the edge and captures the image. Some other proposed systems rotate the camera.

2.1 Measurement and analysis
As shown in Fig. 2, measurement uses 42 test patterns which consist of combined initial gray level and final gray level. The luminance (Y0 to Y6) used in the initial level and the final level use the brightness, which is divided into six values at regular intervals on the axis of lightness based on the transformation equation of L* defined in CIE 1976 starting from the minimum luminance (Y0) and the maximum luminance (Y6) which are measured.

$$L0 = 903.3 \times Y0/Y6 \text{ for } Y0/Y6 \le 0.008856$$
$$Yn = Y6 \times \left(\frac{\left(L0 + \left(100 - L0\right) \cdot n/6\right) + 16}{116} \right)^3 \qquad (2)$$
$$n \in \{0,1,2,3,4,5,6\}$$

The brightness from Y0 to Y6 obtained by the abovementioned method are always laid at subjective equidistance, and therefore, it becomes possible to conduct measurement with a test pattern of combination of the same luminance (given gray levels are different) only if the minimum luminance and the maximum luminance remain the same even when the γ characteristics of the panel is altered.

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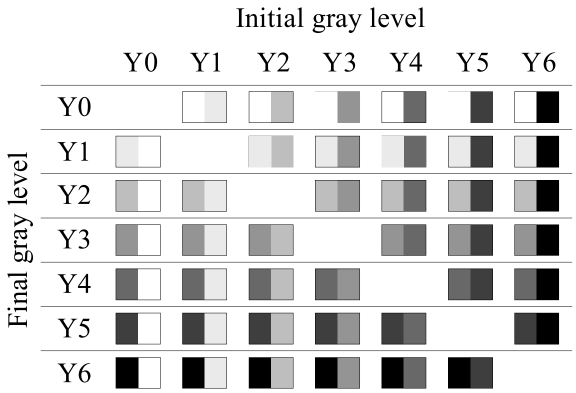

Fig. 2. Combination of gray levels of measurement pattern: Measurement uses 42 patterns, which are combinations of seven luminance display from Y0 to Y6. These gray levels are subjectively equidistance.

The pursuit camera captures an image of the edge area of scrolling 42 test patterns, and the values of Extended Blurred Edge Time (EBET) obtained from the resulting image are averaged to produce MPRT. Fig. 3 shows a graph of relationship between the response curve obtained from the captured image and EBET. The axis of ordinate indicates the relative luminance and axis of abscissa indicates the time. The time “t” given on the axis of abscissa in Fig. 3 is the quotient of the pixel position xLCD (pixel) in the horizontal direction of the captured image divided by the moving velocity “v” (pixel/ms) of the test pattern.

EBET is the time (tf-ti) for the relative luminance to change from 10% to 90% (or from 90% to 10%) on the response curve multiplied by the inverse number (1.25) of interval 0.8 of threshold value.

$$EBET = \frac{t_f - t_i}{0.9 - 0.1} = (t_f - t_i) \cdot 1.25 \qquad (2)$$

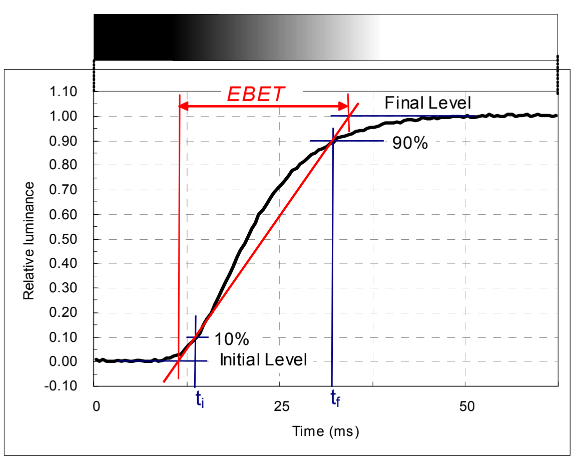

Fig. 3. Response curve: Image at the top: a sample of image captured by the pursuit camera. The profile in the scroll direction (horizontal) of image expressed by relative luminance. Time on the axis of abscissa is obtained by dividing the horizontal pixel position xLCD (pixel) by the moving velocity “v” (pixel/ms) of the test pattern. Draw a straight red line passing the threshold values of 10% and 90% of relative luminance, and determine the time from the Initial level to the Final level as EBET.

In the case of ideal hold type display of which the liquid crystal response time is 0ms, for example, "t_f- t_i" is 13.3ms if we assume the cycle of one frame is 16.7ms, but we can obtain 16.7ms, which is the same value of the hold time, if we multiply it by 1.25 which is the inverse number of threshold distance. Further, we can obtain the same value in an ideal hold type display device even if the value of threshold is altered by the operation of standardization in the future.

