Degradation of motion image quality by motion blur on hold-type displays, such as LCDs and OLED displays, is a well-known issue. To improve motion image quality, a driving method with a shorter temporal aperture has been proposed. However, a shorter temporal aperture requires higher instantaneous luminance on displays. Higher instantaneous luminance accelerates the lifetime degradation of OLEDs. Therefore, we have been developing a driving method with adaptive temporal aperture control for a longer lifetime and better motion image quality. However, two image quality degradations were perceived when this driving method was applied. One of these degradations was caused at the boundary between the different temporal apertures. The other degradation was caused by switching the temporal aperture between frames. In this paper, we propose transition area and period insertion methods to suppress these degradations and discuss the mechanism of these degradations. We then confirm the effectiveness of our proposed methods by making subjective evaluations and calculating the lifetime of OLED displays when adaptive temporal aperture control is applied.

1. Introduction

The degradation of video image quality caused by motion blur is a well-known problem for hold-emission display devices such as liquid crystal displays and organic light-emitting diode (OLED) displays. Even though OLED displays have a fast response, they are still affected by motion blur that results from active-matrix driving because of the hold-emission operation. To reduce motion blur, driving methods of higher frame rates and a shorter emission time within one frame have been proposed.

From the results of subjective tests on motion blur, Kurita et al. concluded that a high frame rate of 360 Hz is required to obtain an image quality that is acceptable to viewers. However, achieving such a high frame rate for large-screen high-definition displays requires a major improvement in device performance. Therefore, a system that achieves, at a frame rate of 120 Hz, motion blur equivalent to that under operation at a frame rate of 360 Hz by reducing the emission time by one-thirds has also been proposed.

However, to maintain the same luminance with a shorter emission time, a higher instantaneous luminance is required. The luminance of an OLED display is roughly proportional to the driving current and the device lifetime is inversely proportional to an exponential function of the driving current, so the increase in instantaneous luminance needed to compensate for the shorter emission time accelerates the degradation of device lifetime.

To address the above issue, we proposed adaptive temporal aperture control as a method of improving image quality while reducing the degradation of device lifetime and verified the effectiveness of the control by simulation. However, dynamically changing the emission time within the window or in the time direction creates a new problem of noticeable artifacts, and methods of suppressing such image quality degradation have also been studied.

We report here the results of subjective evaluation testing of a method for reducing image degradation, conducted using a prototype OLED display equipped with adaptive temporal aperture control. The results show that the method is effective in suppressing image quality degradation and...
improving the device lifetime.

2. Adaptive Temporal Aperture Control
2.1 Overview

In a hold-emission OLED display, emission continues from the time data is written to each line until data writing for the next frame begins [Fig. 1 (a)]. When adaptive temporal aperture control is used, motion blur is suppressed by shortening the emission time [to 25% in the case shown in Fig. 1 (b)] in the dynamic area of the image where motion occurs. In the static area of the image, where there is no motion, emission is held for the entire frame (100% emission time) to avert the degradation of device lifetime by high instantaneous luminance. This method can suppress image degradation from motion blur while also averting the degradation of the OLED display lifetime.

2.2 Prototype OLED display testing system

In the prototype adaptive temporal aperture testing system (Fig. 2), the input from the video player is preprocessed...
to detect movement vectors and extract the dynamic image area where motion blur is likely to be noticeable. Then, the signal converter generates a scanning signal that produces a short emission time within the dynamic area and converts the image signal into a data signal for the compensation of luminance in the parts where the emission time has been shortened. Finally, the drive signals are input to a data driver and a scan driver to drive the OLED panel.

The pixel circuit for the active-matrix\(^4\) OLED panel used in the testing is shown in Fig. 3. The temporal aperture of each pixel is controlled by the timing of the voltage applied to each horizontal line of OLEDs (\(D_{el}\)), which is, in turn, controlled by a voltage drive signal (\(V_{drive}\)) and a write signal (\(V_{gate}\)). Referring to a report that reducing blur to four pixels per frame or less is effective in suppressing motion blur\(^8\), we defined the dynamic region of the image as the region comprising horizontal lines in which there is movement in at least four pixels between frames, and we controlled the temporal aperture in this region to be 25% and the temporal aperture outside this region (the static region) to be 100%.

