New Standard: TEST METHOD FOR PERCEPTUAL MOTION BLUR IN LCD

Note: This background statement is not part of the balloted item. It is provided solely to assist the recipient in reaching an informed decision based on the rationale of the activity that preceded the creation of this document.

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Background

Moving edge blur is an important issue on the current display technology. Various attempts have been made to measure and evaluate the moving edge blur. The common metric widely most used for Liquid Crystal Display (LCD) is the Moving Picture Response Time (MPRT) method. It uses the average of MPRT\textsubscript{ij} values associated with gray\textsubscript{i}-to-gray\textsubscript{j} transition:

\[
MPRT_{AVE} = \frac{1}{N} \sum_{i \neq j} MPRT_{ij}
\]

where \( N \) is the number of measurement. For example, if seven gray levels are used (\( i = 1, 2, \ldots, 7; \ j = 1, 2, \ldots, 7, \) and \( i \neq j \)), there are 42 gray-to-gray transitions (7×7-7 = 42).

Recently, it has been reported that these MPRT\textsubscript{ij} values do not accurately represent the perceptual motion blur in some cases like Dynamic Backlight Influence on Motion Blur Measurement\textsuperscript{1}. In particular, the dynamic backlight (local dimming) which has been added to improve contrast and black level of LCD can produce very large MPRT\textsubscript{ij} values for the transition between dark and bright levels. These large MPRT\textsubscript{ij} values in several transitions substantially increase the MPRT\_AVE value while the perceptual moving edge blur in this case shows slightly increased degradation. Consequently, for this kind of new displays, the conventional MPRT\_AVE may fail to accurately measure perceptual moving edge blur.

To address this problem, this standard describes a new moving edge blur measurement method which provides an accurate estimate of perceptual moving edge blur.

Ballot Voting Information

SEMI Standards Regulations requires a 60% return rate from the total number of registered voting members. There are three valid ways to vote on this letter (yellow) ballot:

1. **Accept Vote (Including Accept with Comments)** – If you are in agreement that this document should be approved, vote accept. If you are in agreement that this document should be approved, but have suggestions for editorial clarification or wish to offer related items for future consideration (new business), please vote accept and include your suggestions at the bottom of the voting sheet.

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The results of this ballot will be discussed at the next Korea FPD Metrology Committee meeting (tentatively scheduled on October 15, 2010) at Seoul, Korea.

Please note that the voting deadline for the document 5054 and other Cycle 5 ballots are due on Wednesday, September 8, 2010. Therefore, we kindly request that you submit your votes in a timely manner for this to move on the next stage of review.
SEMI Draft Document 5054
New Standard: TEST METHOD FOR PERCEPTUAL MOTION BLUR IN LCD

1 Purpose
1.1 This standard describes a method for measuring moving edge blur.
1.1.1 The measurement method provides an accurate estimate of perceptual moving edge blur.

2 Scope
2.1 The standard is applicable to measure moving edge blur characteristics of displays such as LCD (Liquid Crystal Display) modules.

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Referenced Standards and Documents
3.1 VESA² Standards
VESA — Flat Panel Display Measurement Standard Version 2.0
3.2 ITU³ Standards
ITU-T Recommendation P.910 — Subjective Video Quality Assessment Methods for Multimedia Applications
3.3 Reference Documents
3.3.1 SID⁴ Digest of Technical Paper, 2010: pp. 1520-1523 — “Dynamic Backlight Influence on Motion Blur Measurement”
3.3.3 SID Digest of Technical Paper, 2005: pp.1018-1021 — Jun Someya, “Correlation between Perceived Motion Blur and MPRT Measurement”
3.3.4 SID Digest of Technical Paper, 2007: pp.1122-1125 — Michael E. Becker, “Motion Blur Measurement and Evaluation: From Theory to the Laboratory”

NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology
4.1 Definitions
4.1.1 moving edge blur — The moving edge blur is defined as the blur that becomes visible on intrinsically sharp transition between two adjacent areas, with different luminance levels, when the transition smoothly moves across the display as a function of time (see Figure 3 for an exemplary moving edge blur).
4.1.1.1 This moving edge blur occurs when the eye tracks a moving image while the display presents a frame-by-frame representation of the moving object in succession.
4.1.1.2 The object has a constant moving direction. The moving edge image is blurred on the retina over the frame period because the eye continues to move even during a single frame interval.

