An Image Coding Algorithm with Color Constancy Using the Retinex Theory and the Naka-Rushton Equation

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Abstract

We proposed an image-coding algorithm with color constancy based on the center / surround (C/S) retinex model and the Naka-Rushton (N-R) equation; this equation was used in place of the logarithmic function used in the original C/S retinex model in order to encode the intensity information efficiently. Using images acquired at different periods of a day, we compared the output of our algorithm with the original C/S retinex algorithm. The results suggested that the N-R equation can improve the color constancy performance.

Keywords: color constancy, retinex, image sensor, bio-inspired

1. Introduction

Color is a useful cue for image understanding, and is used in a wide range of image processing systems. However, estimating the intrinsic color of an object from an image can be a difficult task because the apparent color changes depending on the color of illumination. Therefore, methods for reducing the influence of illumination changes are required to use color information.

We humans have ability to perceive the appropriate color under a wide range of colored illumination, and the ability is called color constancy. The retinex model is a widely known computational model for achieving color constancy.[1] A lot of modified models have been proposed based on the retinex model.[2] Among such models, one of the most practical models is the center / surround (C/S) retinex model.[3] The model showed that applying logarithmic compression and a C/S antagonistic spatial filter, such as difference of Gaussians (DoG) filter, to three color channels (RGB) of images is a promising way to achieve color constancy. Hardware implementation of a part of the retinex model was also proposed.[4,5]

In the previous study, we have developed a compact image sensor system with color constancy based on the retinex model.[6] The system was composed of an image sensor and a field-programmable gate array (FPGA) with the following functions required by the retinex model: logarithmic compression and DoG filtering. The system was compared with the gray world (GW) algorithm, which is a widely used white-balancing algorithm,[7] in terms of the coded color information and showed a better performance.

However, the color representation of the system was less stable in a particular environment including outdoors. One of the possible reasons for this is the characteristics of the logarithmic compression, whose compression ratio is extremely high in the bright region whereas the ratio is

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relatively low in the dark region. When a large number of gray levels is assigned to dark regions, the gray levels for representing the target object can be insufficient. Efficient compression method is required.

In the present study, we proposed an image coding algorithm with color constancy using the retinex model and the Naka-Rushton (N-R) equation.[8] Employing the N-R equation in place of the logarithmic function is a possible solution for the problem of the compression ratio described above because the balance of the compression ratio is controllable by changing a particular parameter in the N-R equation. We examined the effect of the parameter on the represented color and compared the proposed algorithm with the original C/S retinex model in terms of the coded color information.

2. Color constancy algorithm

2.1. *Center / Surround retinex model*

Fig. 1 (a) shows the flow of the color constancy algorithm based on the C/S retinex model. This algorithm consists mainly of the following three steps: logarithmic transformation, Gaussian filtering, and subtraction of two Gaussian filtered images. These procedures are applied separately to the RGB three channels.

First, the light intensity I, which is the product of the illumination intensity E and the object reflectance ρ, is compressed logarithmically. This process separates the product of the terms into a sum form as follows:

$$\begin{aligned} L(x,y) &= \log I(x,y) \\ &= \log E(x,y) + \log \rho(x,y) \, . \end{aligned} \quad (1)$$

Here, (x, y) represents the coordinates of the image.

Next, Gaussian filters $g(x, y; \sigma)$ with two different standard deviations (σ_1, σ_2 ($\sigma_1 < \sigma_2$)) are applied to the logarithmic image.

Finally, a DoG image is given by the subtraction of the two Gaussian filtered images:

$$\begin{aligned} X(x,y) &= g(\sigma_1) * L(x,y) - g(\sigma_2) * L(x,y) \\ &= g(\sigma_1) * \log E(x,y) - g(\sigma_2) * \log E(x,y) \\ &+ g(\sigma_1) * \log \rho(x,y) - g(\sigma_2) * \log \rho(x,y) \, . \end{aligned} \quad (2)$$

Here, $*$ represents convolution, and the Gaussian kernel $g(x, y; \sigma)$ is denoted as $g(\sigma)$. In this study, we designed filters so that the integrals of the weights of these two filters equal, and therefore, the uniform change of illumination light should be canceled out.

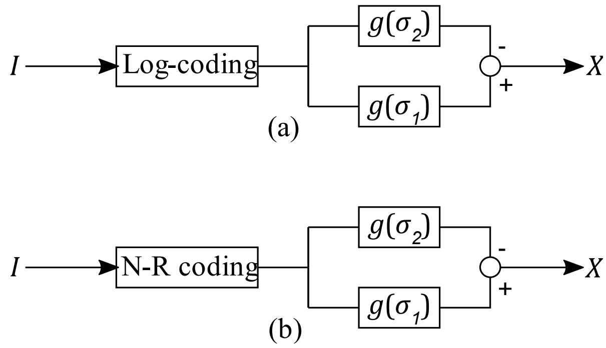

Fig. 1. Processing flow of the C/S retinex model. (a) Original C/S retinex model. (b) Proposed C/S retinex model with N-R equation.