The control method illustrated in Fig. 2 is considered in more detail. The motion detector detects the dynamic area by dividing the image into blocks (16 × 16 pixels) and calculating a motion vector for each block by matching blocks between frames.\(^5\) The motion vectors are used to calculate the proportion of pixels for which there is motion of at least four pixels per frame for each horizontal line. Lines for which the proportion exceeds a threshold are determined to be the dynamic area and the other lines are determined to be the static area. The threshold value is set with consideration given to motion existing in an area above a certain size and excluding movement vector detection errors. Here, we take the dynamic area to be horizontal lines for which the proportion of pixel movement is at least 5% and other areas to be static areas.

In the next step, the signal converter converts image data in accordance with the temporal aperture so that pixels are not displayed at different luminances for the same input signal level when there is a difference in the temporal aperture between the dynamic areas and static areas of the image. Here, the data conversion is performed as illustrated in Fig. 4. In ordinary acquired images, there is a nonlinear gamma relationship between the actual luminance and the signal level, so gamma conversion is performed on the signal level to make the relationship between the luminance and signal level linear.

\[
S_1 = S_m^\gamma 
\]

\(S_1\) = \(S_m^{\gamma}\) \(\quad (1)\)

In the above equation, \(S_m\) is the input signal, \(S_1\) is the signal after gamma conversion, and \(\gamma\) is the display gamma value.

Next, data is converted to correct the difference in luminance due to the difference in emission time (luminance compensation). In this prototype system, the luminance for

\(^4\) A driving method in which each pixel has transistors that control light emission for the pixel.

\(^5\) A method in which the distance of movement between frames is measured by dividing an image into blocks (16 pixels×16 pixels, etc.) and comparing each block to neighboring blocks in the previous frame or in the subsequent frame, and taking the distance of movement to be the distance to the block closest to the original block in terms of pixel value.
the 25% temporal aperture, which is the shortest emission duration, is not changed, but the luminance for the areas of the 100% temporal aperture is converted to one-fourth.

\[ S_2 = \frac{0.25}{d} S_1 \quad (0.25 \leq d \leq 1) \quad \text{........... (2)} \]

In the above equation, \( d \) is the temporal aperture of the region and \( S_2 \) is the signal after data conversion.

The final step is a nonlinear conversion (display characteristic conversion) of the signal levels so as to match the OLED display voltage–luminance characteristic. We express the relationship between the display luminance \( L \) and the signal level \( S \) as Equation (3).

\[ L = \text{Disp}(S) \quad \text{........... (3)} \]

Then the output signal level from the display characteristic conversion \( S_{\text{out}} \) is expressed by Equation (4).

\[ S_{\text{out}} = \text{Disp}^{-1}(S_1) \quad \text{........... (4)} \]

The conversion described above makes it possible to correctly display the luminance that corresponds to the signal level.

### 2.3 Temporal aperture control driver circuit

In the prototype active-matrix OLED panel, the data signals \( (V_{\text{data}}) \) are written to the pixels line by line in the images displayed at the emission intensity that corresponds to the data signal within the emission period (Fig. 5). For arbitrary control of the emission period for each line, we prepared a prototype scan driver that has a scan shift register for the output of the scan signal and an aperture data shift register for the output of the temporal aperture control drive signal (Fig. 6). The scan shift register outputs the gate signal \( (V_{\text{gate}}) \) to the horizontal lines sequentially in one scan period at a rate of one line per clock cycle [Fig. 5 (a)].

An example time chart for the aperture data shift register is illustrated in Fig. 7. During the scan time for one horizontal line, the aperture data for each line is input to the shift register, with 1 indicating emission for the line and 0 indicating no emission for the line. The aperture data thus controls the drive current that is sent to each line in each scan interval. By repeating this process for each scan interval, it

![Figure 5: Drive signals of the prototype system](image-url)
Figure 6: Circuit configuration of the scan driver for adaptive temporal aperture control

Figure 7: Example of drive signal for adaptive temporal aperture control

Figure 8: Prototype display and scan driver
is possible to control the emission of light for each line to an arbitrary time period.

Photographs of the prototype adaptive temporal aperture control OLED display and scan driver are presented in Fig. 8. The panel has a size of 25 inches (diagonal), a resolution of 1920 by 1080, and a frame rate of 120 Hz. This prototype system has been confirmed to suppress motion blur in video images that include movement or scrolling text, for example, by temporal aperture control [Fig. 8 (a)].