EBET is determined for each of 42 test patterns consisting of combinations of luminance Y0 to Y6, and the average of those 42 values of EBET is used as the MPRT.

$$MPRT = \frac{1}{42}\sum EBET_{i,f} \qquad (3)$$

$$EBET_{i,f} = \begin{cases} i = Y0, Y1, Y2 \ldots Y6 \\ f = Y0, Y1, Y2 \ldots Y6 \\ i \neq j \end{cases}$$

3. Experiment of subjective evaluation

In order to quantify the motion blur that humans perceive on LCD, we carried out subjective evaluation experiment using the method of adjustment. Fig. 5 shows the overview of the evaluation apparatus. An LCD monitor is placed on the top of a CRT monitor to create an evaluation apparatus, and a test pattern is displayed on both monitors. A blur-free pattern is continuously supplied to the LCD monitor, as shown at the top on the right-hand side of Fig. 4. To the CRT, a pattern is supplied of which blur width of edge can be adjusted by keyboard operation. At the edge displayed on the LCD, a motion blur is caused by the liquid crystal response time and the effect of hold when the edge scrolls from left to right. On the other hand, the edge displayed on the CRT looks almost the same as the supplied pattern. Test subjects are required to adjust the blur width of the pattern supplied to the CRT so that they will see those two edges having the same blur width. The blur width of the edge displayed on the CRT created by those test subjects, we will use as the result of subjective evaluation experiment.

In order that the images displayed on the CRT and the LCD will have the same brightness as much as possible, the maximum luminance was adjusted by the backlight of LCD monitor, and the minimum luminance was adjusted by the room illumination. To make the shape of the edge of the pattern for CRT into an S-shape near to the motion blur on the liquid crystal panel, a profile was created using a sine function as the base.

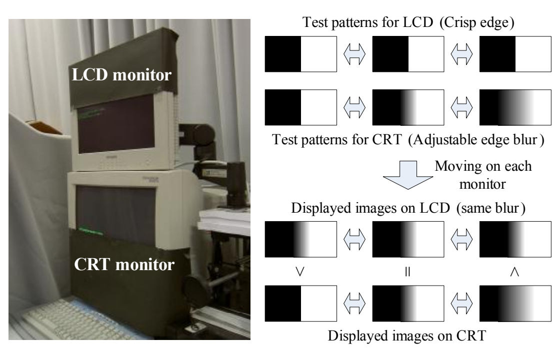

Fig. 4. Apparatus of subjective evaluation by the method of adjustment: The image supplied to the CRT is blurred by keyboard operation until it looks having the same width as the blur displayed on LCD while comparing the images on LCD and CRT.

4. Result of experiment

4.1. Perceived motion blur width

In our subjective evaluation experiment, seven men and four women, all in their 20s to 30s, total eleven were used for test subjects. Those eleven subjects included engineers and non-engineers. In the subjective evaluation, the same 42 test patterns were used as measurement of MPRT, and each test pattern was scrolled from left to right at the speed of 5 pixel/frame. This speed corresponds to approximately 6.4 deg/s in the experiment environment with the pixel pitch of 0.30 mm and viewing distance of about 800 mm. Three experiments were conducted for each test pattern, and obtained values were averaged, which is taken as the experiment result for each test subject. Table 2 summarizes the result of subjective evaluation by eleven test subjects, and the upper row indicates average of blur width, $\bar{x}$, and the lower row the standard deviation, σ. Although data tends to spread widely when blurs is few and when they are many, the ratio of the standard deviation to the average value is 15% or less in approximately 80% of patterns, which reveals the test subjects feel blurs in a similar way.

Final gray level	$\bar{x}$ / σ	Y0	Y1	Y2	Y3	Y4	Y5	Y6
		Initial gray level						
Y0	$\bar{x}$		6.56	6.07	6.18	6.00	5.82	6.47
	σ		1.14	1.23	1.55	1.09	1.16	1.22
Y1	$\bar{x}$	13.86		7.95	7.25	7.26	7.98	9.87
	σ	1.43		0.59	0.88	0.95	1.09	1.23
Y2	$\bar{x}$	14.56	10.36		8.98	9.26	9.41	11.25
	σ	1.66	0.87		1.06	0.70	1.07	1.09
Y3	$\bar{x}$	15.13	10.92	10.34		10.11	10.66	13.35
	σ	1.67	0.81	0.79		0.90	1.31	1.39
Y4	$\bar{x}$	14.27	11.08	10.39	10.16		11.21	15.37
	σ	1.47	1.58	0.89	0.71		0.99	2.50
Y5	$\bar{x}$	14.28	10.81	10.33	10.23	10.70		19.83
	σ	1.92	0.90	1.03	0.88	1.16		3.43
Y6	$\bar{x}$	11.23	9.15	8.94	8.82	8.61	8.66	
	σ	1.12	0.95	0.73	0.75	0.95	0.81	

