采用分段线性的方式对gamma曲线进行 拟合

Image Quality Enhancement by Real-Time Gamma Correction for a CMOS Image Sensor in Mobile Phones

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Abstract— **Real-time gamma correction is an essential function in display devices such as CRTs, plasma TVs, and TFT LCDs [1]. In this paper, we present the image quality enhancement by real-time gamma correction for a CMOS image sensor in mobile phones. The proposed algorithm and system operate with a block structure and the bit width of input and output of the proposed system is 12-bit. The proposed gamma system is reduced the error range and enhanced the image quality compared with conventional system that has 10-bit input and 8-bit output. The proposed system was implemented experimentally by using Xilinx Virtex4 FPGA and was successfully demonstrated with a CMOS image sensor for mobile application.**

Keywords-component;gamma correction, piecewise linear interpolation, booth multiplier

I. Introduction

Gamma correction controls the overall brightness of the images. The images which are not appropriately revised are a possibility of looking pale or too dark. The gamma correction is able to change not only brightness of the images, but also the ratios of RGB. The term, gamma (γ), is constant which is related with the quality of monitors from relationship between the brightness and the input voltage of monitors. Namely, the value of γ is determined experimentally by display characteristics [2]. The relationship between the brightness (intensity) and the input voltage of monitors has the characteristic of the exponential function which is nonlinear. The nonlinear luminance produced by display devices can be described with Eq. (1).

$$f(x) = x^{\gamma} \tag{1}$$

The value of x is between 0 and 1 because of the x is related with the power of the signal amplitude. If the value of γ is constant, Eq. (1) is inverted to Eq. (2).

$$f^{-1}(x) = x^{1/\gamma} \tag{2}$$

Fig. 1 shows the effect of gamma correction. Eq. (1) indicates the red line, asterisk sign: *, (Display Characteristic), Eq. (2) indicates the blue line, square sign: □ (Transmitted Pre-correction). When the value of x is between 0 and 1, and the value of γ is constant if the linear data is entered to the display device, the results seem with quality of brightness produced by display devices which is nonlinear curve which comes to bend in lower part. So, the curve which comes to bend in upper part (Transmitted Pre-correction) is entered to the display devices to get the results which are linear line at Fig. 1 which indicates the green line, circle sign: ○. Like this progress is Gamma Correction. Briefly, the Gamma Correction is revising the nonlinear luminance produced by display devices with the linear straight line [3]. From now, we call Transmitted Pre-correction with the gamma curve.

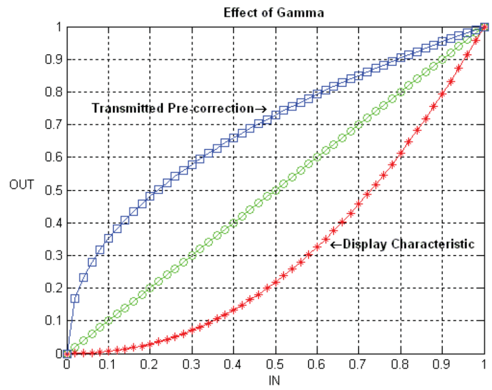


Figure 1. Effect of Gamma Correction[3]

In this paper, we compared the conventional gamma correction algorithm which has 10-bit input and 8-bit output and the proposed algorithm which expands the input and output of the conventional algorithm with 12-bit input and output. The algorithms use piecewise linear interpolation to consider structuring Eq. (2) with the hardware.

II. Fundamental Algorithms

A. Piecewise Linear Interpolation

A curve can be approximated by a straight line over a small interval. First, two points on the curve of *f(x)* are found, we suppose x is between the two points. When we draw the straight line which connects the two points as shown in Fig. 2, the value of *f(x)* and *p(x)* are different. Eq. (3) describes about relationship of *f(x)* and *p(x)* as the value of *f(x)* and *p(x)* are close.

