Simple Adaptive HDR System using Gamma Correction Circuit with Variable Gamma Value

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ABSTRACT

To apply to simple surveillance systems, which are equipped with small camera device such as web camera, we proposed a small-scale adaptive HDR system. Furthermore, we developed new gamma correction circuit to be installed in our system to correct image degradation in the camera image.

1 Introduction

Surveillance cameras, used for day and night to prevent crime, are used to capture images in significant different illuminance with blown out and black down. These image degradations cannot be fully repaired without correction in the camera device itself [1]. However, in general correction systems, the histogram characteristics of images must be corrected using large-scale high-speed digital circuits and programs [2]. Therefore, it has been difficult to apply this method to image quality correction of small cameras used in simple surveillance systems. We proposed new small-scale adaptive HDR (High Dynamic Range) system, automatically supporting for light and dark conditions, that can be applied to the small camera devices. Proposed system is expected to be widely used with small cameras such as web camera. In addition, we have developed a gamma correction circuit that can be implemented in our HDR system to correct image degradation.

2 Proposal and Design of Adaptive HDR System

2.1 Proposed System

The block diagram of the proposed adaptive HDR system is shown in Figure 1 [3][4]. Gamma-corrected video signals are transmitted via the Internet or radio waves, following the changing average luminance value La detected from the output video signal of the camera device.

2.2 Correlation between Image Degradation and Average Luminance of the Original Image

Figure 2(a) shows an example of an image with black down, and Figure 2(b) shows an image after corrected. It is expected that an image with black bars tends to lose low-luminance tones because the average luminance is lower than the mid-range tones.

Figure 3(a) shows an example of an image with blown out and Figure 3(b) shows an image after corrected. Figure 3(a) shows that the average luminance La of the image with blown out is higher than that of the intermediate tones, which is expected to result in the loss of high-luminance tones.

Therefore, we asked eight subjects to evaluate the degree of image degradation for five different images using the subjective evaluation values shown in Table 1.

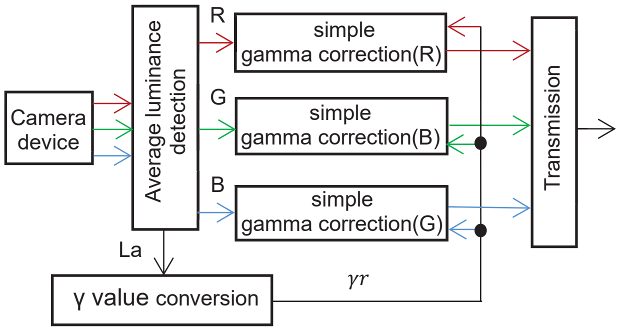

Fig. 1 Block diagram of proposed system

(a) Before correcting (b). After corrected

Fig. 2 Example of black down image

(a) Before correcting (b). After corrected

Fig. 3 Example of blown out image

Table 1. Subjective evaluation value on image damage

Evaluation value Ew: blown out Eb: black down	Image degradation
1	very superior
2	slightly superior
3	cannot say either way
4	slightly bad
5	very bad

Figure 4 shows the measurement results of subjective evaluation according to the average luminance value La of five types of images (3 types: black down, 2 types: blown out) [5]. From Figure 4, the effect of black down is significant for images with low average luminance values and blown is noticeable for images with high average luminance values.

Figure 5 shows the relationship between the gamma correction value and the average luminance value La of the original image when the evaluation value becomes 3 or lower and the image degradation is generally resolved. However, in Figure 5, the values for black down and blown out are used for the original images whose average luminance La is less than 128 or greater than 128, respectively. Figure 5 shows that the optimal gamma correction value γr for the average luminance La can be expressed by Equation (1). Where γr should be larger than zero.

$$\gamma r = La(5.0 \times 10^{-5} La + 0.0021) \quad (1)$$

Using the above equation, the gamma-corrected images are shown in Figures 2(b) and 3(b).

However, because the optimal gamma correction value γr in Figure 1 was switched separately for black down and blown out, blown out occurred in the black down corrected image and black down occurred in the blown out corrected image. Simultaneous improvement of both image quality degradations is a future issue.