Table 1. Blur width measured by the method of adjustment: Average $\bar{x}$ of subjective evaluation result (upper row) and standard deviation σ (lower row) for 11 subjects when scrolling at 5 pixel/frame. Data spreads widely when blurs is few or many. Ratio of standard deviation to average value is 15% or less in about 80% patterns.

4.2 Perceived motion blur widths and EBETs

Fig. 5 compares the perceived motion blur widths from subjective evaluation experiment with EBETs from the MPRT measurement. The axis of ordinate indicates the perceived motion blur width (pixel), and the axis of abscissa the time (ms) of EBET. Perceived motion blur widths are the number of pixels while the profile of luminance of test pattern displayed on CRT changes from 10% to 90% (or 90% to 10%) multiplied by 1.25 in a similar way to EBET determined from luminance profile of captured image as shown in Chapter 2. For measurement of EBETs, MPRT-1000 by Otsuka Electronics was used.

The analysis disclosed a different tendency when the combination of initial gray level and final gray level changes to darker side (e.g., Y6 to Y0) and when it changes to brighter side (e.g., Y0 to Y6), and the former is plotted in blue points, and the latter in red points for distinction in Fig. 5. The correlation coefficient of all 42 test patterns is 0.938. The correlation coefficient of 21 test patterns that change to darker side is 0.981, and the correlation coefficient of 21 test patterns that change to brighter side is 0.779.

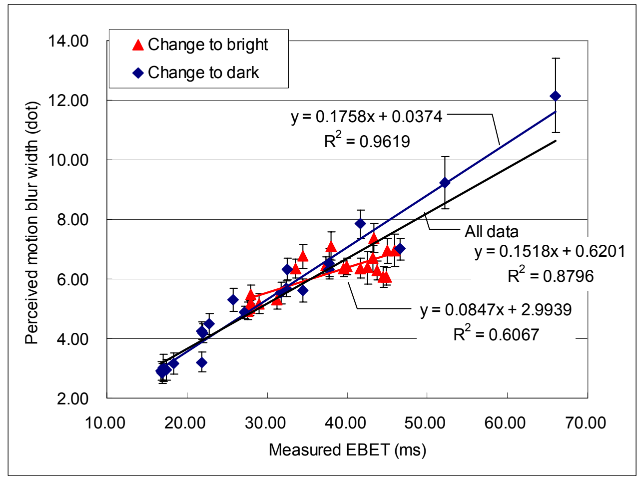

Fig. 5. Comparison of perceived motion blur widths with EBETs: Motion blur width from subjective evaluation of 42 patterns and EBET from MPRT measurement are plotted. Red: result of 21 test patterns changing from dark to bright. Blue: result of 21 test patterns changing from bright to dark. Black: Approximated line for 42 test patterns. Remarkably strong correlation is found between subjective evaluation and EBET measurements in all 42 test patterns, producing a correlation coefficient of 0.938.

4.3 Threshold and correlation

How the threshold used for analysis affects the correlation between subjective evaluations and EBET measurements was investigated. Table 2 shows how correlation coefficient is affected by threshold values, where combination of lower (darker) threshold and upper (brighter) threshold is set to 5%-95%, 10%-90%, 15%-85% and 20%-80%. Checking the correlation coefficient of all 42 test patterns, we found the correlation coefficient by threshold values of 10%-90%, which are used in the current MPRT method, was the highest value of 0.938. However, the correlation coefficient by threshold value of 15%-85% is 0.936, which tells us the threshold around those values do not affect the correlation very much.

Threshold	5%-95%	10%-90%	15%-85%	20%-80%
Change to bright	0.623	0.779	0.773	0.817
Change to dark	0.943	0.981	0.980	0.980
Total	0.902	0.938	0.936	0.930

Table 2. Relationship between thresholds and correlation coefficient: In totality, correlation is the maximum with thresholds of 10%-90% adopted in the MPRT method. Correlation of patterns that change to darker side is remarkably high.