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³ International Telecommunication Union – Telecommunication Standardization Sector, http://www.itu.int/
⁴ The Society For Information Display, http://www.sid.org/
4.1.2 proportional integral derivative (PID) control — The PID is a type of feedback controller used in motor control system.

4.1.2.1 PID control is combination of proportional control, proportional-integral control, and proportional derivative control.

4.1.3 refresh rate — The refresh rate is the number of times a display's image is repainted or refreshed per second.

4.1.3.1 The refresh rate is expressed in Hz. A refresh rate of 60Hz means the image is refreshed 60 times in a second. The refresh period is the inverse of the refresh rate.

5 Standards Measurement Condition

5.1 Measurement shall be carried out under the following standard conditions.

5.1.1 Environmental conditions

- Temperature: 20 ± 5°C
- Humidity: 25% - 85% RH (non condensing)
- Pressure: 86kPa – 106kPa (25inHg – 31inHg)

5.1.2 Viewing direction is the perpendicular to the display under test.

5.1.3 Surrounding illumination is below 1lux (dark room condition).

5.1.4 Warm-up time is normally 20 minutes.

5.1.4.1 This warm-up time may be different depending on the display devices. In such cases, it can be determined between manufacturers and customers. Exceptions must be verified and reported.

5.1.5 Measurement shall be not carried out under vibration and windy conditions or when there is a presence of vibration.

5.1.6 Measurement is clarifying at screen center.

5.1.7 The integration time of measurement must be equivalent to an integer multiple of the refresh period.

6 Measurement Method

6.1 It is noted that different setups, test patterns, and procedures described in reference documents for evaluating moving edge blur may be used, provided that they produce equivalent measurement results.

6.2 Setup

6.2.1 The following measurement system is recommended.

6.2.1.1 Figure 1 shows an overview of the recommended measurement system, which includes a display under test (DUT), a video signal generator, a data acquisition board, a motion control board, a CCD camera, a rotating motor, a frame grabber board, and a control system.

6.2.1.2 Edge blur images are captured using a pivotting pursuit camera system. A schematic diagram of the measurement system is shown in Figure 2.

6.2.1.3 The description of each component is as follows:

6.2.1.3.1 DUT — The display to be measured.

6.2.1.3.2 A video signal generator — It generates test patterns for the display.

6.2.1.3.2.1 The video signal generator has a control unit for test pattern selection and start-stop of the measurement procedures.

6.2.1.3.2.2 The output interface of the video signal generator includes LVDS, DVI, or HDMI.

6.2.1.3.2.3 It should also include a trigger signal to start the data acquisition process.

6.2.1.3.3 A data acquisition board detects the digital trigger signal and converts it to the analogue trigger signal.

6.2.1.3.4 A motion control board controls the motor movements through position feedback and Proportional Integral Derivative (PID) control signals.

6.2.1.3.5 A CCD camera and a rotating motor operate in sync with the commands from the control system to track and acquire moving images displayed on DUT.

6.2.1.3.6 A frame grabber board captures images from the CCD camera through a camera link interface and transfers them to the control system for further processing.
6.2.1.3.7 A control system starts the measurement procedure, collects and processes all data.

6.2.1.3.7.1 A personal computer can be used.

6.2.1.3.7.2 The test pattern selection and test pattern moving are controlled by the control system through a RS232 port.

6.2.1.3.8 Real-Time System Integration (RTSI) — It is used to exchange time and control signals between the frame grabber, the data acquisition board, and the motion control board.

![Figure 1: The Recommended Measurement System](image)
6.3 Test Pattern

6.3.1 The following test pattern is recommended.

6.3.1.1 A total 42 test patterns are generated with seven start gray levels $L_i$ ($i = 1, 2, ..., 7$) and seven final gray levels $L_j$ ($j = 1, 2, ..., 7$) including black and white.

6.3.1.2 $L_i$ is the gray level of the right part and $L_j$ is the gray level of the left part when the pattern is moving from left to right (Figure 3).

6.3.1.3 The five intermediate gray levels are determined to provide perceptively equal lightness interval from black to white.

