Improvement of Low Gray-Level Linearity using Perceived Luminance of Human Visual System in PDP-TV

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***Abstract*--A new method is proposed to enhance the image quality at low gray-levels by performing the error diffusion using the 9-subfield and the optimal gamma, which is estimated by analyzing the relationship between the perceived luminance and the output luminance-level of the PDP in order to enhance the linearity.**

I. INTRODUCTION

Recently, much research has been focused on improving the image quality of the Plasma Display Panel (PDP) to satisfy the consumer's demand for high quality products. However, there are several factors deteriorating the image quality [1]. One of the factors is the low gray-level contour due to the inverse gamma correction [2]. From the viewpoint of human visual perception, the low gray-level contour is quite serious because the output luminance of PDP does not guarantee the linearity at low gray-levels. Therefore, our research estimates the optimal gamma value by analyzing the relationship between the perceived luminance and the output luminance level. Then, we propose a new image quality enhancement method by performing the error diffusion based on the estimated optimal gamma value and the 9-subfield system.

II. PROPOSED ALGORITHM

In general, the PDP using the Address and Display period Separated (ADS) driving scheme performs the inverse gamma correction with respect to the input gray-level signals, as shown in Eq. (1).

$$Y = k\left(\frac{x}{255}\right)^{2.2} \tag{1}$$

where k denotes the maximum gray-level representing the white point and Y is the ideal luminance-level for displaying input gray-level x. However, the luminance-level of the PDP is much restricted in this expression. Therefore, the inverse gamma-corrected value needs to be replaced with an expressible luminance-level. The transformation is defined in a look-up table (LUT), which is determined by modeling the luminance-level using the proposed 9-subfield system [2]. When the output luminance-level is fixed, the output luminance B of the PDP is determined by Eq. (2).

$$B = (L_{MAX} - L_R)\frac{Y}{255} + L_R \tag{2}$$

where L_R is the luminance during a reset and address period, and L_{MAX} is the maximum luminance of the actual PDP. Then, the perceived luminance P by human eyes is experimentally related to the output luminance B of the PDP, as expressed by [3]

$$P = 2.29B^{0.382} \tag{3}$$

An ideal display should have linear perceived luminance characteristics to an input gray-level [4]. As shown in Fig. 1, however, the relationship between the input gray-level of the PDP and the human perceived luminance shows non-linear characteristics. We can find two problems in Fig. 1. The first problem is non-linearity at low gray-levels. Due to the luminance during a reset and address period, it is difficult to represent the linear perceived luminance at low gray-level with the gamma value of 2.2. The second one is low gray-level contours as results of a number of gray-levels are merged into a fixed output luminance-level, especially for low input signal levels up to 50.

In order to compensate the non-linearity of the perceived luminance at a low gray-level, we apply another gamma value of 1.8 to a range under 90 as shown in Eq. (4). In addition, Y needs to be replaced with an expressible luminance-level using LUT [2].

$$Y = \begin{cases} 25.792\left(\dfrac{x}{90}\right)^{1.8} & 0 \le x \le 90 \\ 255\left(\dfrac{x}{255}\right)^{2.2} & 90 < x \le 255 \end{cases} \tag{4}$$

The current study adds one more subfield to the conventional 8-subfield system to improve the low gray-level expression. Generally, in the case of a PDP using a sustain frequency of 200 kHz, two pulses are applied to each electrode, X and Y, to make the first subfield. Therefore, as shown in Fig. 2, the proposed 9-subfield system includes an additional subfield with only one pulse, which is applied to each

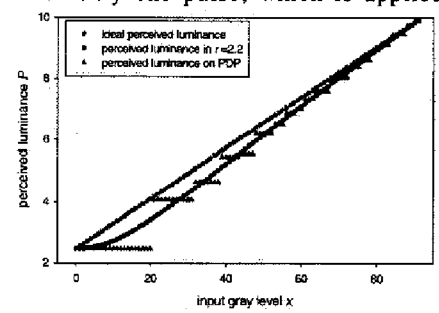

Fig. 1. Relation between input gray-level and perceived luminance on the 8-subfield system using gamma 2.2.

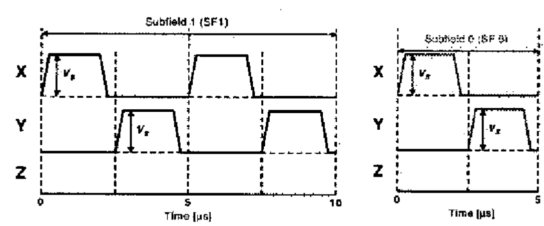

Fig. 2. Addition of subfield 0 in PDP using sustain frequency of 200 kHz.