Table 3 checks correlation coefficient, with the lower threshold fixed to 10%, while the upper threshold is changed. When the upper threshold is set to 90% to 80%, the correlation is stronger than 95% and 70%. In 90% to 80%, the correlation varies very little in 21 test patterns changing to dark, but in 21test pattern changing to bright, correlation shows a trend to become stronger. In all 42 test patterns, correlation coefficient is the highest of 0.945 for threshold of 10%-85%, which makes a small difference of 0.007 from the result for threshold of 10%-90%.

Threshold	10%-95%	10%-90%	10%-85%	10%-80%	10%-70%
Change to bright	0.653	0.779	0.826	0.844	0.796
Change to dark	0.936	0.981	0.983	0.985	0.973
Total	0.899	0.938	0.945	0.943	0.899

Table 3. Relationship between threshold value on bright-side and correlation coefficient: Correlation coefficient with dark-side threshold fixed to 10%. For total correlation is the maximum at bright-side threshold of 85%. Correlation in 21 test patterns changing to bright is the maximum at bright-side threshold of 80%.

4.4 Contrast of perceived motion blur width and EBET

The diagrams in Figs. 6 and 7 compare perceived motion blur width with EBET by test patterns, with the threshold values set to 10%-90%. Fig. 6 shows the result of 21 test patterns that changes to brighter side and Fig. 7 shows that of 21 test patterns that changes to darker side. As shown in Table 3 previously, the subjective evaluation result agrees with the measurement result in Fig. 7. In Fig. 6 too, the same trend is shown in totality although a little gap is noticed in patterns having Y3, Y4 and Y5 at the final gray level.

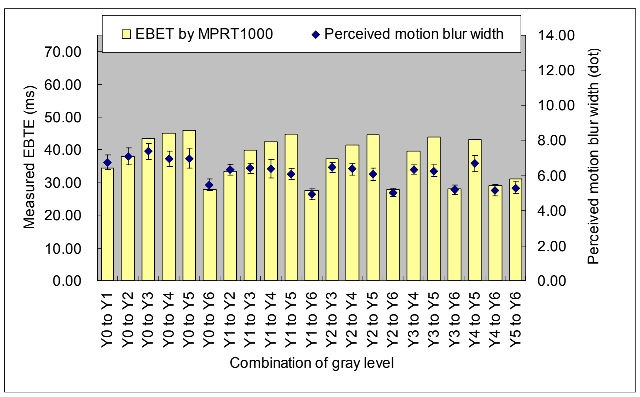

Fig. 6. Comparison between EBET and perceived motion blur width: Comparison of 21 patterns changing to bright, thresholds set to 10%-90%. Bars indicate EBET values and the spots the perceived motion blur width by subjective evaluation. Gap is involved in the result of patterns having Y3, Y4 and Y5 at the final gray level although the correlation coefficient is as high as 0.779.

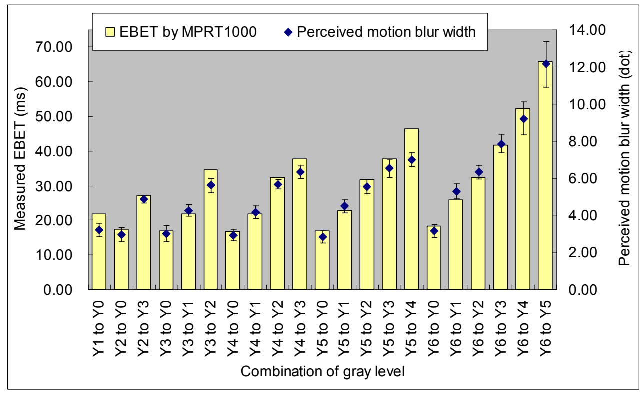

Fig. 7. Comparison between EBET and perceived motion blur width: Comparison of 21 patterns changing to dark, thresholds set to 10%-90%. Bars indicate EBET values and the spots the perceived motion blur width by subjective evaluation. Correlation coefficient is extremely high of 0.981, and subjective evaluation agrees with the measurement result in their trend.

5. Conclusion

The motion blur obtained in our subjective evaluation experiment using the method of adjustment has been compared with the EBET obtained in MPRT measurement, and as a result, it has been demonstrated that both data are in a good accordance. For the thresholds set to the range from 10%-90% to 20%-80%, or, from 10%-90% to 10%-80%, the correlation coefficient is 0.930 or higher, not showing a conspicuous change, and therefore, we can say the currently used range of 10%-90% is successful threshold values.

As mentioned above, it has been confirmed that the MPRT method is a measurement method that can quantify motion blurs on LCD as perceived by humans. In the future, we will conduct more detailed investigation about the relationship between subjective evaluation and measurement result, using different monitors to conduct additional experiments.

6. References

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