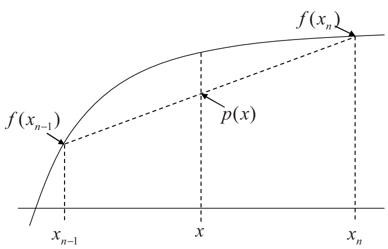


Figure 2. The method of Linear Interpolation[3]

$$p(x) = \frac{f(x_n) - f(x_{n-1})}{x_n - x_{n-1}}(x_n - x) \tag{3}$$

Piecewise linear interpolation expands this progress to the whole curve as shown in Fig. 3.

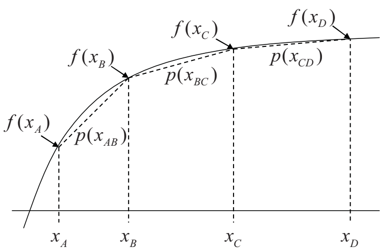


Figure 3. The method of Piecewise Linear Interpolation[3]

We divide *f(x)* into three sections to get more precisions. And we can describe Eq. (4) as *f(x)* is close to connection of each section [3].

$$f(x) \cong p(x) = p_1(x)\Big|_{x=A}^{x=B} + p_2(x)\Big|_{x=B+1}^{x=C} + p_3(x)\Big|_{x=C+1}^{x=D} \tag{4}$$

We compared with gamma function and both the conventional algorithm and the proposed algorithm. When we compared with them, we changed the value of γ into 2.2, 2.0, 1.8, 1.6, 1.4, 1.2, and 1.0.

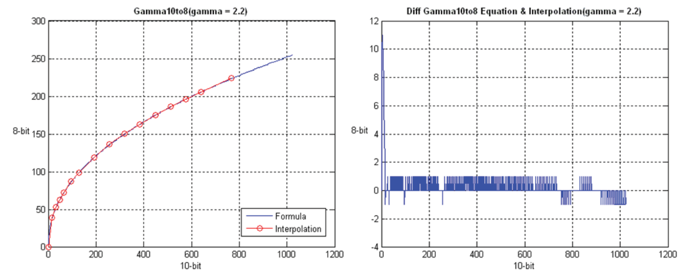
B. *Conventional Gamma Correction*

The conventional algorithm which has 10-bit input and 8-bit output uses the piecewise linear interpolation divided by 15 sections. These sections are expressed by each simple equation. Eq. (5) indicates the conventional piecewise linear interpolation.

$$f(x) \cong p_1(x)\Big|_{x=X_1}^{x=X_2} + p_2(x)\Big|_{x=X_2+1}^{x=X_3} + \cdots + p_{16}(x)\Big|_{x=X_{16}+1}^{x=X_{17}} \tag{5}$$

Eq. (6) presents revised Eq. (2) with 10-bit input and 8-bit output. Eq. (6) is to compare the gamma curve of the conventional algorithm and approximately ideal gamma curve.

$$f(x) = (2^8 - 1)\left(\frac{x}{2^{10} - 1}\right)^{1/\gamma} \tag{6}$$



(a) (b)

Figure 4. (a) Results by Eq. (6) and the conventional algorithm (b)Difference between results by Eq. (6) and the conventional algorithm (γ = 2.2)

The input of the conventional algorithm and Eq. (6) is 0 ~ 1023 and the output is 0 ~ 255. Fig. 4(a) shows the results by Eq. (6) and the conventional algorithm when the value of γ is 2.2, simultaneously. As you can see in Fig 4(a), we know two curves are analogous. Fig. 4(b) shows the difference that the error range is between -1 and +11.

Table 1 shows the difference (error range), mean squared error (MSE), and standard deviation (STD). It is about the results of the difference in Fig. 4(b) depend on each the value of γ.

