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Degradation of Moving Image Quality Induced by Pulse Width Modulation Grayscale Expression Methods

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ABSTRACT

When an image on the display device utilizes the pulse width modulation method for expressing grayscale moves and observer's eye tracks the image, visual artifacts such as distortion, ghost, and color breakup appear. Gray-level-dependent temporal distribution of light emission in a field is transformed into spatial visual artifacts.

1. Introduction

Display devices express grayscale by use of various methods. LCD and OLED employ the pulse amplitude modulation (PAM) method in which grayscale is expressed according to the current or voltage level. In order to ensure sufficient luminance, light emission period extend within a display field. This hold-type PAM is adequate to express still images, however motion blur is observed when expressing moving image [1]. The pulse width modulation (PWM) method is another typical grayscale expression technique which is employed in PDP, DMD, and LED, etc. An adoption of PWM method is also examined for direct-type micro LED display since constant current operation is effective to prevent luminous efficiency deterioration and color shift [2, 3, 4]. A use of PWM grayscale expression also results in the degradation of moving image quality. PWM generates not only motion blur, but also distortion of image which do not appear with the hold-type PAM. This paper clarifies a mechanism of moving image degradation with the various PWM grayscale methods.

2. Principle

2.1. Various Pulse Width Modulation Methods

In this study, five PWM methods shown in Fig. 1 are investigated. Here F on the vertical axis represents the display field time of 16.7 ms. For an ease the study, the scan periods are neglected and the rise and fall of light emission are assumed to be fast enough. In addition, 60 Hz of field frequency is employed and the number of gray levels is 256. Figures 1 (a), (b), (c) are PWM in standard left-aligned mode, center-aligned mode, and both-edges-aligned mode. Hereafter these modes are referred to as PWM_S, PWM_C, and PWM_E, respectively. (d) is the pulse frequency modulation method, PFM. (e) is the binary-coded pulse width modulation, PWM_B in which light emission periods are arranged according to 1-2-4-..64-128.

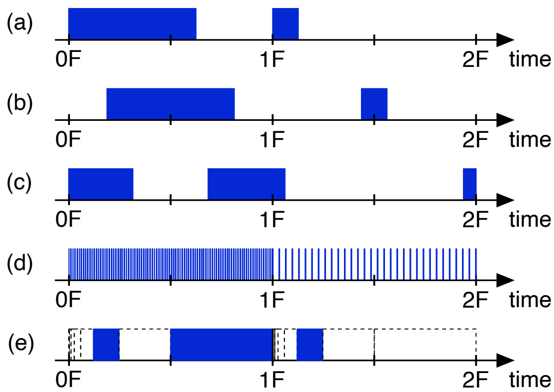

Fig. 1 Light emission patterns of gray levels 160 (1st field) and 32 (2nd field) for various pulse width modulation methods. (a) PWM_S, (b) PWM_C, (c) PWM_E, (d) PFM, (e) PWM_B.

2.2. Mechanism of Moving Image Degradation

Assume that stripe pattern having gray levels 0-160-0-63-0 shown in Fig. 2 (a) moves to the left at 3 pixels per field (P/F) on the display. When the eye follows the pattern, the trace of light emission [5] and resultant retinal stimulation, which is obtained by the accumulation of light emission during 1F, for PAM, PWM_S, PWM_C and PWM_E are shown in Figs. 2 (b)-(e).

Let T be the period from the start to the end of the light emission within a field as shown in Fig. 2. T represents the temporal spread of light emission within a field. An apparent stripe width w' is expressed as $w'=vT+w$, where v is the speed of image and w is the width of stripe. This is the well-known "motion blur". The apparent width can be made small by decreasing T.

Other degradations, which has not been well described, are shape distortion and positional shift. Since the apparent width w' depends on the value vT, the shape of the image changes if T depends on the gray level. In Figs. 2 (c) and (d), the apparent width of the 63rd-gray stripe is smaller than that of the 160th-gray stripe since T of the 63rd-gray level is shorter. The difference in width is the difference in T multiplied by v.

