Quantitative evaluation of image sticking on displays with different gradual luminous variation

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Abstract — To comparatively evaluate various driving methods of an electronic display in respect to image sticking, a consistent and reliable quantification method is required. For proper evaluation, the entire area of a display is often monitored by using a chessboard pattern, and long-range gradual luminous variation in the background is eliminated. Estimation in terms of a single number is also preferred for simple comparison of image sticking. However, the prior method that uses the initial luminance for normalization and estimates the range-to-maximum ratio is not well-suited for the driving methods that relieve image sticking by restoring luminance uniformity. We have developed a method of extracting reference values for normalization and introduced the relative standard deviation (RSD) into our estimation. The resulting method is insensitive to the temporal change in the long-range gradual luminous variation and sufficiently indicative to allow driving methods to be compared effectively. The reference extraction method and the indicative capability of the RSD have been assessed by experiments using a real active-matrix organic light-emitting-diode (AMOLED) display cell.

Keywords — Image sticking, gradual luminance variation, long-range non-uniformity (LRNU), luminance, AMOLED.

DOI # 10.1889/JSID18.3.228

1 Introduction

For years, the electronic-display market has been dominated by liquid-crystal displays (LCDs) and plasma-display panels (PDPs). However, recently, active-matrix organic light-emitting-diode (AMOLED) displays have obtained a share of the market. Although these display technologies are based on different mechanisms, they all suffer from image sticking to some extent: if a pattern is displayed for a sufficiently long time, its shape remains noticeable even when other images are displayed.1–4 Image sticking makes the lifetime of a display device less than that of its constituent pixels and is therefore a critical issue in all three of the display technologies mentioned above.

Various studies have examined the cause material and mechanism of image sticking, proposed improvements in structure and fabrication processes to retard the image sticking, and developed compensative driving methods to relieve image sticking.5–7 Quantitative methods of evaluating image sticking have also been introduced to control product quality or assess the effectiveness of various remedies.8–12 Experiments designed to assess the effect of cause material and structure on the image sticking may be satisfactorily performed by observing a limited region of a display area. However, when the product quality of a display device or the image quality depending on a specific driving method is of concern, a wider region of the display area should be considered. To this end, the quantitative evaluation methods mentioned above utilize a chessboard pattern,8–12 and contrast sensitivity tests for it have also been conducted.13

Among several possible quantitative metrics, the image sticking value (ISV)8 seems to be the most useful for comparatively evaluating compensative driving methods designed to relieve image sticking. The computation of an ISV involves a normalization process, which eliminates long-range variation in luminance. The significance of image sticking is then estimated as the range-to-maximum ratio (hereafter called RMR) of normalized luminance values. The normalization process uses a set of initial luminance values as a set of reference values, but this approach becomes inappropriate when a long-range gradual variation in luminance is partially removed by a subsequent compensative driving method. In addition, the RMR does not accurately reflect the variation in the deviation from the reference value.

In this paper, we have analyzed our initially introduced evaluation method,14 where we have developed a new set of reference values which can be used to remove the long-range non-uniformity (LRNU) without regard to the previous state of a display device. These new reference values are extracted from a set of measured luminance values. We have also introduced the relative standard deviation (RSD) as a measure of image sticking, instead of the RMR. This allows us to compare various driving methods more consistently. The RSD reflects variation in the deviation from the reference values more effectively. In the subsequent sections, we review prior evaluation methods and
present the details of our method of extracting reference values, some analysis on the RSD, and experimental results.

2 Prior methods of evaluating image sticking

The evaluation procedure using a chessboard pattern is illustrated in Fig. 1. A display device under test is aged by displaying an image of a chessboard pattern for a determined time period. After aging, a desired image of a uniform gray level (e.g., white, black, or half-gray) is displayed, and the image sticking on this display is evaluated. The image-sticking pattern may be a positive or negative version of the chessboard pattern.\(^8,9,12\) In the case of AMOLED displays, that is a negative version of the chessboard, as illustrated in Fig. 1.

The desired image is sometimes called background,\(^12,13\) and long-range gradual variation in the luminance of that background under display is eliminated during an image-sticking test.\(^8,10,13\) This is because such long-range spatial non-uniformity of luminance does not affect the recognition of image sticking. The ISV proposed by Lee et al.\(^5\) and other analysis techniques proposed by Park et al.\(^10\) remove the LRNU by normalizing measured luminance: the measured luminance value is divided by a reference value,\(^8\) or a reference value may be subtracted from it.\(^10\) The luminance of each block constituting the chessboard pattern is measured with the desired image displayed before aging, and this initial luminance becomes the reference for normalization.