2.3 Gamma Correction in this System

As shown in Figure 6, the gamma correction characteristics can be analyzed using a gradation characteristic graph with the captured image luminance Lin on the horizontal axis and the output image luminance Lout in relation to it on the vertical axis [6]. The relationship between the captured image luminance and output image luminance in a surveillance camera can be expressed by Equation (2) [7].

$$L_{out} = L_{in}{}^{\gamma} \quad (2)$$

As shown in Figure 6, the output video luminance Lout has a nonlinear characteristic proportional to the input captured video luminance Lin. when γ = 1, the characteristics of the uncorrected condition are shown. When γ < 1, the image becomes brighter on average and the luminance change in dark areas is emphasized; when γ > 1, the image becomes darker on average and the luminance change in bright areas is emphasized [8].

3 Gamma Correction Circuit Capable of Changing the Power Exponent to Any Value

A block diagram of the gamma correction circuit is shown in Figure 7 [9] [10]. In this circuit, the logarithmically converted input signal Vin is multiplied by the exponent value γ and then converted to an exponent. By electronically varying the exponent value γ used for multiplication, the exponent can be instantly controlled.

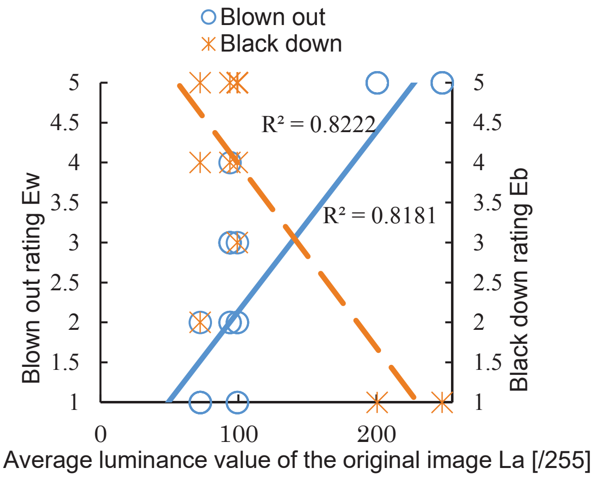

Fig. 4 Subjective evaluation results of the image

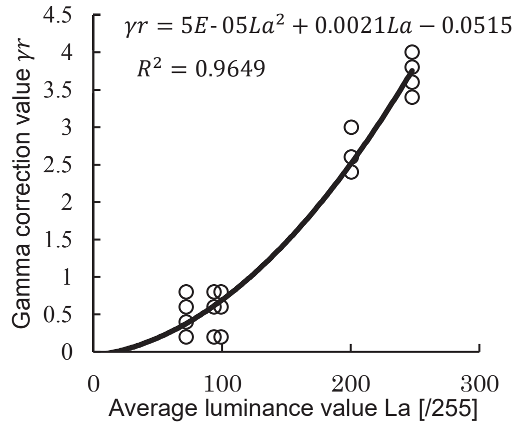

Fig. 5 Average luminance value-the Optimal gamma correction value characteristics

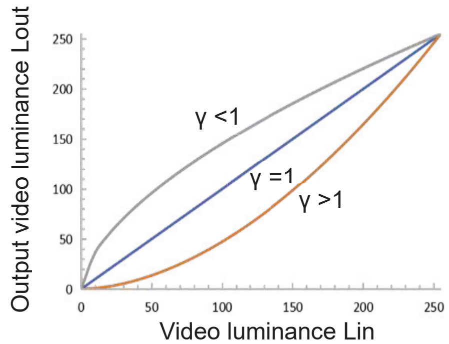

Fig. 6 Gamma correction characteristics in proposed circuit

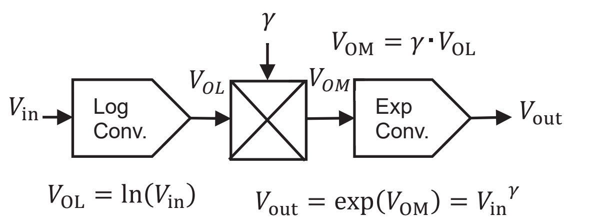

Fig. 7 Block diagram of gamma correction circuit

3.1 Design of Gamma Correction Circuit

The prototype gamma correction circuit is shown in Figure 8. Until now, our laboratory has achieved the logarithmic and exponential characteristics required for signal conversion using MOSFET pairs that operate in weak inversion in integrated circuits (11). In this study, a high-speed power conversion circuit is realized by measuring and sorting a pair of commercially available individual component transistors in order to accommodate high-speed video signals.

