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PDP-TV varies the emission luminance of gray-levels because PDP-TV controls the total number of sustain pulses according to average picture level (APL) change, which is quite essential for power management of PDP. Thus, one inverse gamma correction LUT using the peak white luminance of PDP leads to the distortion of the perceived luminance in actual PDP-TV. A new method is proposed to enhance the image quality by using variable inverse gamma corrections according to the APL change. The proposed variable correction method can minimize the distortion of the perceived luminance caused by the inherent background luminance in PDP.

Keywords: APL; average picture level; gray-level linearity; inverse gamma correction; PDP-TV; plasma display panel

INTRODUCTION

There are several critical factors needed for enhancing the image quality in the plasma display panel (PDP). One of such factors is the nonlinearity of grayscale [1]. There have already been various attempts to improve gray-level linearity in PDP. A multi-luminance-level subfield method [2] and an error diffusion method based on the light emission characteristics of PDP [3] were developed to solve this problem. However, these methods did not consider the fact that the emitted luminance during a reset period influences the perceived luminance, which is defined as the luminance actually recognized by human eyes. Therefore, they often fail to reduce the false contours in dark areas effectively because of the nonlinear perceived luminance characteristics to an input gray-level. Recently, modified inverse

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gamma correction method based on human visual system and the peak white luminance of PDP was developed to improve PDP grayscale linearity [4]. However, most of gray-levels in PDP do not produce the peak white luminance because PDP-TV changes the total number of sustain pulses according to average picture level (APL). Thus, one inverse gamma correction look-up table (LUT) based on the peak white luminance of PDP does not optimize the gray-level linearity in actual PDP-TV.

In this paper, our research analyzes how the change of the maximum luminance influences the perceived luminance as the APL changes. The proposed method creates multiple inverse gamma correction LUTs depending on APLs for achieving best linearity of PDP based on the analyzed result. These LUTs change the gamma-corrected input video signal nonlinearly so that a viewer perceives the resultant luminance more linearly. The converted signal is then applied to the system using the address and display period separated (ADS) driving scheme to visually verify that the proposed method can improve the gray-level linearity in the PDP-TV.

EXPERIMENT

PDP-TV controls the total number of sustain pulses in order that the maximum luminance in higher APL would not violate the constraint of stable power consumption [5]. In general, the APL is computed by the following equation

$$APL = \frac{1}{C \times R} \sum_{i=1}^{C} \sum_{j=1}^{R} I(i,j), \tag{1}$$

where $I(i,j)$ is the gray-level at a pixel location (i,j), R is the number of rows, and C is the number of columns. After APL is calculated, the total number of sustain pulses is determined. Then, the maximum luminance for a given APL is determined by the modeling of the output luminance of PDP considering APL [5]. Figure 1 shows the relationship between APL and the total number of sustain pulses.

Figure 2 shows the conceptual block diagram of the signal flow, which represents how the input video signal is perceived in a human eye. The gamma-corrected input video signal x is formulated by

$$Y = \mathrm{z}(x) = k \times \left(\frac{x}{255}\right)^{\gamma}, \tag{2}$$

where γ represents the gamma value of 2.2 and k denotes the maximum gray-level representing a white point [4]. Y is the analog

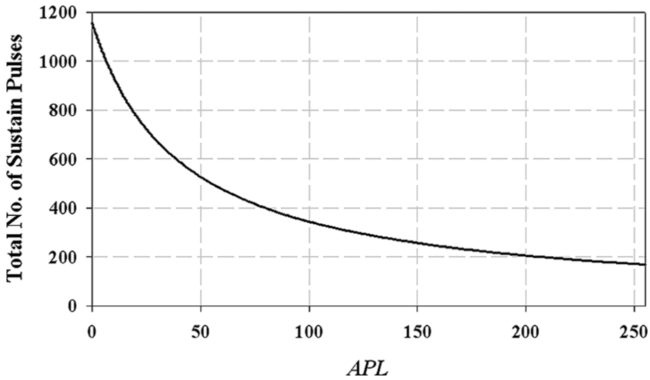

FIGURE 1 Relationship between APL and total number of sustain pulses.