6.3.2 The following motion is recommended to generate test images.

6.3.2.1 Motion direction: Left to right (horizontal)

6.3.2.2 Speed: 10ppf (pixels per frame)

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**Figure 2**
A Schematic Diagram of the Recommended Measurement System

**Figure 3**
A Test Pattern with a Moving Edge between Two Gray Levels
6.4 Procedure

6.4.1 The following procedure is recommended to measure the moving edge blur.

6.4.1.1 A moving test pattern from the video signal generator is displayed on the DUT and the control system waits for the trigger signal.

6.4.1.2 As soon as the trigger signal is received by the control system, the motion control board is activated and the motor is rotated to track the moving test pattern on the DUT.

6.4.1.3 When the moving edge reaches the center of the DUT, the frame grabber board captures the moving edge and passes it to the control system for further processing. An exemplary moving edge is shown in Figure 3.

6.4.1.4 The luminance cross-section of the captured moving edge is called as Moving Edge Spatial Profile (MESP, in pixels).

6.4.1.5 Moving Edge Temporal Profile (METP, in milliseconds) is computed by dividing MESP by the speed of the moving edge \( V \) (in ppf) as follows:

\[
METP = \frac{MESP}{V} \tag{1}
\]

6.4.1.6 Moving Picture Response Time (MPRT, in milliseconds) is calculated by computing the time between the 10\% and 90\% levels of METP (Figure 4). For example, \( MPRT_{ij} \) associated with the test pattern of start gray level \( L_i \) and final gray level \( L_j \) is computed as follows:

\[
MPRT_{ij} = t_{ij,90\%} - t_{ij,10\%} \quad (i = 1, 2, \ldots, 7; \quad j = 1, 2, \ldots, 7, \text{ and } i \neq j) \tag{2}
\]

![Figure 4](image)

**Figure 4**

Moving Picture Response Time (MPRT\(_{ij}\)) with Level Intercepts \( t_{ij,10\%} \) and \( t_{ij,90\%} \)
6.5 Calculation

6.5.1 Sort $MPRT_{ij}$ ($i = 1, 2, \ldots, 7; j = 1, 2, \ldots, 7$, and $i \neq j$) values in ascending order.

6.5.2 Compute the average of the five smallest $MPRT_{ij}$ values

$$MPRT\_AVE\_MIN5 = \frac{(1^{st} \text{ smallest } MPRT_{ij} + 2^{nd} \text{ smallest } MPRT_{ij} + 3^{rd} \text{ smallest } MPRT_{ij} + 4^{th} \text{ smallest } MPRT_{ij} + 5^{th} \text{ smallest } MPRT_{ij})}{5}$$

(3)

6.5.3 Use the average of the five smallest $MPRT_{ij}$ values as the moving edge blur value.

6.5.4 For some applications, it may be useful to use the inverse of $MPRT\_AVE\_MIN5$

$$\text{Inverse of } MPRT\_AVE\_MIN5 = \frac{5}{(1^{st} \text{ smallest } MPRT_{ij} + 2^{nd} \text{ smallest } MPRT_{ij} + 3^{rd} \text{ smallest } MPRT_{ij} + 4^{th} \text{ smallest } MPRT_{ij} + 5^{th} \text{ smallest } MPRT_{ij})}$$

(4)

NOTE 1: Instead of computing the average of the five smallest $MPRT_{ij}$ values, the average of the smallest 10% of the total measurements can be used. For example, when the total number of measurements is 42, the four smallest $MPRT_{ij}$ values (about 10% of the total measurements) can be used

$$MPRT\_AVE\_MIN10\% = \frac{(1^{st} \text{ smallest } MPRT_{ij} + 2^{nd} \text{ smallest } MPRT_{ij} + 3^{rd} \text{ smallest } MPRT_{ij} + 4^{th} \text{ smallest } MPRT_{ij})}{4}$$

(5)

$$\text{Inverse of } MPRT\_AVE\_MIN10\% = \frac{4}{(1^{st} \text{ smallest } MPRT_{ij} + 2^{nd} \text{ smallest } MPRT_{ij} + 3^{rd} \text{ smallest } MPRT_{ij} + 4^{th} \text{ smallest } MPRT_{ij})}$$

(6)
6.6 Report

6.6.1 Report could have the following data.

- The speed of moving edge $V$
- The refresh rate $f$
- The average of the five smallest $MPRT_{ij}$ values (Optionally the inverse of the average of the five smallest $MPRT_{ij}$ values)
- The start gray levels $L_i$ ($i = 1, 2, \ldots, 7$) and final gray levels $L_j$ ($j = 1, 2, \ldots, 7$) of the test patterns
- The Moving Picture Response Time $MPRT_{ij}$ ($i = 1, 2, \ldots, 7; j = 1, 2, \ldots, 7$, and $i \neq j$) values
- Statistics of Moving Picture Response Time $MPRT$: the average, minimum, and maximum values

6.6.2 Tabular or graphical reports can be used. An example of a tabular report is shown in Table 1 and an example of a graphical report is shown in Figure 5.