3.2 Logarithmic Conversion Circuit

The logarithmic conversion section uses bipolar transistor pairs Q_2 and Q_3 as the logarithmic voltage conversion devices for the signal current. The logarithmic conversion voltage V_{OL} generated by I_{E2} proportional to the input voltage V_{in} and the current I_{E3} flowing in R_5 can be expressed by Equation (3).

$$V_{OL} = X1 - X2 = V_t \cdot ln\left(\frac{IE2}{IE3}\right) = V_t \cdot ln\left(\frac{V_{in}}{IE3 \cdot R4}\right) \quad (3)$$

3.3 Multiplier Circuit

The exponent value γ to be multiplied in the multiplication circuit can be varied by the gamma control voltage Vγ. A four-quadrant analog multiplier MP is used to obtain the multiplication output voltage V_{OM} by multiplying the output V_{OL} of the logarithmic converter by Vγ. V_{OM} can be expressed by Equation (4).

$$V_{OM} = \frac{(X1 - X2) \cdot (Y1 - Y2)}{10V} \cdot \frac{R12 + R13}{R12} = \frac{V\gamma}{2} \cdot V_t \cdot ln\left(\frac{V_{in}}{IE3 \cdot R4}\right) \quad (4)$$

3.4 Exponential Conversion Circuit

In the exponential converter section, bipolar transistor pair Q_5 and Q_6 are used as conversion devices of signal voltage to exponential current. the output voltage V_{out} proportional to the constant current I_{E5} flowing in R_{14} can be expressed by Equation (5).

$$V_{out} = IE5 \cdot R15 \cdot e^{\frac{VOM}{Vt}} \quad (5)$$

From Equation (3), Equation (4) and Equation (5), the relationship between input voltage V_{in} and output voltage V_{out} can be expressed by Equation (6).

$$V_{out} = V_{in}^{\frac{V\gamma}{2}} \quad (6)$$

The power exponent value γ is the value in Equation (7).

$$\gamma = \frac{V\gamma}{2} \quad (7)$$

4 Control Circuit for the HDR System

This system is applicable to small cameras such as web camera. In this study, we used a surveillance camera that utilizes a microcontroller board Raspberry Pi installed in our laboratory. The microcontroller board connected to a web camera, outputs PWM signal converted from the average luminance La of captured image [11].

5 Experimental Results

5.1 Logarithmic Conversion Circuit

The conversion characteristics of the logarithmic conversion circuit are shown in Figure 9. The logarithmic characteristic of the input voltage on a logarithmic scale is a straight line from 0.1V to 3.5V, and the logarithmic characteristic shown in the above Equation (3) is obtained.

5.2 Multiplier Circuit

In Equation (7), when the voltage Vγ is controlled at 1.0 V, 2.0 V, and 4.0 V, the power exponent value γ is set at 0.50, 1.0, and 2.0.