output luminance-level for displaying the input gray-level on the panel. The output luminance L of the panel is given by

$$L = f(Y, APL) = \{L_{\mathrm{MAX}}(APL) - L_{\mathrm{R}}\}\frac{Y}{255} + L_{\mathrm{R}}, \tag{3}$$

where $L_{\mathrm{MAX}}(APL)$ is the maximum luminance of PDP for a given APL. L_{R} has not been considered properly in a traditional inverse gamma correction because it is zero for the ideal display. However, in the actual PDP with ADS driving scheme, L_{R} has to be considered because it is about $0.9\,\mathrm{cd/m^2}$ and causes serious distortion of gray level linearity. Then, the relationship between the perceived luminance P and the output luminance L is experimentally determined [6] and given by

$$P = g(L) = cL^{\beta}, \tag{4}$$

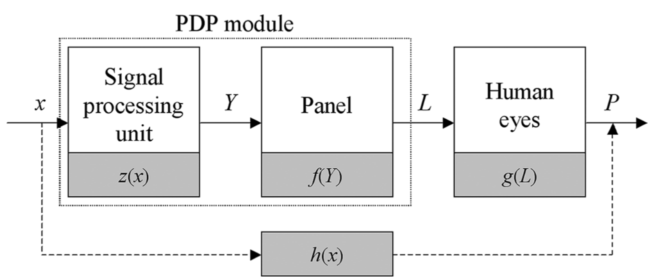

FIGURE 2 Block diagram for signal flow.

where $c = 2.29$ and $\beta = 0.382$ [7]. In an ideal PDP without L_R, the relation between the input signal x and the perceived luminance P is given by

$$P_{\text{ideal}} = h_{\text{ideal}}(x, APL) = c\left\{L_{\text{MAX}}(APL) \times \left(\frac{x}{255}\right)^{\gamma}\right\}^{\beta}. \tag{5}$$

Figure 3 shows how the perceived luminance P varies with the input gray-level x. In ideal PDP, since $c \times L_{\text{MAX}}(APL)^{\beta}$ is just a scale factor of a function, the function normalized to the maximum perceived luminance always shows the same shape in all APLs. This means that the normalized perceived luminance does not need to be changed, even if APL changes. However, as shown in Figures 3(b) and 3(c), the actual PDP with L_R shows different characteristics according to the APL change. Moreover, slow increase of the perceived luminance in the low input gray-level will lead to the low gray-level contour artifact. Therefore, in order to compensate human visual

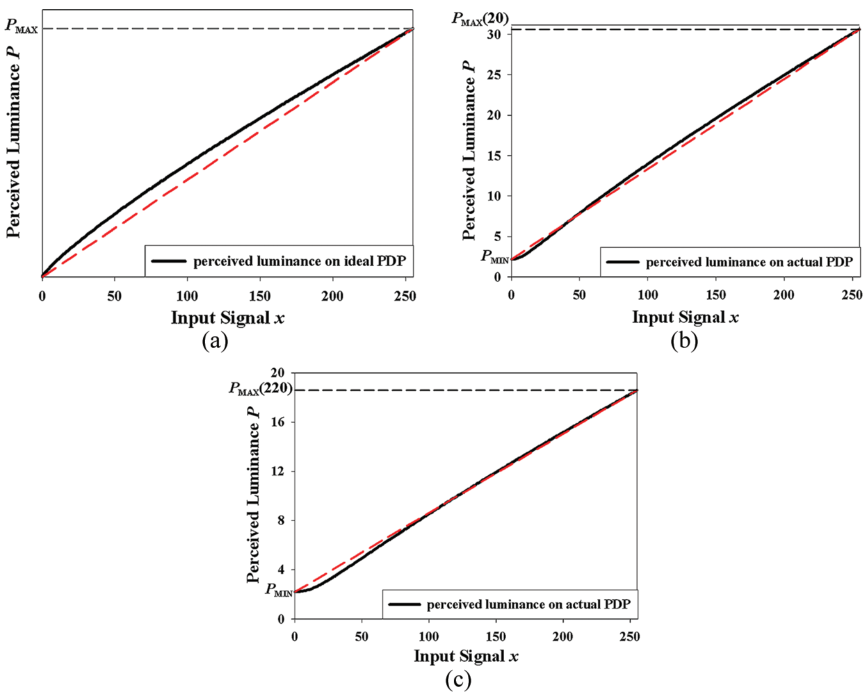

FIGURE 3 Relationship between input gray-level and perceived luminance (a) on ideal PDP and on actual PDP at (b) APL of 20 and (c) APL of 220.

characteristics against the input gray-level x regardless of APL changes, human visual characteristics of the actual PDP with L_R must be made similar with those of the ideal PDP. In addition, this effort can reduce the low gray-level contours.