Table 1 An Exemplary Tabular Report

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<th>Refresh rate (Hz)</th>
<th>MPRT_AVE_MIN5 (msec)</th>
<th>Inverse of MPRT_AVE_MIN5</th>
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<th>MPRT (msec)</th>
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NOTE 2: Moving Picture Temporal Profile $MPT_{ij}$ ($i = 1, 2, \ldots, 7; j = 1, 2, \ldots, 7$, and $i \neq j$) is useful to examine whether the start gray levels $L_i$ ($i = 1, 2, \ldots, 7$) and final gray levels $L_j$ ($j = 1, 2, \ldots, 7$) of the test patterns were chosen at perceptually equal lightness intervals from black to white. It is unnecessary to display the data in this manner since there are other ways to display the data for the purpose.

Figure 5
An Exemplary Graphical Report

6.7 Summary
6.7.1 The aforementioned method provides accurate estimates of the perceptual moving edge blur even for display technologies such as the dynamic backlight which has been employed to improve contrast and black level of LCD.

6.7.2 The measurement method is based on $MPRT$. Conventional setups, test patterns and procedures can be used, which are developed to measure $MPRT$ values.

6.7.3 A number of $MPRT_{ij}$ values are computed with various gray $i$-to-gray $j$ transitions. Then, these $MPRT_{ij}$ values are sorted in ascending order and the average of the five smallest $MPRT_{ij}$ values is used as the moving edge blur value.

6.7.4 For some applications, the inverse of the average of the five smallest $MPRT_{ij}$ values may be used as the moving edge blur value. In addition, the motion speed, the refresh rate, the start and final gray levels, and individual $MPRT_{ij}$ values can be reported.

6.7.5 In addition, the motion speed, the refresh rate, the start and final gray levels, and individual $MPRT_{ij}$ values can be reported.

7 Calibration
7.1 Measurement system shall be calibrated based on the manufacturers’ operation manuals.

7.2 When the measurement characteristics change by calibration, they shall be recorded.
APPENDIX 1

Subjective Tests

NOTICE: The material in this appendix is an official part of SEMI [xxx] and was approved by full letter ballot procedures on [insert date of approval by responsible regional standards committee].

A1-1 Test Images

A1-1.1 To evaluate the relationship between the moving edge blur test method proposed in this standard and the perceptual moving edge blur, two subjective tests were performed.
A1-1.2 In the first test, the six test images were selected, which have been widely used for perceptual moving edge blur measurement (Figure A1-1).
A1-1.3 On the other hand, the fifteen test images were used in the second test.
A1-1.4 The test images were moved at a speed of 8 and 12ppf (pixels per frame) and shown to the viewers for about 10 - 15 seconds.

Note 1: Figure A1-1a is resolution, Figure A1-1b is blue note, Figure A1-1c is sailing ship, Figure A1-1d is violin, Figure A1-1e is boat house, and Figure A1-1f is Japanese old street. Figure A1-1a is made in Samsung, Figures A1-1b to A1-1f are in Sibasoku video generator (TG45AX).

Figure A1-1
Six Test Images

A1-2 Display under Test

A1-2.1 The specifications of TV displays used in the subjective test are described in Table A1-1.
A1-2.2 In the first test (Test session 1), ten TV displays were used.
A1-2.3 In the second test (Test session 2), eight TV displays were used. Brightness and contrast parameters have been set up according to manufacturers’ recommendations.
A1-3 Test Conditions
A1-3.1 In the first test, since there were six test images, ten TV displays and two ppf values (8 and 12), there were 120 test conditions (6 x 10 x 2 = 120).
A1-3.2 In the second test, since there were fifteen test images with eight TV displays, there were 120 test conditions (15 x 8 = 120).