TABLE I. THE RESULTS OF CONVENTIONAL ALGORITHM

Gamma	Difference	MSE(LSB)	STD(LSB)
2.2	-1~11	1.2020	1.0647
2.0	-2~7	0.8673	0.8695
1.8	-2~6	0.6732	0.7409
1.6	-1~4	0.6273	0.6412
1.4	-2~2	0.5434	0.5873
1.2	-2~1	0.5902	0.5567
1.0	-1~0	0.4985	0.5002

We can discover that the larger the value of γ, the larger error range. Consequently, we propose the algorithm which has the expanded input and output with 12-bit to reduce the error range and to make more analogous two gamma curves.

C. *Proposed Gamma Correction*

The proposed gamma correction which has 12-bit input and output uses the piecewise linear interpolation divided by 30 sections. These sections are expressed by each simple equation. Eq. (7) indicates the proposed piecewise linear interpolation. In this paper, we propose that the increment of section length is 2's power to reduce hardware complexity and to improve the image quality when we divide the sections of gamma curve. The larger the input, the larger the increment of section length since the variation of gamma curve slope is very large in case of the small input.

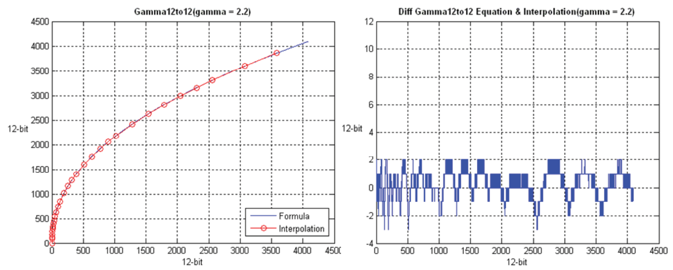
$$f(x) \cong p_1(x)\Big|_{x=X_1}^{x=X_2} + p_2(x)\Big|_{x=X_2+1}^{x=X_3} + \cdots + p_{30}(x)\Big|_{x=X_{30}+1}^{x=X_{31}} \tag{7}$$

Eq. (8) presents revised Eq. (2) with 12-bit input and output. Eq. (8) is to compare the gamma curve of the proposed algorithm and approximately ideal gamma curve.

$$f(x) = (2^{12} - 1)\left(\frac{x}{2^{12} - 1}\right)^{1/\gamma} \quad (8)$$

The input and output of the proposed algorithm and Eq. (8) are between 0 and 4095. Fig. 6(a) shows the results by the formula and the proposed algorithm when the value of γ is 2.2. The result of formula is the blue line, and the result of the proposed algorithm is the red line and circle. It appears that the two curves are analogous. Fig. 6(b) shows the difference between the formula results and the proposed results.

The input of the proposed algorithm and Eq. (8) is 0 ~ 4095 and the output is 0 ~ 4095. Fig. 5(a) shows the results by Eq. (8) and the proposed algorithm when the value of γ is 2.2, simultaneously. As you can see in Fig 5(a), we know two curves are analogous. Fig. 5(b) shows the difference that the error range is between -3 and +2.



(a) (b)

Figure 5. (a) Results by Eq. (8) and the proposed algorithm (b)Difference between results by Eq. (8) and the proposed algorithm (γ = 2.2)

Table 2 shows the difference (error range), mean squared error (MSE), and standard deviation (STD). It is about the results of the difference in Fig. 5(b) depend on each the value of γ.

TABLE II. THE RESULTS OF PROPOSED ALGORITHM

Gamma	Difference	MSE(LSB)	STD(LSB)
2.2	-3~2	1.0605	0.9893
2.0	-3~2	0.8501	0.9219
1.8	-3~2	0.8342	0.9121
1.6	-2~2	0.7173	0.8433
1.4	-3~2	0.5869	0.7547
1.2	-2~1	0.3525	0.5897
1.0	0	0	0

We can discover that the error range of the proposed algorithm is smaller than the conventional algorithm. Specially, when the value of γ is 2.2, the error range reduces between -3 and +2 from between -1 and +11, and the MSE and STD reduces, too. In case of other value of γ, MSE and STD of the proposed algorithm is larger than the conventional algorithm, because the conventional algorithm has 10-bit input and 8-bit output, on the other hand the proposed algorithm has 12-bit input and output. However, the error rate of the proposed algorithm is not larger than the conventional algorithm, if we consider that the maximum of 8-bit and 12-bit is respectively 255 and 4095.