In case of the actual PDP, suppose that $h_{new}(x, APL)$ is similar with $h_{ideal}(x, APL)$. Then, the perceived luminance P_{new} can be formulated as

$$P_{new} = h_{new}(x, APL) = \frac{P_{MAX}(APL) - P_{MIN}}{P_{MAX}(APL)} h_{ideal}(x, APL) + P_{MIN}, \quad (6)$$

where $P_{MAX}(APL)$ is the maximum perceived luminance value for a given APL and P_{MIN} is the perceived luminance with respect to the L_R. From (4), $P_{MAX}(APL)$ and P_{MIN} are defined as

$$\begin{aligned} P_{MAX}(APL) &= c \times L_{MAX}(APL)^{\beta} \quad \text{and} \\ P_{MIN} &= c \times L_R^{\beta}. \end{aligned} \quad (7)$$

Hence, the desired luminance-level can be formulated as

$$\begin{aligned} Y &= z_{new}(x, APL) = f^{-1}(g^{-1}(h_{new}(x, APL))) \\ &= a \times \left(\left(b \times \left(L_{MAX}(APL) \times \left(\frac{x}{255} \right)^{\gamma} \right)^{\beta} + L_R^{\beta} \right)^{\frac{1}{\beta}} - L_R \right) \\ \text{where } a &= \frac{255}{L_{MAX}(APL) - L_R} \quad \text{and} \\ b &= \frac{L_{MAX}(APL)^{\beta} - L_R^{\beta}}{L_{MAX}(APL)^{\beta}}. \end{aligned} \quad (8)$$

When the light emission characteristics of the PDP are determined, that is, L_{MAX} and L_R are measured at each APL, $z_{new}(x, APL)$ in (8) can be represented as a look-up table.

RESULTS AND DISCUSSION

The resultant relationship between the input gray-levels and the perceived luminance on the actual PDP using the conventional and the proposed inverse gamma correction method at sampled APLs is shown in Figure 4. Against the conventional inverse gamma correction method, the proposed methods not only show the linear characteristics since its curve is closer to the ideal response curve, but also reduce the number of merged signals into a fixed output level. As shown in Figure 4, 15 signals in the lowest part of the input signal are merged into a fixed perceived luminance of 2.455, while the number of merged signals of the proposed method is $3 \sim 5$ according to APL, which is