The significance of image sticking can be estimated as the range-to-maximum ratio of the normalized luminance (NL) of each block, which is expressed as

\[
ISV = \frac{\text{max}_{NL} - \text{min}_{NL}}{\text{max}_{NL}}, \tag{1}
\]

where \(\text{max}_{NL}\) is the maximum of the NL values and \(\text{min}_{NL}\) is their minimum.\(^8\) Although the significance can also be analyzed through cartography,\(^12\) estimation in a single number is preferred for simple comparison of various driving methods. The ISV is larger for more severe image sticking.

Because calculation of the ISV utilizes a set of initial luminance values as a set of reference values, it is not well-suited for assessing compensative driving techniques that relieve image sticking by restoring uniform luminance. These techniques are liable to cause changes in the long-range luminous variation of the background, compromising the validity of the reference luminance values. Moreover, compensative driving techniques can adjust their own parameters over time as the significance of image sticking increases.

Another problem with the ISV is that Eq. (1) uses only the maximum and minimum deviations from the reference values, and the distribution of the deviations is not taken into account. This distribution might result from partially compensated image sticking or a partial failure in compensation, which is not indicated by the ISV.

To improve these limitations of the ISV in comparing compensative driving methods, we have developed a new quantitative evaluation method, which removes the long-range gradual luminous variation of the background in adaptation to its change and makes a consistent and indicative estimation on the significance of the image sticking.

3 Proposed quantitative evaluation method

3.1 Normalization using extracted reference values

During the aging of an AMOLED display cell with a chessboard pattern, the organic light-emitting diodes (OLEDs) in the white blocks of the chessboard pattern are stressed to degrade, while those in the black blocks are released. As a result, the luminance distribution of the black blocks is unlikely to be affected by the aging process. In our method of extracting reference values, each black block is considered to be a reference block and each white block is a test block. This nomenclature is applicable to all emissive displays including plasma and field-emission displays, as well as AMOLEDs. However, non-emissive displays such as LCDs present a different situation. In a normally white LCD, the liquid-crystal materials in the black blocks experience a stronger electrical field than those in the white blocks. If we are to apply our technique to normally white LCDs, we may use the white blocks as reference blocks.

Our method of extracting reference values is based on the assumption that the reference blocks of the chessboard pattern reflect the LRNU pattern of a display image. The measured luminance of a reference block becomes the reference value for that block; but the reference value for a test block is defined as the average luminance of the reference blocks that are adjacent to the test block. The following expressions apply to an AMOLED display cell that has been aged with the chessboard pattern of Fig. 1. To deal with the edges and corners of the chessboard pattern, we define the availability \(A_{m,n}\) of the block in the \(m\)-th row and \(n\)-th column to the left top corner, using a unit step function \(u(x)\), which is expressed as follows:

\[
A_{m,n} = u(M-m)u(m-1)u(N-n)u(n-1), \tag{2}
\]

where
and $M$ and $N$, respectively, are the total number of rows and columns in the chessboard pattern. Then, the luminance $L_{m,n}$ of the block in the $m$-th row and $n$-th column can be determined as follows:

$$L_{m,n} = \begin{cases} \text{measured luminance if } A_{m,n} = 0 \\ 0 \text{ otherwise} \end{cases}.$$  \hfill (4)

The reference value of the block in the $m$-th row and $n$-th column, $R_{m,n}$, can then be expressed in terms of the values of $L_{m,n}$ and $A_{m,n}$, and the integers $i$ and $j$, where $1 \leq i \leq \lceil M/2 \rceil$ and $1 \leq j \leq \lceil N/2 \rceil$.

For the reference (black) blocks,

$$R_{2i-1,2j-1} = L_{2i-1,2j-1}$$  \hfill (5a)

and

$$R_{2i,2j} = L_{2i,2j}.$$  \hfill (5b)

For the test (white) blocks,

$$R_{2i-1,2j} = \frac{L_{2i-1,2j} + L_{2i-1,2j-1} + L_{2i,2j} + L_{2i-1,2j+1}}{A_{2i-1,2j} + A_{2i-1,2j-1} + A_{2i,2j} + A_{2i-1,2j+1}},$$  \hfill (6a)

and

$$R_{2i,2j} = \frac{L_{2i-1,2j} + L_{2i-1,2j-1} + L_{2i+1,2j-1} + L_{2i,2j}}{A_{2i-1,2j-1} + A_{2i,2j-1} + A_{2i+1,2j-1} + A_{2i,2j}}.$$  \hfill (6b)

The extracted reference values are used for normalization, which eliminates the LRNU in the measured luminance values. The normalized luminance of the block in the $m$-th row and $n$-th column can be computed as follows:

$$NL_{m,n} = L_{m,n}/R_{m,n},$$  \hfill (7)

where $1 \leq m \leq M$ and $1 \leq n \leq N$.