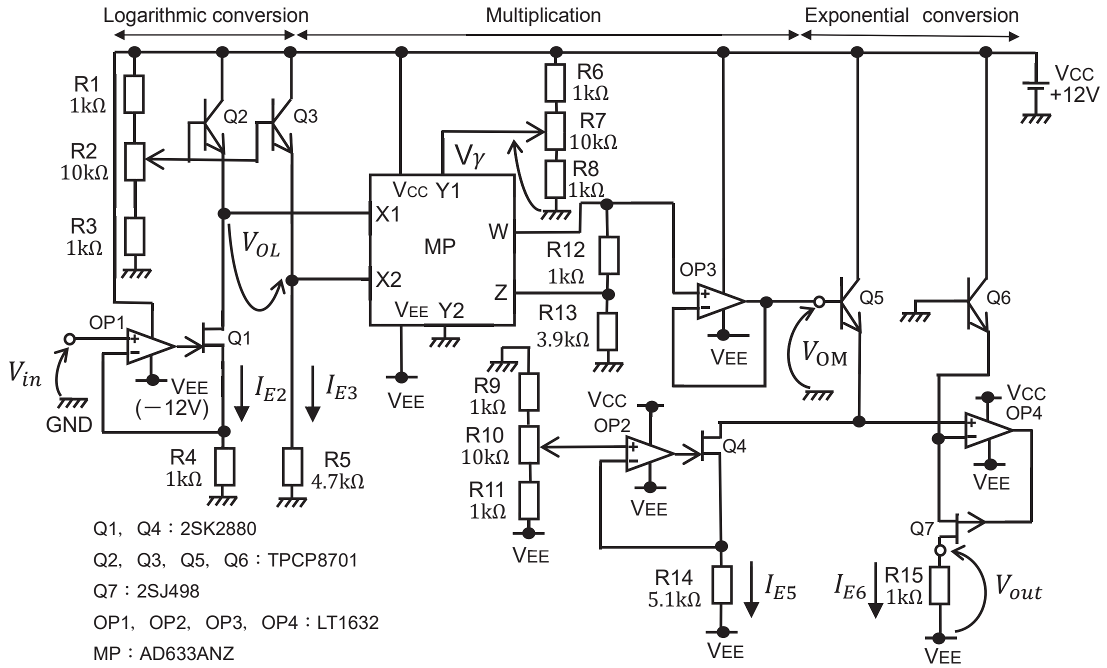

Fig. 8 Circuit configuration of the Gamma correction

5.3 Exponential Conversion Circuit

The conversion characteristics of the exponential conversion circuit are shown in Figure 10. It can be seen that the characteristic line with the output voltage on a logarithmic scale is approximately a straight line from 0.3V to 4V, satisfying Equation (5).

5.4 Input/Output Characteristics of the Overall Circuit

The input-output characteristics of the entire circuit are shown in Figure 11, where all three characteristic curves intersect at a single operating point (1.0V, 1.0V) at the input-output reference voltage, indicating that Equation (6) is satisfied.

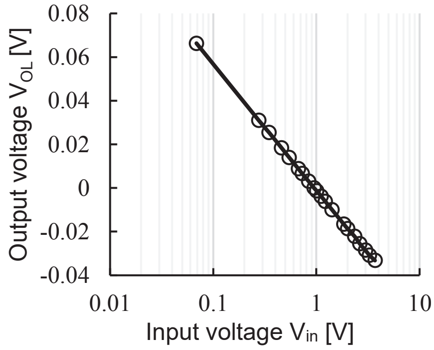

Fig. 9 Converting characteristic of logarithmic converting circuit

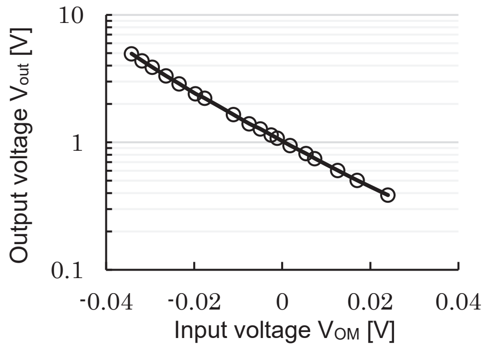

Fig. 10 Converting characteristic of exponential converting circuit

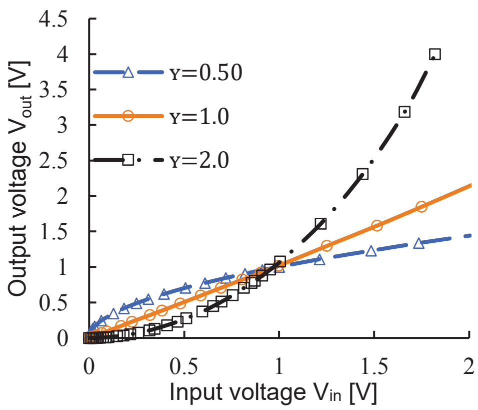

Fig. 11 Input-output characteristics of the overall circuit (Liner scale)

6 Conclusions

An adaptive HDR system was proposed to solve video degradation in a small-scale surveillance system using small camera elements. It is shown that the system can generally compensate for image degradation by controlling the gamma correction value according to the average luminance value of the captured images. We also proposed a formula for converting average luminance values to gamma correction values.

We also proposed and fabricated a prototype gamma correction circuit for use in an adaptive HDR system, and confirmed that the exponential values can be electronically controlled as designed. We also confirmed that the proposed gamma correction circuit improved the image quality.

Future task is correcting image damages of black down and blown out at the same time. And another task is to increase higher cut off frequency of the gamma correction circuit.

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