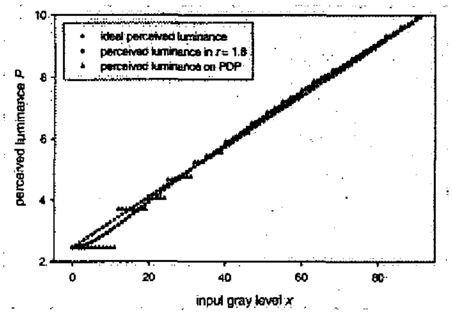

Fig. 3. Relation between input gray-level and perceived luminance on the 9-subfield system using gamma 1.8.

electrode, to express a 0.5-gray-level.

Figure 3 shows relationship between the input gray-level and the perceived luminance on the 9-subfield system using gamma value of 1.8 in the input gray-levels up to 90. Figure 3 shows that perceived luminance linearity is improved much than Fig. 1 in low gray-levels. An error measure was set up to quantify the error between the ideal perceived luminance and those of PDP according to input gray-levels.

$$Error = \sqrt{P_{Ideal}^{\ 2}(x) - P_{PDP}^{\ 2}(x)} \qquad (5)$$

Average error by the extent of an input gray-level is depicted in Fig. 4. The results for the error measure, as shown in Fig. 4, confirmed a significant decrease in error when using the proposed gamma method.

Figure 5 shows luminance-levels of the 8-subfield PDP using conventional gamma method and of the 9-subfield PDP-TV using the proposed gamma method. In a conventional PDP driving scheme, the problem of false contours is serious for low gray-levels, because the input gray-levels between 0 and 20 merge to only one output luminance-level and the input gray-levels between 0 and 50 only have six output luminance-levels. However, in a proposed PDP driving scheme, low gray-level expression is improved based on increasing the number of output gray-levels up to 13 instead of 6 levels in the conventional system used to express the input gray-levels up to 50. Furthermore, only the input gray-levels between 0 and 11 merge to one output luminance-level.

Finally, to reduce low gray-level contour more effectively, we employ error diffusion method based on emission characteristics of the PDP [2]. Figure 6 shows the experimental results for the rose image in which gray-levels are stretched up to 230 for a display purpose. Image (b) is the

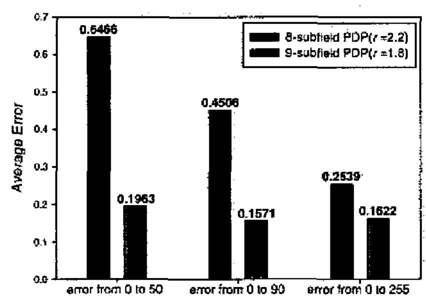

Fig. 4. Comparison of average error values.

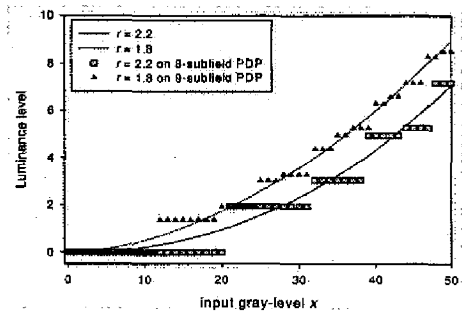

Fig. 5. Available luminance-levels after inverse gamma correction.

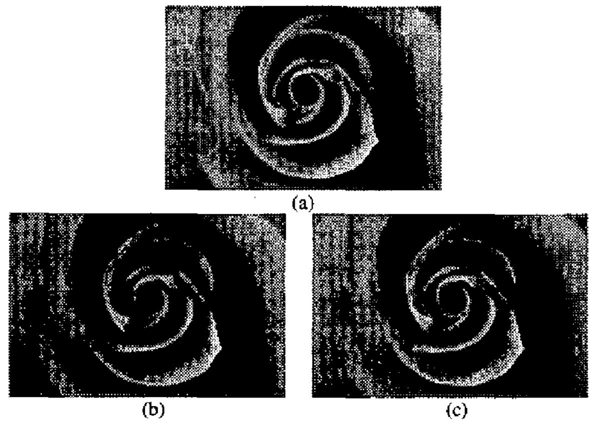

Fig. 6. Simulation results of inverse gamma correction on rose images. (a) Analog method on ideal display, (b) Inverse gamma correction using conventional gamma on 8-subfield system and (c) inverse gamma correction using proposed gamma on 9-subfield system.

simulation result when applying the conventional gamma method, which shows clear low gray-level contours. In contrast, there are almost no low gray-level contours in image (c) when using the proposed method.

III. CONCLUSION

To reduce image quality degradation due to low gray-level contours and non-linearity at low gray-levels, this paper proposed a new method carrying out the error diffusion using the optimal gamma value and the 9-subfield system. Simulation confirmed that the proposed 9-subfield system with error diffusion based on human visual perception is able to significantly improve low gray-level linearity and suppress low gray-level contours in inverse gamma-corrected images on a PDP-TV.

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