3.2 Estimation with the relative standard deviation

To estimate the significance of image sticking, we use RSD instead of RMR. The RSD is frequently employed in dispersion comparison.\textsuperscript{15,16} We define the extracted image-sticking value (EISV) as a measure of image sticking:

$$EISV = \frac{\sigma_{NL}}{\mu_{NL}},$$  \hfill (8)

where $\mu_{NL}$ is the mean and $\sigma_{NL}$ is the standard deviation of the $NL$, which is obtained using the extracted reference values.

The effectiveness of the RSD can be explained by reference to Figs. 2 and 3, the simulated images of the displays showing the image sticking, and analyzed in terms of two parameters. Although image sticking is assessed using an input image with a uniform gray level, the image sticking in Figs. 2 and 3 is illustrated by different gray levels. This is because those figures will be displayed on a screen or printed on a sheet of paper, either of which may exhibit uniform expression of a gray level. In the subsequent discussion, the gray level is assumed to be proportional to the luminance value in question.

Figure 2 shows an example in which the RSD is better suited than the RMR for the evaluation of image sticking. The negative version of the chessboard pattern shown in Fig. 1 is easier to recognize in the left-hand image than in the other two images. However, all three images have the same RMR value of 0.1. In the left-hand image, 32 blocks have a gray level of 200 and 32 blocks have a gray level of 180. In the central and right-hand images, there are 32 blocks with a gray level of 200, 16 with a gray level of 190, and 16 with a gray level of 180. All the blocks in all three images have the same reference gray level of 200. Clearly, the central and the right-hand images will have the same $\sigma_{NL}$ and $\mu_{NL}$. The left-hand image has a larger $\sigma_{NL}$, a smaller $\mu_{NL}$, and thus a larger RSD, which is $\sigma_{NL}/\mu_{NL}$. The RSD effectively identifies the severer image sticking in the left-hand image or, in another interpretation, identifies the partially compensated image sticking in the central and right-hand images. The severer image sticking in the left-hand image was confirmed by two-alternative forced-choice (2AFC) tasks on each pair. During 2AFC
tasks, observers were requested only to choose a more significant image sticking from the pair shown to them.

Because the reference blocks contain no information about the signification of image sticking, the image sticking may reasonably be related to a statistical measure of the normalized luminance of the test blocks. Thus, we can measure the image sticking in Fig. 2 by estimating the mean \( \mu'_T \) of the values of 1 – \( NL_T \), where \( NL_T \) is the normalized luminance of each test block:

\[
\mu'_T = \frac{\sum (1 - NL_T)}{N_T},
\]

where \( N_T \) is the total number of the test blocks. The left-hand image has a larger value of \( \mu'_T \) than the other two, corresponding to severer image sticking.

If the value of \( \mu'_T \) is the same for a number of images, then the standard deviation \( \sigma'_T \) of 1 – \( NL_T \) becomes important, as shown in Fig. 3. The negative version of the chessboard pattern that appears in Fig. 1 is more obvious in the central and right-hand images, even though all three images have the same \( \mu'_T \) value of 0.04. In the left-hand image, 32 blocks have a gray level of 200 and 32 have a level of 192. In the central and right-hand images, 32 blocks have a gray level of 200, 16 blocks have a gray level of 198, and 16 blocks have a gray level of 186. All the blocks in all three images have the same reference gray level of 200. The central and right-hand images have the same value of \( \sigma'_T \), 0.030; however, the \( \sigma'_T \) is zero in the left-hand image. This suggests that \( \sigma'_T \) is larger for more severe image sticking. When compensative driving methods are compared, we can see \( \sigma'_T \) as a way of identifying the partial failure in image-sticking compensation that is apparent in the central and right-hand images. The severer image sticking in the central and right-hand images was also confirmed by 2AFC tasks.