Let t_c be the temporal center of light emission

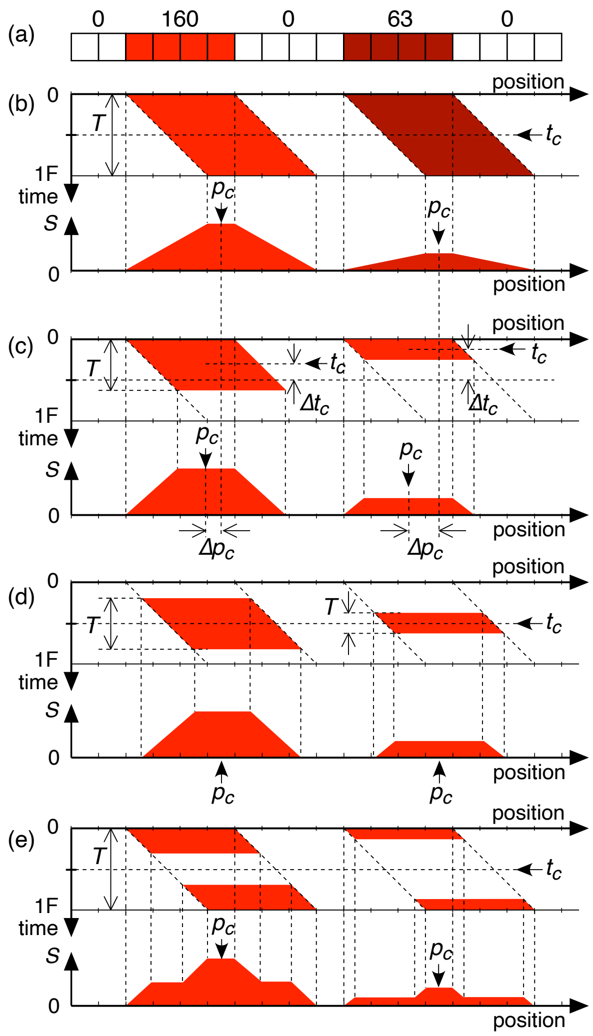

Fig. 2 Mechanism of moving image degradation. (a) Image pattern. Trace of light emission on retina and retinal stimulation *S* for (b) PAM, (c) PWM$_S$, (d) PWM$_C$, and (e) PWM$_E$.

amount in a field as shown in the figure. The variation of t_c depending on the gray level is transformed into spatial shift of image on retina. In the figure, the central position of the apparent stripe, P_C, of PWM$_S$ is shifted to the left from that of PAM. The difference in position, ΔP_C, is expressed as $v\Delta t_c$, where Δt_c is the time difference between t_c of PAM and PWM$_S$. With PWM$_S$, Δt_c increases as the gray level decreases, resulting in a larger shift. This makes the 0-160-0-63-0 stripes appear to have a narrower pitch. Except for PWM$_S$, Δt_c is constant for all gray levels, thus no positional shift occurs.

Chromatic colors in a color image are produced by R, G, and B sub-pixels having different gray levels. When the temporal distribution of light emission in a field of each sub-pixel is different, position and spread of their transformed spatial distribution is also different, resulting in the color breakup. Therefore, PWM$_S$, PWM$_C$, PWM$_E$, and PWM$_B$ generate color breakup.

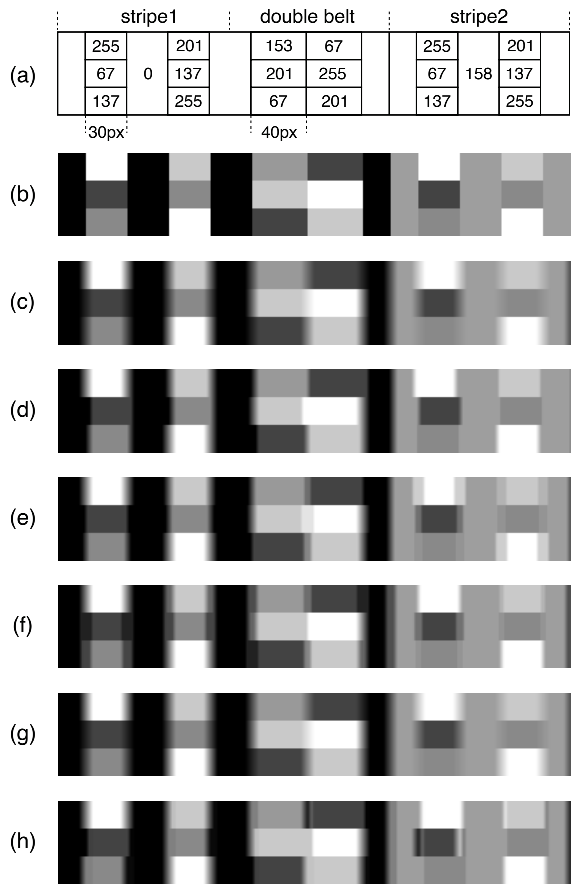

Fig. 3 Simulation results. (a) Configuration of test pattern, (b) Original test pattern, (c) PAM, (d) PWM$_S$, (e) PWM$_C$, (f) PWM$_E$, (g) PFM, (f) PWM$_B$.

It can be concluded that moving image degradation generated by the combination of motion blur due to longer light emission period, and shape distortion, positional shift, and color breakup due to the variation of light emission period and temporal center of light emission amount depending on the gray level.