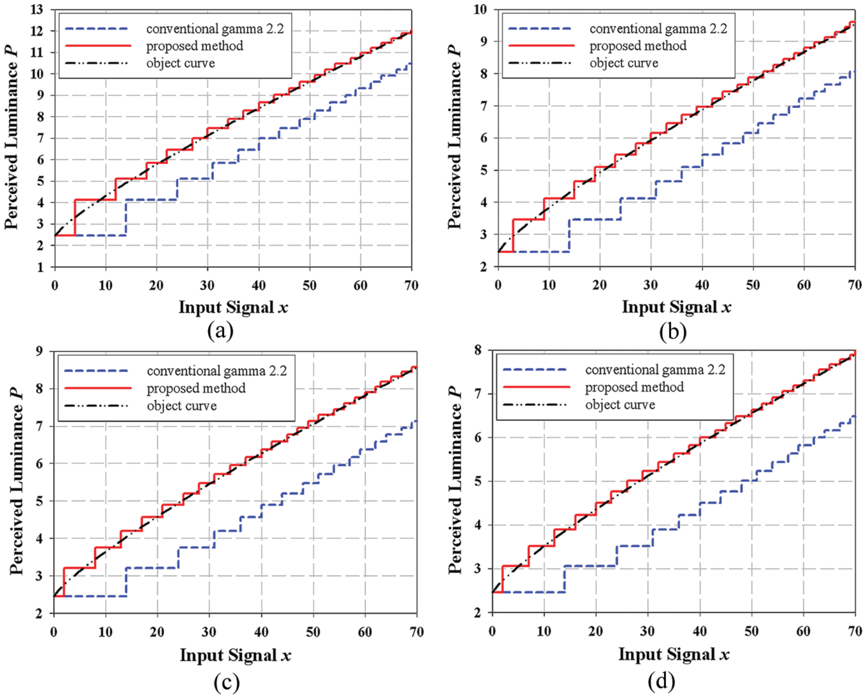

FIGURE 4 Perceived luminance response curves to input signal up to 70 at APL of (a) 20, (b) 50, (c) 150, and (d) 220.

about a third or fourth of that of the conventional method. Table 1 shows the number of expressible levels after inverse gamma correction. When the proposed method is used, the number of output gray-levels with respect to the input gray-levels up to 50 is increased from 8 to 15.

TABLE 1 Expressible Levels After Inverse Gamma Correction

	Number of expressible levels	
Gamma corrected input signal	Conventional gamma	Proposed gamma
up to 10	1	3
up to 20	2	5
up to 50	8	15
up to 70	16	25

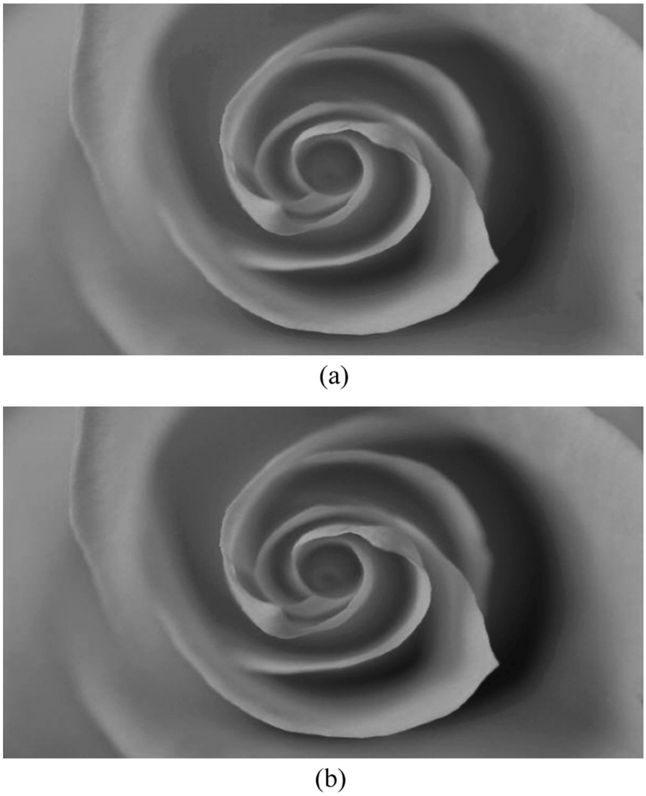

FIGURE 5 Actual pictures taken in 42-inch PDP when APL is 50. (a) Conventional inverse gamma correction method and (b) Proposed inverse gamma correction method.

Figure 5 is actual pictures taken in 42-inch PDP for the rose image when APL is 50. Figures 5(a) and 5(b) are the results of the conventional gamma method and the proposed gamma method, respectively. As shown in Figure 5, significant low gray-level contours appear in the conventional method. In contrast, low gray-level contours are effectively removed when using the proposed method. It is found that the similar result can be observed in every APL.

CONCLUSIONS

A new method is proposed to reduce image quality degradation due to the lack of gray-scale smoothness by using APL-adaptive inverse gamma correction method based on the light emission characteristics of PDP and human visual perception. The proposed method produces a set of the optimal inverse gamma LUTs to reduce the number of merged signals by using $L_{MAX}(APL)$ modeled at each APL. In addition, the proposed method is effective for actual PDP under the constraint of the power management system of PDP. The proposed method is found to significantly improve the gray-level linearity in the PDP-TV.

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