A1-4 Test Systems
A1-4.1 The test images generated by a video signal generator were distributed to the ten or eight TV displays using the HDMI splitter (Figure A1-2).
A1-4.2 The viewer was seated in front of the TV displays (Figure A1-2) and only one viewer watched a TV display at a time.
A1-4.3 After finishing watching a test signal on a TV display, the viewer moved to the next TV display.
A1-4.4 The TV displays were placed on an oval shape (Figure A1-3). Figure A1-4 shows the test room.

<table>
<thead>
<tr>
<th>TV Number</th>
<th>Test session 1</th>
<th>Size (inch)</th>
<th>Resolution</th>
<th>Frame Rate (Hz)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>TV #1</td>
<td>TV #1</td>
<td>47</td>
<td>1920 x 1080</td>
<td>120</td>
<td>LED Scanning</td>
</tr>
<tr>
<td>TV #2</td>
<td>TV #2</td>
<td>47</td>
<td>1920 x 1080</td>
<td>120</td>
<td>CCFL Scanning</td>
</tr>
<tr>
<td>TV #3</td>
<td>TV #3</td>
<td>47</td>
<td>1920 x 1080</td>
<td>120</td>
<td>CCFL Scanning</td>
</tr>
<tr>
<td>TV #4</td>
<td>TV #4</td>
<td>46</td>
<td>1920 x 1080</td>
<td>240</td>
<td>LED</td>
</tr>
<tr>
<td>TV #5</td>
<td>TV #5</td>
<td>46</td>
<td>1920 x 1080</td>
<td>60</td>
<td>CCFL</td>
</tr>
<tr>
<td>TV #6</td>
<td>TV #6</td>
<td>46</td>
<td>1920 x 1080</td>
<td>60</td>
<td>CCFL</td>
</tr>
<tr>
<td>TV #7</td>
<td>TV #7</td>
<td>46</td>
<td>1920 x 1080</td>
<td>60</td>
<td>CCFL</td>
</tr>
<tr>
<td>TV #8</td>
<td>TV #8</td>
<td>52</td>
<td>1920 x 1080</td>
<td>60</td>
<td>CCFL</td>
</tr>
<tr>
<td>TV #9</td>
<td>-</td>
<td>46</td>
<td>1920 x 1080</td>
<td>60</td>
<td>CCFL</td>
</tr>
<tr>
<td>TV #10</td>
<td>-</td>
<td>46</td>
<td>1920 x 1080</td>
<td>60</td>
<td>LED</td>
</tr>
</tbody>
</table>

Figure A1-2
The Subjective Test Systems
A1-5 Viewing Conditions

A1-5.1 The viewing conditions were chosen in accordance with the ITU-T Rec. P. 910 are described in Table A1-2.

Table A1-2 Viewing Conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viewing distance</td>
<td>2.5H (H indicates the height of TV screen)</td>
</tr>
<tr>
<td>Background room illumination</td>
<td>≤ 20lux</td>
</tr>
</tbody>
</table>

A1-6 Viewers

A1-6.1 All viewers were screened for normal visual acuity with or without corrective glasses (visual acuity of 0.9 or better on both eyes) and normal color vision.

A1-6.2 All viewers were non-experts in the area of image quality assessment.

A1-6.3 The total number of viewers was 85 (35 for test session 1 and 50 for test session 2).
A1-7 Subjective Testing Method

A1-7.1 The Absolute Category Scale (ACR) method of ITU-T Rec. P.910 was used as the subjective testing method. In the ACR method (Figure A1-5), each test condition is presented once and at the end of each test presentation, the viewers provide a quality rating using the following rating scale:

- 5 Excellent
- 4 Good
- 3 Fair
- 2 Poor
- 1 Bad

Test Image #1  Test Image #2  Test Image #3
10–15 sec vote vote vote
10–15 sec

Figure A1-5
ACR Basic Test Cell

A1-8 Results

A1-8.1 In the first test (Test session 1), six test images widely used for perceptual moving edge blur measurement were used. Table A1-3 shows the correlation coefficients between subjective scores and MPRT_AVE, MPRT_AVE_MIN5, and inverse of MPRT_AVE_MIN5 values for the first test.

A1-8.2 In Table A1-3, MPRT_AVE represents the average of the 42 measurement values and MPRT_AVE_MIN5 represents the average of the five smallest MPRT_AVE values (see 6.5 Calculation).