However, verification of the basic operation in actual hardware revealed two major problems: artifacts exist at the control boundaries between dynamic regions and static regions in the image, and there is a noticeable blinking effect when the temporal aperture is switched between frames. The causes of these problems are explained and methods of improvement are evaluated in the next section.

3. Reducing Image Distortion with Transition Areas and Transition Periods

3.1 Mechanism behind and suppression of image quality degradation in the spatial direction

The mechanism behind the image degradation that occurs when the emission pattern differs in adjacent image areas and a method for suppressing that degradation are illustrated in Fig. 9. In Fig. 9 (a), the vertical axis is the vertical direction of the image and the horizontal axis is time. In the upper part of the figure, the emission time is long and the emission intensity is low; in the lower part of the figure, the emission time is short and the emission intensity is high. Because the human eye senses brightness by integration over a certain period of time, brightness is perceived as the same in both areas if the line of sight does not move. However, if the line of sight moves in the vertical direction on the screen (when tracking), integration over the movement of the line of sight (indicated by the blue line and arrow in the figure) results in perception of darkness between both areas as shown in Fig. 9 (b). Therefore, a transition area in which the emission time is gradually changed, as shown in Fig. 9 (c), is established. As a result, the change in perceived brightness can be suppressed compared with that in the conventional method, as shown in Fig. 9 (d).

3.2 Mechanism behind and suppression of image quality degradation in the temporal direction

The emission intensity for which the pixel emission time changes from short to long between frames and the temporal
change in perceived brightness owing to the integration effect in human vision are illustrated in Fig. 10, where the tall yellow rectangles indicate the emission intensity adjusted for the temporal aperture and the orange line represents the temporal change in integrated brightness within one frame. When there is no transition period for the switch between short and long emission times between frames [Fig. 10 (a)], there is a large fluctuation in the integrated brightness within one frame that is perceived as a blinking effect. This effect can be reduced by establishing a transition period in which the emission time changes gradually in the time direction, with the center of gravity of the emission at the temporal center of one frame. As shown by the orange line in Fig. 10 (b), the effect of the transition period is to reduce the fluctuation in the integrated brightness in one frame and to suppress the perceived blinking.

3.3 Subjective evaluation
In the previous section, we explained how image quality degradation caused by a change in the temporal aperture can be suppressed by introducing a transition region in the spatial direction and a transition period in the temporal direction. In this section, we report the results of subjective experiments conducted to test the effect of this method.

The conditions for the evaluation experiments are listed in Table 1. The three still images used are a natural scene, a 70% gray band, and a 70% gray rectangle (respectively images A, B, and C in Fig. 11). When video images are used for evaluation, it is difficult to isolate temporal changes and spatial changes, so only still images are used in this evaluation to verify the basic suppression effect in the spatial and temporal dimensions individually.

The evaluation sequences used to evaluate the effect of introducing the spatial transition region and the temporal transition period are presented in Fig. 12. The sequences alternate between method A and method B, in one of which

![Figure 10: Mechanism behind and suppression of image quality degradation when temporal aperture control is switched](image-url)
the temporal aperture is varied by using spatial transition areas or temporal transition periods of various widths, and in the other, a constant temporal aperture is maintained. The evaluators respond by indicating in which displayed images they noticed a change such as blinking or image degradation or that they did not notice change in any of the images.

The results of a subjective evaluation of the change in the spatial transition using images A and B from Fig. 11 are presented in Fig. 13. Although a gray rectangle image such as image C is often used for evaluation, the tall gray region is expected to enable a more accurate evaluation, considering that the subject of evaluation here is the width of the transition for vertical movement of the line of sight; thus, image B was used. The values on the horizontal axis in Fig. 13 represent the evaluated widths of the transition region. The change in width from line to line was linear. For
example, the change in width for each line was 1.8% for a transition width of 40 lines, which changed the temporal aperture from 25% to 100% (or the reverse). The vertical axis in the figure represents the perception rate as indicated by the responses of the evaluators for each transition width. The perception rate is the proportion of responses for which the evaluator could perceive a difference between method A and method B.