It can be shown that both \( \mu'_T \) and \( \sigma'_T \) are related to the standard deviation of the normalized luminance. From Eq. (9),

\[
\sigma'^2_T = \frac{\sum (1-\mu')^2}{N_T} - \mu'^2_T = \frac{\sum NL_T^2}{N_T} - (1-\mu')^2,
\]

and

\[
\mu_{NL} = \frac{N_R + \sum NL_T}{N_R + N_T} = 1 - \frac{N_T}{N_R + N_T} \mu'_T,
\]

where \( N_R \) is the total number of reference blocks. By combining these two equations, we obtain

\[
\sigma^2_{NL} = \frac{N_R + \sum NL_T^2}{N_R + N_T} - \mu^2_{NL} = - \frac{N_T}{N_R + N_T} \left( \frac{N_R}{N_R + N_T} \mu'^2_T + \sigma'^2_T \right).
\]

The standard deviation \( \sigma_{NL} \) is a monotonically increasing function of \( \mu'^2_T \) and \( \sigma'^2_T \), either of which may be dominant if it is sufficiently large. This corresponds with our observation of the image-sticking phenomenon, suggesting that \( \sigma_{NL} \) may be a reasonable measure of image sticking.

To obtain the relative standard deviation, \( \sigma_{NL} \) is divided by \( \mu_{NL} \). The value of \( \mu_{NL} \) is always positive, and increases as \( \mu'_T \) becomes more negative. Therefore, positive and negative \( \mu'_T \) values of the same magnitude produce different values of the BSD. However, the effect of this scaling was not significant in our experiment with an AMOLED display cell.

It should be mentioned that normalization was not required for the images in Figs. 2 and 3 because all the reference blocks have the same gray level. There is no LRNU, and normalization would simply scale the gray level of each block by a constant factor.

4 Experimental results

The effectiveness of the proposed quantitative evaluation method was assessed by driving an AMOLED display cell with three different driving methods. Images A, B, and C in Fig. 4 were obtained by applying different driving methods to the same AMOLED display cell, which had been aged for 4 hours with the 8 × 8 chessboard pattern shown in Fig. 1. This AMOLED display has a green color and a diagonal size of 0.73 in. Although the cell is small, characteristics of image sticking and long-range non-uniformity are both apparent.

Image A was produced using a driving method with no compensation for image sticking, whereas image B was obtained using systematic compensation circuits which measure OLED voltages and refer to a look-up table. In addition to image sticking, image A exhibits long-range luminous variation: we can see that the lower right-hand area of image A is darker than the rest of the image. Image B shows that systematic compensation almost eliminates this long-range non-uniformity (LRNU), and also reduces image sticking. The LRNU is almost maintained in the image C, which was obtained by manually adjusting the display data for the white (test) blocks of the chessboard pattern with an aim to make the image sticking hardly noticeable.
The difference in LRNU between images A, B, and C are already shown by the measured luminance values in Fig. 5. The luminance of each block was measured with a spectro-radiometer while that block alone was turned on. Because the AMOLED display cell is small in size, the load effect is negligible in this measurement. However, our luminance measurement system cannot reliably obtain absolute luminance values for the small blocks on this display cell, and thus values are given in arbitrary units (a.u.).

The initial luminance values of the AMOLED display cell are also shown in Fig. 5. At the beginning of the aging process, there should be no image sticking, and all the three driving methods produce the same results. As image sticking begins to appear and becomes more severe, a compensative driving method adjusts its parameters and relieves the image sticking, and may cause changes in the LRNU. This involves a tradeoff between power consumption and image quality. Therefore, a set of initial luminance values may not be an appropriate representation of the LRNU when evaluating driving methods that aim to reduce image sticking, as we mentioned in Secs. 1 and 2.

Normalized luminance values estimated from the data in Fig. 5 are plotted in Fig. 6. The reduction in image stick-
ing that is apparent in image B is more clearly identified if normalization is performed using the extracted reference values rather than the initial values.

After producing the images in Fig. 4, the AMOLED display cell was further aged. Images A, B, and C in Fig. 7 show the results of a total of 6, 8, and 10 hours of aging time. Measured and normalized luminance values are also shown in Figs. 8 and 9, respectively. As confirmed by the 2AFC tasks on each pair in question, the significance of image sticking increases with aging time in all cases; systematic compensation always improves the situation; however, manual compensation always does better. These features of image sticking and compensation can be identified in Fig. 8 and are well maintained after normalization using the extracted reference values, as shown in Fig. 9.