D. *Comparison Results*

Table 3 shows the results of the comparison with the conventional and the proposed algorithm about input bits, output bits, difference, MSE, and STD.

As you can see in Table 3, we know that difference, MSE, and STD of the proposed algorithm is the smaller than the conventional.

TABLE III. THE RESULTS OF COMPARISON

	Conventional System	Proposed System
Input[bit]	10	12
Output[bit]	8	12
Difference	-1~11	-3~2
MSE(LSB)	681.3320	1.0605
STD(LSB)	15.3663	0.9893

III. ARCHITECTURE

Fig. 6 shows the block diagram of the proposed system at R-channel. The block diagrams of G and B-channel are equal to Fig. 6. The proposed system consists of five major blocks; Sect_Sel, Y_Seed_Sel, Slope_ACC, X_Inc_ACC, and Booth_Multiplier.

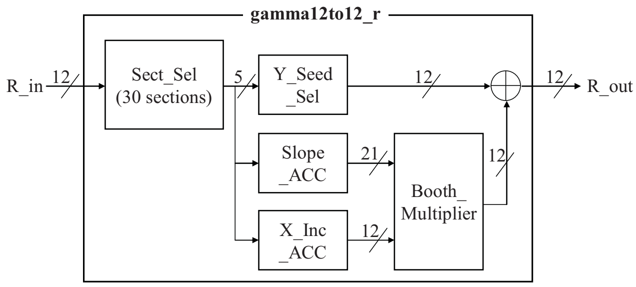


Figure 6. Block diaram of the proposed system (R-channel)

The digitized data in the 12-bit RGB data from the CMOS image sensor is inputted into the proposed system. The Sect_Sel block selects section of input data. The Y_Seed_Sel block selects the arranged y of the section. The Slope_ACC block accumulates the slope of simple equation of the section. The X_Inc_ACC block accumulates the increment of input data and arranged x of the section. The Booth_Multiplier block multiplies the Slope_ACC results and X_Inc_ACC results of the section. The block simplifies a multiplier with shifter and adder to consider the hardware operation time. To multiply, first, the block translates the X_Inc_ACC results to sum of the 2's power. Then, it shifts the Slope_ACC results to left as the degree of each the translated result. Finally, it adds each the result of the left shift.

IV. Hardware Experimental Results

The both of systems are designed using Verilog-HDL and are verified using the Synopsys simulator. The systems are synthesized into gates to observe hardware complexity by using the Synopsys synthesizer with the TSMC 0.25μm ASIC library, as shown in Table 4.

TABLE IV. GATE COUNTS

	Conventional System	Proposed System
Max timing[ns]	13.28	13.44
Gate Counts[EA]	8307	29399

Fig. 7 shows an FPGA demonstration board for the proposed system. There are three major building devices which comprise a CMOS sensor module, a USB-to-PC interface, and a Xilinx XC4VLX100-FF1148 FPGA device. The image data inputted from a CMOS sensor is processed by the Xilinx device and the processed data is then transferred to the display device by using a USB-to-PC interface.

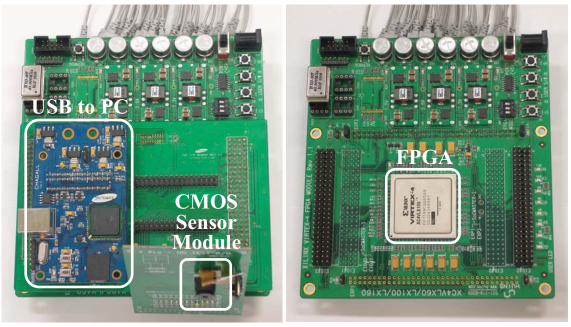


Figure 7. A FPGA demonstration board

The conventional and proposed algorithms are compared by FPGA demonstration board. Fig. 8(a) is an input image, Fig. 8(b) shows the result by the conventional algorithm when the value of γ is 2.2, and Fig. 8(c) shows the result by the proposed algorithm when the value of γ is 2.2. We use the white circle of Fig. 8 to compare Fig. 8(b) and Fig. 8(c) since it is difficult that we find the difference between Fig. 8(b) and Fig. 8(c).