A1-8.3 As can be seen in Table A1-3, the average correlation coefficient of the proposed MPRT_AVE_MIN5 is 0.91 while the average correlation coefficient of MPRT_AVE is 0.84.

A1-8.4 In all the test images, MPRT_AVE_MIN5 showed noticeably better performance than MPRT_AVE.

A1-8.5 The inverse of MPRT_AVE_MIN5 showed even better performance. The reason is that the perceptual moving edge blur was saturated when MPRT_AVE_MIN5 was larger than about 10 msec as explained in the A1-2.4. The inverse of MPRT_AVE_MIN5 automatically takes care of this saturation problem, thus providing better correlation coefficients in the first test, which had four TV displays with MPRT_AVE_MIN5 > 10 msec.

Table A1-3 Correlation Coefficients of MPRT_AVE, MPRT_AVE_MIN5, and Inverse of MPRT_AVE_MIN5 (Test Session 1)

<table>
<thead>
<tr>
<th>Test image</th>
<th>Motion Speed</th>
<th>MPRT_AVE</th>
<th>MPRT_AVE_MIN5</th>
<th>Inverse of MPRT_AVE_MIN5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violin</td>
<td>8 ppf</td>
<td>-0.85</td>
<td>-0.90</td>
<td>0.93</td>
</tr>
<tr>
<td>APDC pattern</td>
<td></td>
<td>-0.77</td>
<td>-0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>Blue note</td>
<td></td>
<td>-0.80</td>
<td>-0.90</td>
<td>0.89</td>
</tr>
<tr>
<td>Boat house</td>
<td></td>
<td>-0.74</td>
<td>-0.83</td>
<td>0.88</td>
</tr>
<tr>
<td>Sailing ship</td>
<td></td>
<td>-0.85</td>
<td>-0.90</td>
<td>0.89</td>
</tr>
<tr>
<td>Japanese old street</td>
<td></td>
<td>-0.87</td>
<td>-0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>Violin</td>
<td>12 ppf</td>
<td>-0.87</td>
<td>-0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>APDC pattern</td>
<td></td>
<td>-0.87</td>
<td>-0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Blue note</td>
<td></td>
<td>-0.81</td>
<td>-0.90</td>
<td>0.92</td>
</tr>
<tr>
<td>Boat house</td>
<td></td>
<td>-0.83</td>
<td>-0.91</td>
<td>0.91</td>
</tr>
<tr>
<td>Sailing ship</td>
<td></td>
<td>-0.84</td>
<td>-0.92</td>
<td>0.91</td>
</tr>
<tr>
<td>Japanese old street</td>
<td></td>
<td>-0.80</td>
<td>-0.87</td>
<td>0.90</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>-0.84</td>
<td>-0.91</td>
<td>0.92</td>
</tr>
</tbody>
</table>
A1-8.6 Table A1-4 shows the correlation coefficients between subjective scores and \( MPRT\_AVE \), \( MPRT\_AVE\_MIN5 \), and inverse of \( MPRT\_AVE\_MIN5 \) values for the second test (Test session 2).

A1-8.7 As can be seen in Table A1-4, the average correlation coefficient of the proposed \( MPRT\_AVE\_MIN5 \) is 0.96 while the average correlation coefficient of \( MPRT\_AVE \) is 0.86.

A1-8.8 In almost all test images, \( MPRT\_AVE\_MIN5 \) showed considerably better performance.

A1-8.9 Only in “CZP” test image, \( MPRT\_AVE\_MIN5 \) showed slightly lower correlation (0.72 vs. 0.69).

A1-8.10 The inverse of \( MPRT\_AVE\_MIN5 \) also showed improved performance and provided better correlation coefficients than \( MPRT\_AVE \) in all the test images.