The various evaluation methods that were discussed in Secs. 2 and 3 have been used to evaluate the significance of the image sticking shown in images A, B, and C. The results are given in Table 1. Both RMR and RSD are presented as percentages (i.e., %RMR and %RSD) to make them easier to read. The relative standard deviations given as percentages are also known as coefficients of variation (CV). The values of $\mu_T'$ and $\sigma_{NL}$ are multiplied by 100 for ease of comparison.

The RMR of the normalized luminance values that were estimated by using initial luminance values ($NL_I$) has similar values for images A and B. This even suggests that image sticking is more significant in image B than in image A after the AMOLED display cell has been aged for 4 and 6 hours. However, when the RMR of the normalized luminance values was estimated using the extracted reference value ($NL_E$), the results are similar for images B and C. Calculating the RMR in this way also suggests that the difference between images B and C decreases with aging time.

We conclude that the RMR is not an effective measure of image sticking.

Although the values of $\mu_T'$ determined from the normalized luminance value $NL_E$ correctly discriminate between the different levels of image sticking in images A, B, and C, they fail to identify the development of image sticking in image C as the aging time increases. However, the values of $\sigma_{NL}$ and RSD obtained from $NL_E$ succeed in differentiating between the images A, B, and C, and also in tracking the increase in image sticking in all the images. We conclude that the values of $\sigma_{NL}$ and RSD obtained from $NL_E$ can effectively quantify image sticking, and that they have a role in the evaluation of compensative driving methods designed to relieve image sticking.

To compare the effectiveness of $\sigma_{NL}$ and the RSD of $NL_E$, we may scale the reference values obtained from Eqs. (5) and (6), so that their mean equals the mean of the measured luminance values. The scaled reference value for the block in the $m$-th row and $n$-th column, $S_{mn}$, is expressed as

$$S_{mn} = (\mu_L/\mu_R) R_{mn}, \quad (13)$$

where $\mu_L$ is the mean of $L_{mn}$ and $\mu_R$ is the mean of $R_{mn}$. Then the normalized luminance can be redefined as follows:

$$NL_{mn} = L_{mn}/S_{mn}. \quad (14)$$

For the 12 examples provided by images A, B, and C, each aged for four different lengths of time, the $\mu_{NL}$ of the redefined normalized luminance is always unity with an error less than 0.0004. When $\mu_{NL}$ is unity, the RSD reduces to $\sigma_{NL}$. However, scaling the reference values by a constant does not change the value of the RSD. Therefore, in effect, we may regard dividing $\sigma_{NL}$ by $\mu_{NL}$ as scaling the reference

<table>
<thead>
<tr>
<th>Evaluation method</th>
<th>Image</th>
<th>4 hours</th>
<th>6 hours</th>
<th>8 hours</th>
<th>10 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>%RMR of $L_I^a$ (ISV)</td>
<td>Image A</td>
<td>23.4</td>
<td>26.4</td>
<td>30.9</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>26.6</td>
<td>28.9</td>
<td>30.6</td>
<td>32.7</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>10.8</td>
<td>12.7</td>
<td>16.2</td>
<td>15.9</td>
</tr>
<tr>
<td>%RMR of $L_E^b$</td>
<td>Image A</td>
<td>23.5</td>
<td>26.9</td>
<td>31.0</td>
<td>33.7</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>14.2</td>
<td>17.0</td>
<td>20.8</td>
<td>22.2</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>15.8</td>
<td>18.3</td>
<td>20.3</td>
<td>22.1</td>
</tr>
<tr>
<td>$\mu_T'$ of $L_E$ multiplied by 100</td>
<td>Image A</td>
<td>18.7</td>
<td>21.5</td>
<td>25.2</td>
<td>27.5</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>10.8</td>
<td>13.0</td>
<td>15.9</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>0.5</td>
<td>-0.8</td>
<td>-0.4</td>
<td>-0.2</td>
</tr>
<tr>
<td>$\sigma_{NL}$ of $L_E$ multiplied by 100</td>
<td>Image A</td>
<td>9.7</td>
<td>11.1</td>
<td>13.0</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>5.7</td>
<td>6.8</td>
<td>8.3</td>
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</tr>
<tr>
<td></td>
<td>Image C</td>
<td>3.2</td>
<td>3.8</td>
<td>4.2</td>
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</tr>
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</table>

The normalized values $L_I$ were estimated by using initial luminance values.