Lower perception rates indicate that changes such as blinking and image degradation were not perceived, so it can be concluded that the hypothesized improvement effect was obtained. From the results presented in Fig. 13, we can see that the perception rate decreases at a transition width of about 40 lines or more for image A (natural scene). For image B (70% gray), we can see a large decrease in perception rate when the transition rate width is 80 lines or more, but if the number of lines is further increased, there is no proportional decrease in the perception rate. We consider the reason for this result to be that the rather poor uniformity of luminance within the OLED display screen used in the evaluations resulted in a change in the uniformity of luminance, causing the perception of a change in the temporal aperture. From these results, we conclude that it is possible to suppress image degradation at temporal aperture boundaries by establishing a transition region of 40 to 80 lines.

The results of a subjective evaluation of change for the temporal transition using images A and C from Fig. 11 are presented in Fig. 14. The values on the horizontal axis in Fig. 14 represent the transition period widths that were evaluated. In the same way as for the spatial transition evaluation, the change in width from frame to frame was linear. For example, the change in width for one frame was 1.5%, which changed the temporal aperture from 25% to 100% (or the reverse) over a transition width of 50 frames. The evaluation results presented in Fig. 14 show that, for both evaluation images, the perception rate decreased for transition widths of 30 frames or more and was less than 40% for a transition width of 50 frames. From these results, we conclude that the blinking effect can be suppressed by transition periods of about 50 frames or more (0.4 s at 120 Hz).

4. Improvement of Device Lifetime

We also investigated the effect of adaptive temporal aperture control on OLED lifetime. The service life of an OLED device, \( T \), is known to be expressed in terms of initial luminance, \( L_0 \), by

\[
T \sim \frac{1}{L_0^x} \quad \text{................ (5)}
\]

where \( x \) is an exponent that has a value from 1 to 2. From this relationship, the device lifetime for temporal aperture \( d \), \( T_d \), can be expressed as

\[
T_d = \left( \frac{L}{d} \right)^{x-1} \times \frac{1}{L} = \frac{1}{L} \times d^{x-1} \quad (0 < d \leq 1) \quad \text{................ (6)}
\]

where \( L \) represents the instantaneous luminance for the emission interval. Accordingly, the relationship between the temporal aperture and the relative lifetime is shown in Fig. 15, given that the relative lifetime is 1 when \( x \) is 1.7 and \( d \) is 1. We can see that when the temporal aperture is shortened to 25%, for example, the relative lifetime decreases to about 0.4.

Next, we consider dynamic temporal aperture control in which the temporal aperture is set to 25% for the dynamic...
image region and to 100% for the static region, and the respective relative lifetime values are taken to be $T_{0.25}$ and $T_{1.0}$. In this case, the estimated lifetime ($T_{apt}$) for when adaptive temporal aperture control is used can be expressed by Equation (7), where $\alpha$ is the proportion of the video image occupied by the dynamic region.

$$\frac{1}{T_{apt}} = \frac{a}{T_{0.25}} + \frac{1-a}{T_{1.0}}$$

.........(7)

A graph showing the relationship between the relative lifetime and the proportion of the dynamic region with $x = 1.7$ is presented in Fig. 16. Taking the relative lifetime to be 1 when the dynamic region proportion is 0 (equivalent to $d = 1$ in Fig. 15), we can see that the relative lifetime decreases as the dynamic region proportion increases. Detecting motion vectors for the movement of at least four pixels per frame in ordinary TV programs and calculating the proportion of dynamic regions for each program resulted in values of roughly 20% to 40%, so the relative lifetime is expected to range between 0.6 and 0.75 when adaptive temporal aperture control is used. When the temporal aperture is fixed at 25%, the relative lifetime is 0.4, as described above, so applying adaptive temporal aperture control can be expected to improve the device lifetime by a factor of about 1.5 to 1.8 while maintaining image quality.

5. Conclusion

We constructed an OLED display panel with adaptive temporal aperture control and used it in evaluation experiments. Then, the mechanisms behind the image degradations that occurs at the boundaries of temporal aperture control were revealed. In addition to explaining the mechanisms, we presented evaluation results that confirmed its effectiveness in suppressing image degradations. Specifically, degradation that occurs when the temporal aperture changes in the spatial direction can be suppressed by establishing a spatial transition region of 80 lines or more, and the blinking phenomenon that occurs when there is a change in the temporal aperture in the time direction can be suppressed by establishing a transition period of 50 frames or more. We also considered the effect of adaptive temporal aperture control on OLED lifetime and determined that it is possible to reduce lifetime degradation while maintaining image quality.

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References