3. Results

3.1. Simulation of Moving Image Degradation

To compare the degradation with the methods, perceived images of a test image having 370 x 60 pixels shown in Fig. 3 (b) were obtained by computer simulation. It was assumed that the image moving horizontally to the right at a speed of 10 P/F (9.4 deg/sec) was displayed on 2K display and the viewing distance was three times the screen height. The results are shown in Fig. 3. Table 1 lists T and t_c for a gray level g in each method. Degradation generates according to these values.

3.2. Motion Blur and Ghost

First, we focus on the stripe1 region in Fig. 3. The width of blurred edge of the stripe depends on T. T becomes shorter at lower gray level with PWM$_S$ and

Table 1. Light emission period, T, and temporal center of light emission amount, t_c, for a gray level g.

	T [F]	t_c [F]
PAM	1	0.5
PWM_S	$g/255$	$g/255/2$
PWM_C	$g/255$	0.5
PWM_E	1	0.5
PFM	1–2(ceil(255/2g)–1)/255	~0.5

PWM_C, resulting in less blurred edge as seen in Figs. (d) and (e). With PWM_B, separated distribution of light emission transforms to stepwise spatial distribution, hereafter called ghost, as shown in Fig. 2 (e). Therefore, although the blur width with PWM_E is identical to that with PAM, perceived stripe pattern changes. With PFM, T is more than 0.9 when the gray level is more than 10, thus perceived image is similar to PAM.

Next, we focus on the border of double belt pattern. Let g_L and g_S be the large and small gray levels of the double belt pattern. Figure 4 depicts the time-space diagram and retinal stimulation at the border area. The width of change, w_t, between g_L and g_S for the methods are listed in Table 2. The w_t with PWM_S depends on the gray level difference of the belts as found in Fig. 4 (a). The smaller gray level difference, the smaller blur. For PWM_C, w_t is determined by g_L. Two-step luminance variation, “ghost," appears as shown in Fig 4 (b). Ghost also appears with PWM_E as shown in Fig. 4 (c). The w_t is determined by g_S. For the same reason, ghosts appear at the edges of stripes in the stripe2 region, where background is not zero, with PWM_C and PWM_E. With PFM, w_t depends on T of g_L. As mentioned above, T is almost 1F in most cases, and thus perceived image looks similar to PAM.

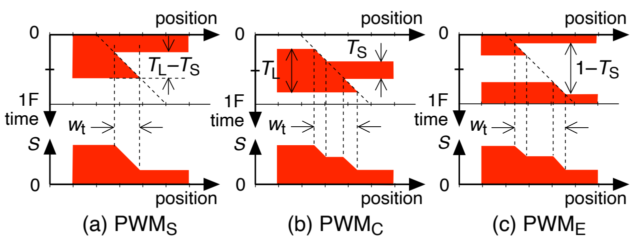

Fig. 4 Time-space diagram of light emission and retinal stimulation at the border area of the double belt pattern.

Table 2. Transition width of g_L-g_S double belt pattern for various grayscale methods.

	w_t
AM	v
PWM_S	$v\,(g_L–g_S)/255$
PWM_C	$v g_L/255$
PWM_E	$v\,(1–g_S/255)$
PFM	v (1–2(ceil(255/2g_L)–1)/255)

T and t_c of PWM_B fluctuate against the gray level and the light emission is split for most gray levels. This causes shape distortion, positional shift, and ghost. In addition, the dynamic false contour will appear [6].

3.3. Shape Distortion and Positional Shift

Since the width of blur depends on T, the lower the gray level, the narrower the perceived stripe width with PWM_S and PWM_C, as seen in Fig. 3 (d) and (e). Therefore, thickness of stripes with PWM_C in stripe1 and stripe2 region becomes not uniform.

Positional shift of perceived image occurs with PWM_S and PWM_B, in which t_c depends on the gray level. Horizontal distance between the strips changes as seen in Figs. 3 (d), (h). It no longer looks like a straight stripe due to the uneven edge position of each gray area.

4. Discussion

Assuming browsing a typical news website, a test image shown in Fig. 5 was made for evaluation of the methods. Figure 6 compares the simulated results when the image moves upward at a 9 deg/sec, which is little faster for reading text. Motion blur is reduced with PWM_S due to short T but color breakup appears and the face is distorted due to spatial shift. Color breakups appear at the edge of the objects with PWM_S, PWM_C, PWM_E. Ghost appears wit PWM_C and PWM_E. It can be found from Fig. 4, shift amount of ghosting depends on T_L for PWM_C and (1–T_S) for PWM_E. For bright image such as Fig. 5, ghosting with PWM_C is large. The perceived image with PFM is similar to PAM. PWM_B produces dynamic false contour and false color.