The values $L_E$ were estimated by using extracted reference values.

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values to bring their mean equal to the mean of the measured luminance values.

The effect of division becomes clearer when we normalize the measured luminance by subtracting a reference value. If we define the normalized luminance as

\[ NL_{m,n} = L_{m,n} - R_{m,n} + \mu_R, \]  

we obtain

\[ \mu_{NL} = \mu_L. \]  

The standard deviation of the normalized luminance can be expressed by casting Eq. (12) in terms of the mean (\( \mu'_T \)) and standard deviation (\( \sigma_T \)) of \( R_T - L_T \), where \( R_T \) and \( L_T \) are the reference and luminance of a test block. Then,

\[ \frac{\sigma_{NL}^2}{\mu_{NL}^2} = \frac{N_T}{N_R + N_T} \left( \frac{\mu_R^2}{\sigma_R^2} + \frac{\sigma_T^2}{\mu_T^2} \right) \]  

(17)

Therefore, dividing \( \sigma_{NL} \) by \( \mu_{NL} \) is equivalent to dividing \( R_T - L_T \) by \( \mu_L \). The RSD is formulated in terms of relative deviations from reference values. However, if the luminance is normalized by dividing it by a reference value, then \( 1 - NL_T \) is already a relative deviation from a reference value. Consequently, dividing \( \sigma_{NL} \) by \( \mu_{NL} \) has no significant effect.

The extracted reference values and the RSD are still effective even when the measured luminance is normalized using Eq. (15). Evaluation results obtained using normalized luminance values from Eq. (15) are listed in Table 2, which has similar characteristics to Table 1.

<table>
<thead>
<tr>
<th>Evaluation method</th>
<th>Image</th>
<th>4 hours</th>
<th>6 hours</th>
<th>8 hours</th>
<th>10 hours</th>
</tr>
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<tbody>
<tr>
<td>%RMR of ( L_T )</td>
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<td></td>
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<tr>
<td>ISV</td>
<td>Image A</td>
<td>25.4</td>
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<td></td>
<td>Image B</td>
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<td>13.9</td>
<td>18.3</td>
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<tr>
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<td></td>
<td>Image C</td>
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<td>17.9</td>
<td>19.9</td>
<td>21.8</td>
</tr>
<tr>
<td>( \mu'_T ) of ( L_E )</td>
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<td></td>
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<tr>
<td>ISV</td>
<td>Image A</td>
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<td>70.8</td>
<td>78.3</td>
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<td>44.5</td>
<td>51.9</td>
<td>58.7</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>1.5</td>
<td>-2.4</td>
<td>-1.4</td>
<td>-0.5</td>
</tr>
<tr>
<td>( \sigma_{L_E} ) of ( L_E )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISV</td>
<td>Image A</td>
<td>27.7</td>
<td>32.0</td>
<td>36.5</td>
<td>40.3</td>
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<tr>
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<td>Image B</td>
<td>18.9</td>
<td>23.3</td>
<td>27.1</td>
<td>30.7</td>
</tr>
<tr>
<td></td>
<td>Image C</td>
<td>9.3</td>
<td>11.2</td>
<td>13.2</td>
<td>14.6</td>
</tr>
<tr>
<td>%RSD of ( L_E )</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>EISV</td>
<td>Image A</td>
<td>10.6</td>
<td>12.4</td>
<td>14.9</td>
<td>16.4</td>
</tr>
<tr>
<td></td>
<td>Image B</td>
<td>6.0</td>
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</tr>
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<td>Image C</td>
<td>3.2</td>
<td>3.7</td>
<td>4.2</td>
<td>4.6</td>
</tr>
</tbody>
</table>

*The quantity \( \mu'_T \) is the mean of \( R_T - L_T \), where \( R_T \) and \( L_T \) are the reference and luminance values of a test block.

5 Conclusion

We have developed a new method to measure image sticking using a chessboard pattern. Measured luminance values are normalized using extracted reference values acquired from reference blocks, which have not been stressed. The significance of image sticking is then estimated using the relative standard deviation. The reference values effectively represent long-range gradual luminous variations in the image, and facilitate the adaptive removal of these variations. The effectiveness of using extracted reference values, and the indicative capability of the RSD and \( \sigma_{NL} \), have been verified by an experiment on an AMOLED display cell.

Acknowledgment

This work was supported by the Technology Innovation Program (10033657 & 10033812) funded by the Ministry of Knowledge Economy (MKE) of Korea.

References