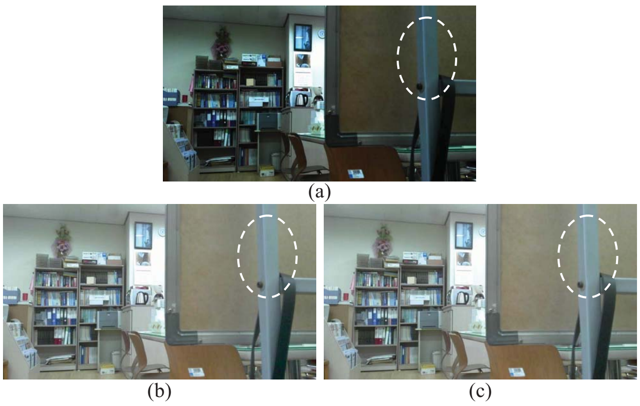


Figure 8. (a) The input image (b) The result applying the algorithm of conventional (γ = 2.2) (c) The result applying the proposed algorithm (γ = 2.2)

Fig. 9 shows the results of comparison with the conventional and the proposed algorithm. The result applying the gamma function to input image is the blue line and spot. The result applying the conventional algorithm is the green line and asterisk and the proposed algorithm is the red line and circle. Fig. 9 compares them in RGB-channels.

We can discover that the result image of the proposed algorithm is closer than the conventional algorithm to the result applying the gamma function.

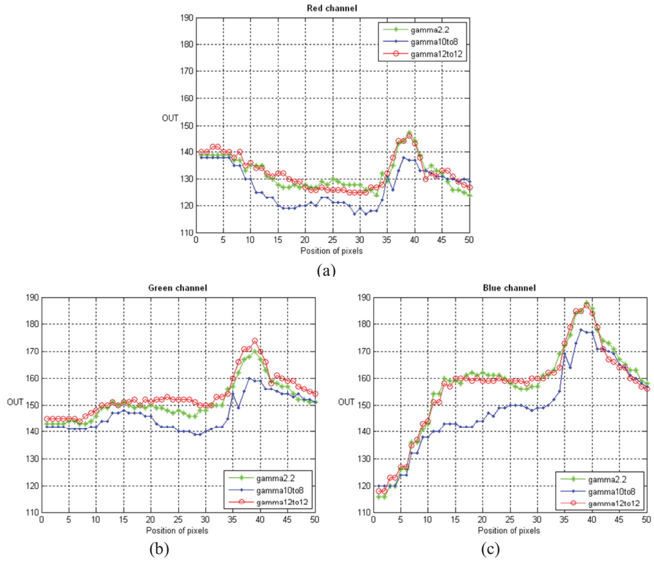


Figure 9. The comparison with the conventional algorithm and the proposed algorithm: (a) R-channel (b) G-channel (c) B-channel

V. Conclusion

We have discussed and compared the correction algorithm of conventional which has 10-bit input and 8-bit output and the gamma function (Eq. (6)). And we have discussed and compared the proposed gamma correction algorithm which has 12-bit input and output and the gamma function (Eq. (8)). And then, we have compared the two compared results to discuss and compare the algorithm of conventional and the proposed algorithm. Consequently, we can evaluate that the proposed algorithm is more improved performance than the algorithm of conventional by Table 3, Table 4 and Fig. (8). Although the gate counts of proposed system are more complex than the conventional, the image quality of proposed system is improved than the conventional

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