The above procedures are applied separately to the RGB channels, yielding images X_R, X_G, and X_B, respectively, in which the influence of illumination is reduced.

In this study, we proposed an image coding algorithm with color constancy based on the C/S retinex model by replacing the logarithmic transformation with the N-R equation (Fig. 1 (b)).

2.2. *Naka-Rushton equation*

It is known that the response of photoreceptor cells of the biological retina to light stimuli follows the N-R equation[9]:

$$V = V_m \frac{I^n}{I^n + I_h^n}, \quad (3)$$

where V is the response of photoreceptor cells, V_m is the maximum response value, I is the light intensity, I_h is the parameter that changes depending on the adaptation state. n is a fitting parameter whose values for actual animals are between 0.7 and 1. In this study, we set $n = 1$.

Fig. 2 shows the input-output relationship of the logarithm and the N-R equation. Compared to the logarithm, the N-R equation spends less values to express the low-luminance information, and more values to express the high-luminance information. The problem of the logarithmic transformation, in which too much values are assigned to low-luminance information, can be alleviated by the above property of the N-R equation. The

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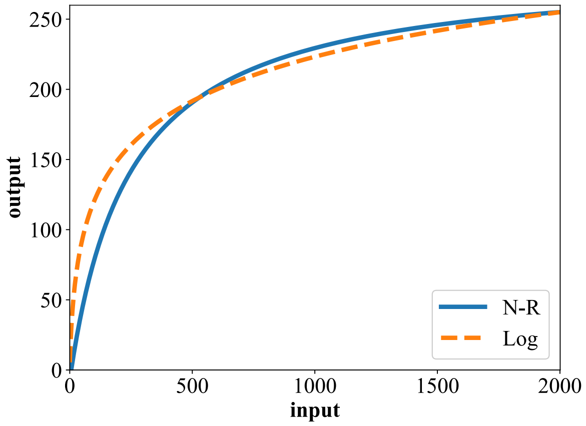

Fig. 2. Input-output relationship of the logarithmic function and the Naka-Rushton equation. The dashed and solid lines plot the logarithmic function and the Naka-Rushton equation, respectively.

N-R equation also has the advantage that the response characteristics can be easily controlled by changing I_h.

Also, the N-R equation with $n = 1$ is approximated by logarithmic function at the neighborhood of $I = I_h$, and therefore, the cancelation of illumination described in section 2.1 can be also applied to the proposed model for a particular range of light intensity.

2.3. *Parameters for Naka-Rushton equation*

The algorithm proposed in this study uses the N-R equation to compress the input image *I*. Eq. (4) is the implemented form of the equation, and is obtained by adding parameter I_{min} to Eq. (3) and by setting $n = 1$.

$$V = \begin{cases} V_m \dfrac{(I - I_{min})}{(I - I_{min}) + I_h} & (I_{min} \le I \le I_{max}) \\ 0 & (I < I_{min}) \\ 255 & (I > I_{max}) \end{cases} \qquad (4)$$

where I_{min} and I_{max} represent the minimum and maximum pixel values to be converted. Values for I_{min} and I_{max} were determined by the cumulative histogram $H_c(k)$ of the input image, where k is the pixel value, instead of using the actual minimum and maximum pixel values for I_{min} and I_{max} directly because these values can fluctuate greatly for each frame. For convenience, the minimum values of k that satisfy inequality (5) and (6) were used for I_{min} and I_{max}, respectively.

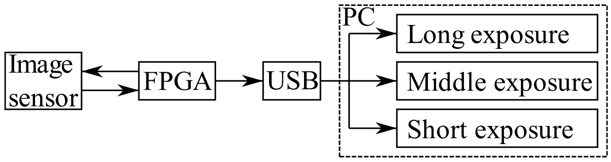

Fig. 3. System structure. The FPGA sends images acquired with three different exposure times to the PC, and the three images are recorded separately in the PC.

$$H_c(k) > \frac{N_T}{256} \qquad (5)$$

$$H_c(k) > N_T - \frac{N_T}{256} \qquad (6)$$

Here, N_T represents the total number of pixels. In this study, $N_T = 19200$.

V_m was determined so that the maximum value of V became 255 and is given by:

$$V_m = \frac{255(I_{max} - I_{min} + I_h)}{I_{max} - I_{min}}$$

I_h is a parameter that affects the characteristics of the converted image. In this study, we investigated how the performance of color constancy was influenced by the value of I_h. The minimum value of k that satisfies inequality (7) was used for I_h:

$$H_c(k) > N_r. \qquad (7)$$

The value of N_r was selected from 1000 to 19000 in the present study. The performance of color constancy was evaluated by changing N_r.