Table A1-4 Correlation Coefficients of \( MPRT\_AVE \), \( MPRT\_AVE\_MIN5 \), and Inverse of \( MPRT\_AVE\_MIN5 \) (Test Session 2)

<table>
<thead>
<tr>
<th>Test image</th>
<th>Motion speed</th>
<th>( MPRT_AVG )</th>
<th>( MPRT_AVE_MIN5 )</th>
<th>Inverse of ( MPRT_AVE_MIN5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Violin</td>
<td>8 ppf</td>
<td>-0.89</td>
<td>-0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>APDC pattern</td>
<td></td>
<td>-0.82</td>
<td>-0.91</td>
<td>0.88</td>
</tr>
<tr>
<td>Blue note</td>
<td></td>
<td>-0.83</td>
<td>-0.96</td>
<td>0.92</td>
</tr>
<tr>
<td>Boat house</td>
<td></td>
<td>-0.83</td>
<td>-0.96</td>
<td>0.90</td>
</tr>
<tr>
<td>CZP</td>
<td></td>
<td>-0.72</td>
<td>-0.69</td>
<td>0.74</td>
</tr>
<tr>
<td>Temple</td>
<td></td>
<td>-0.90</td>
<td>-0.96</td>
<td>0.91</td>
</tr>
<tr>
<td>Buildings</td>
<td></td>
<td>-0.86</td>
<td>-0.97</td>
<td>0.95</td>
</tr>
<tr>
<td>TG91E6</td>
<td></td>
<td>-0.85</td>
<td>-0.96</td>
<td>0.91</td>
</tr>
<tr>
<td>Sailing ship</td>
<td></td>
<td>-0.85</td>
<td>-0.97</td>
<td>0.93</td>
</tr>
<tr>
<td>H Sweep (Y/GBR)</td>
<td></td>
<td>-0.64</td>
<td>-0.64</td>
<td>0.69</td>
</tr>
<tr>
<td>Japanese old street</td>
<td></td>
<td>-0.83</td>
<td>-0.95</td>
<td>0.93</td>
</tr>
<tr>
<td>Line</td>
<td>12 ppf</td>
<td>-0.87</td>
<td>-0.94</td>
<td>0.93</td>
</tr>
<tr>
<td>President</td>
<td></td>
<td>-0.84</td>
<td>-0.96</td>
<td>0.91</td>
</tr>
<tr>
<td>Plugue</td>
<td></td>
<td>-0.49</td>
<td>-0.64</td>
<td>0.54</td>
</tr>
<tr>
<td>Bridge</td>
<td></td>
<td>-0.84</td>
<td>-0.94</td>
<td>0.89</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>-0.86</td>
<td>-0.96</td>
<td>0.92</td>
</tr>
</tbody>
</table>

A1-8.11 Figures A1-6 to A1-14 show the scatter plots between subjective scores and \( MPRT\_AVE \), \( MPRT\_AVE\_MIN5 \), and inverse of \( MPRT\_AVE\_MIN5 \) values for some of the test images of the first test (Test session 1).

A1-8.12 It can be seen that the proposed \( MPRT\_AVE\_MIN5 \) provided better estimation of the perceptual moving edge quality than \( MPRT\_AVE \).

A1-8.13 In particular, TV #5 was an outlier in \( MPRT\_AVE \) which failed to correctly estimate the perceptual edge quality of TV #5 while \( MPRT\_AVE\_MIN5 \) correctly estimated the perceptual moving edge quality.

A1-8.14 It was observed that the perceptual moving edge blur (perceived moving edge quality) was saturated if \( MPRT\_AVE\_MIN5 \) was roughly larger than 10 msec. In other words, the perceptual moving edge blur did not change when \( MPRT\_AVE\_MIN5 \) was larger than about 10 msec. Thus, one may use an upper bound for \( MPRT\_AVE\_MIN5 \). Alternatively, it is possible to use the inverse of \( MPRT\_AVE\_MIN5 \). By taking the inverse, the saturation problem is automatically solved without introducing the upper bound. Therefore it can be seen that the inverse of \( MPRT\_AVE\_MIN5 \) also showed good performance and successfully solved the saturation problem.
Note 2: Figure A1-6a shows the scatter plot between subjective scores and $MPRT_{AVE}$. Figure A1-6b shows the scatter plot between subjective scores and $MPRT_{AVE\_MIN5}$. Figure A1-6c shows the scatter plot between subjective scores and inverse of $MPRT_{AVE\_MIN5}$.

**Figure A1-6**
Average of the Twelve Test Images (Test Session 1)

Note 3: Figure A1-7a shows the scatter plot between subjective scores and $MPRT_{AVE}$. Figure A1-7b shows the scatter plot between subjective scores and $MPRT_{AVE\_MIN5}$. Figure A1-7c shows the scatter plot between subjective scores and inverse of $MPRT_{AVE\_MIN5}$.