The features of each method are summarized as follows. PWM_S reduces motion blur, however positional shift and color breakup are generated. Since t_c is fixed, positional shift does not occur with PWM_C. However, shape depends on the gray level and thus ghost appears. Although position and width of perceived image do not vary according to the gray level with PWM_E, ghost appears. The perceived image with PFM is similar to PAM. PWM_B generates dynamic false contour and false color. It should be noted that various techniques for reducing the dynamic false contour were

Fig. 5 Test image considering swipe up operation. 512x256 pixels

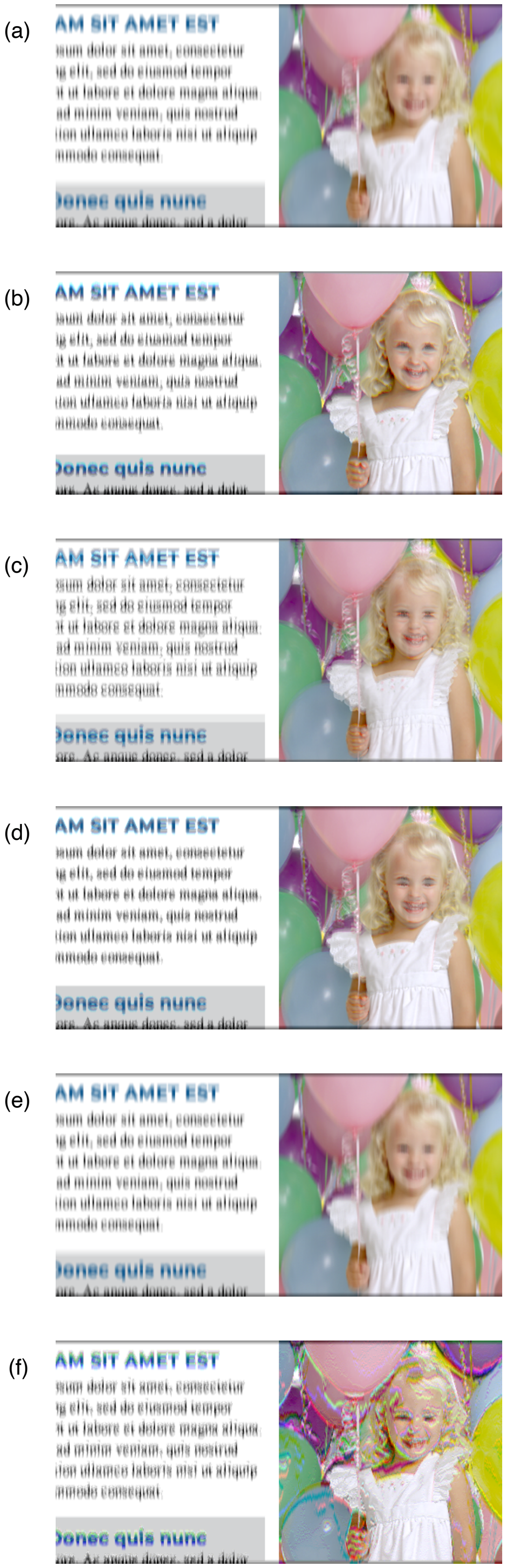

Fig. 6 Perceived images of Fig. 5. (a) PAM, (b) PWM$_S$, (c) PWM$_C$, (d) PWM$_E$, (e) PFM, (f) PWM$_B$.

Table 3. SSIM and PSNR of images in Fig. 3

	SSIM	PSNR [dB]
AM	0.753	20.5
PWM$_S$	0.767	19.4
PWM$_C$	0.773	20.8
PWM$_E$	0.720	19.3
PFM	0.753	20.5
PWM$_B$	0.734	19.3

proposed and they were scarcely noticeable in the commercially available PDPs.

None of these methods is perfect for express moving image since each method has advantages and disadvantages. Table 3 compares SSIM and PSNR of the perceived images in Fig. 3. These are only for reference since they are not appropriate evaluation measures for this study. For the test pattern in Fig. 3, PWM$_C$ has a slightly better scores due to no positional shift and small ghosting.

5. Conclusions

A simulation study revealed that motional artifacts appear when moving images are displayed with the PWM grayscale expression methods. The origin of image degradation is that the spread of light emission in a field and temporal center of light emission amount vary according to the gray levels. With the standard left-aligned PWM, position shift, distortion, and color breakup deteriorate image quality. With the center-aligned PWM, ghost would be unacceptable. Although motion blur is identical to PAM, the pulse frequency modulation is a preferred approach since the other artifacts do not appear. Increase in power consumption due to increase in switching frequency may be problem with the method. Another solution is reduction of duty ratio. However, flickering will occur with large display.

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