**Figure A1-7**
Violin Test Image at 8ppf (Test Session 1)

Note 4: Figure A1-8a shows the scatter plot between subjective scores and $MPRT_{AVE}$. Figure A1-8b shows the scatter plot between subjective scores and $MPRT_{AVE\_MIN5}$. Figure A1-8c shows the scatter plot between subjective scores and inverse of $MPRT_{AVE\_MIN5}$.

**Figure A1-8**
APDC Pattern Test Image at 8ppf (Test Session 1)
Note 5: Figure A1-9a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-9b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-9c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-9
Blue Note Test Image at 8ppf (Test Session 1)

Note 6: Figure A1-10a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-10b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-10c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-10
Boat House Test Image at 8ppf (Test Session 1)

Note 7: Figure A1-11a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-11b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-11c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-11
Violin Test Image at 12ppf (Test Session 1)
Note 8: Figure A1-12a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-12b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-12c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-12
APDC Pattern Test Image at 12ppf (Test Session 1)

Note 9: Figure A1-13a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-13b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-13c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-13
Blue Note Test Image at 12ppf (Test Session 1)

Note 10: Figure A1-14a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-14b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-14c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-14
Boat House Test Image at 12ppf (Test Session 1)
A1-8.15 Figures A1-15 to A1-19 show the scatter plots between subjective scores and \( MPRT\_AVE \), \( MPRT\_AVE\_MIN5 \), and inverse of \( MPRT\_AVE\_MIN5 \) values for some of the test images of the second test (Test session 2). The results of the second test are similar to those of the first test. The proposed \( MPRT\_AVE\_MIN5 \) provided better estimation than \( MPRT\_AVE \). TV#5 was also an outlier in \( MPRT\_AVE \) while \( MPRT\_AVE\_MIN5 \) correctly estimated the perceptual moving edge quality. The inverse of \( MPRT\_AVE\_MIN5 \) showed better performance by automatically solving the saturation problem.

Note 11: Figure A1-15a shows the scatter plot between subjective scores and \( MPRT\_AVE \). Figure A1-15b shows the scatter plot between subjective scores and \( MPRT\_AVE\_MIN5 \). Figure A1-15c shows the scatter plot between subjective scores and inverse of \( MPRT\_AVE\_MIN5 \).

Figure A1-15
Average of the Fifteen Test Images (Test Session 2)

Note 12: Figure A1-16a shows the scatter plot between subjective scores and \( MPRT\_AVE \). Figure A1-16b shows the scatter plot between subjective scores and \( MPRT\_AVE\_MIN5 \). Figure A1-16c shows the scatter plot between subjective scores and inverse of \( MPRT\_AVE\_MIN5 \).

Figure A1-16
Violin Test Image (Test Session 2)

Note 13: Figure A1-17a shows the scatter plot between subjective scores and \( MPRT\_AVE \). Figure A1-17b shows the scatter plot between subjective scores and \( MPRT\_AVE\_MIN5 \). Figure A1-17c shows the scatter plot between subjective scores and inverse of \( MPRT\_AVE\_MIN5 \).

Figure A1-17
APDC Pattern Test Image (Test Session 2)
Note 14: Figure A1-18a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-18b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-18c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-18
Blue Note Test Image (Test Session 2)

Note 15: Figure A1-19a shows the scatter plot between subjective scores and MPRT_AVE. Figure A1-19b shows the scatter plot between subjective scores and MPRT_AVE_MIN5. Figure A1-19c shows the scatter plot between subjective scores and inverse of MPRT_AVE_MIN5.

Figure A1-19
Boat House Test Image (Test Session 2)

A1-9 Conclusions

A1-9.1 The proposed MPRT_AVE_MIN5 provided an accurate estimate of the perceptual moving edge blur and can be a valuable measurement method for the LCD display industry.

A1-9.2 The subjective test showed that the proposed MPRT_AVE_MIN5 provided a better estimate of the perceptual moving edge blur than the conventional MPRT (MPRT_AVE) and solved some outlier problem which affected MPRT_AVE.

A1-9.3 Additionally, the subjective test also showed that the inverse of MPRT_AVE_MIN5 provided a better estimate of the perceptual moving edge blur than MPRT_AVE and did not suffer from the saturation problem which both MPRT_AVE and MPRT_AVE_MIN5 had.

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