3. Experiments and Results

3.1. *Environment for experiment*

Fig. 3 shows the system structure used in this study. The system mainly consists of a CMOS image sensor (OmniVision, OV5642) and an FPGA (Xilinx Artix-7 XC7A100T). Three images with eight-bit data of 160 × 120 pixels acquired by the image sensor with three different exposure times are sent to a PC via the FPGA and a USB interface, and are recorded in the PC. These

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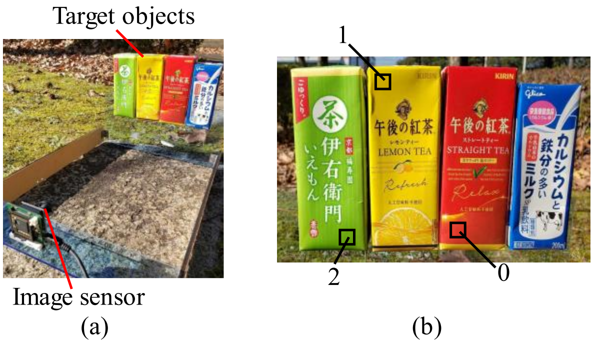

Fig. 4. (a) Outdoor environment for the experiment. (b) Target objects (green, yellow, red, and blue). Three regions (0, 1, and 2) indicated in the figure was used in the experiment.

three images are integrated into one image by replacing overexposure pixels, which was defined as pixels whose values exceeded 240, with pixels acquired with a shorter exposure time. We applied the C/S retinex algorithm with the N-R equation, hereinafter referred to as N-R C/S retinex, and the original C/S retinex algorithm to the image data. We evaluated the results in accordance with the method explained in Section 3.2.

Fig. 4 (a) shows the outdoor environment for the experiment, in which images were acquired at different periods of a day (i.e., at the daytime and the evening). Beverage cartons (Fig. 4 (b)) of four colors (green, yellow, red, and blue) were used as subjects.

3.2. *Data analysis*

In this study, we investigated the effect of the value of I_h in the N-R equation on the color constancy performance by changing N_r, and compared the color constancy performance of the N-R C/S retinex and the original retinex. The color constancy performance was evaluated in terms of the hue value in the HSV color space of the image processed by the retinex model.

Here, the HSV color space is a color space expressed by hue, saturation, and brightness. Hue expresses the type of color in the range of 0 to 360. Saturation expresses color vividness in the range of 0 to 100 %. The brightness expresses the brightness of the color in the range of 0 to 100 %.

3.3. *Results*

Fig. 5 shows the relationship between N_r and the hue in regions 0, 1, and 2, which are shown in Fig. 4, of the

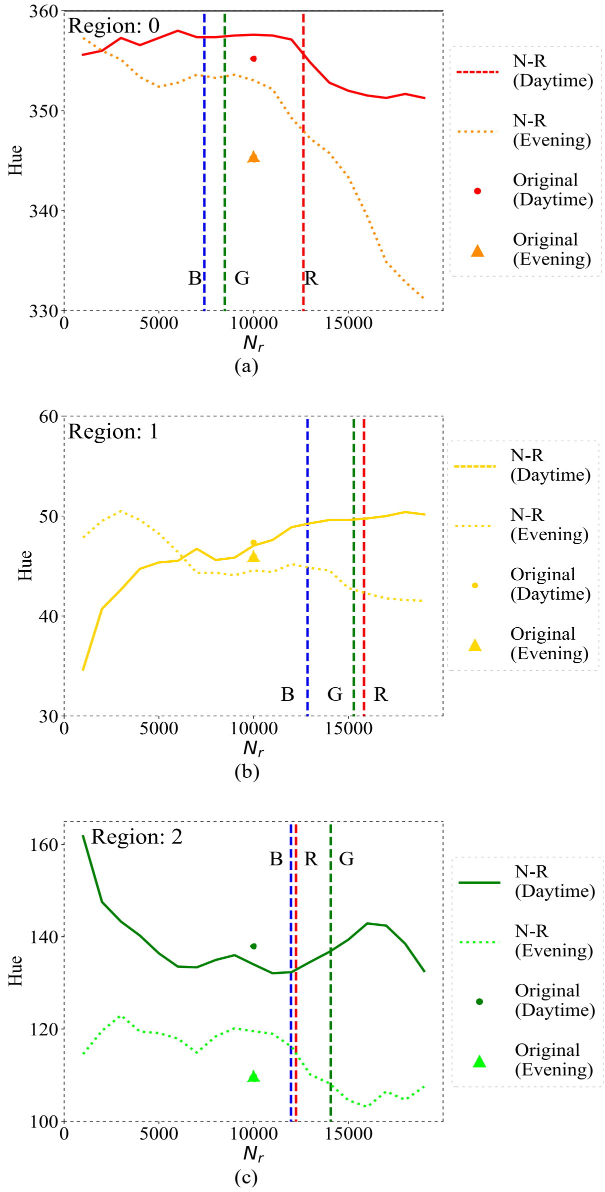

Fig. 5. Relationship between $\boldsymbol{N_r}$ and the hue of the output image. (a)(b) and (c) show the relationship in regions 0, 1, and 2 (shown in Fig. 4), respectively. The vertical dashed lines represent the position in the cumulative histogram of the target region. The color of the lines indicates the corresponding color channel.

output image. The difference between the hue in the daytime and that in the evening of the N-R C/S retinex was small when N_r was around the half of the total number of pixels, i.e., $N_r = 9600$, and the difference was smaller than that of the original C/S retinex depending on the value of I_h. On the other hand, when the value of N_r

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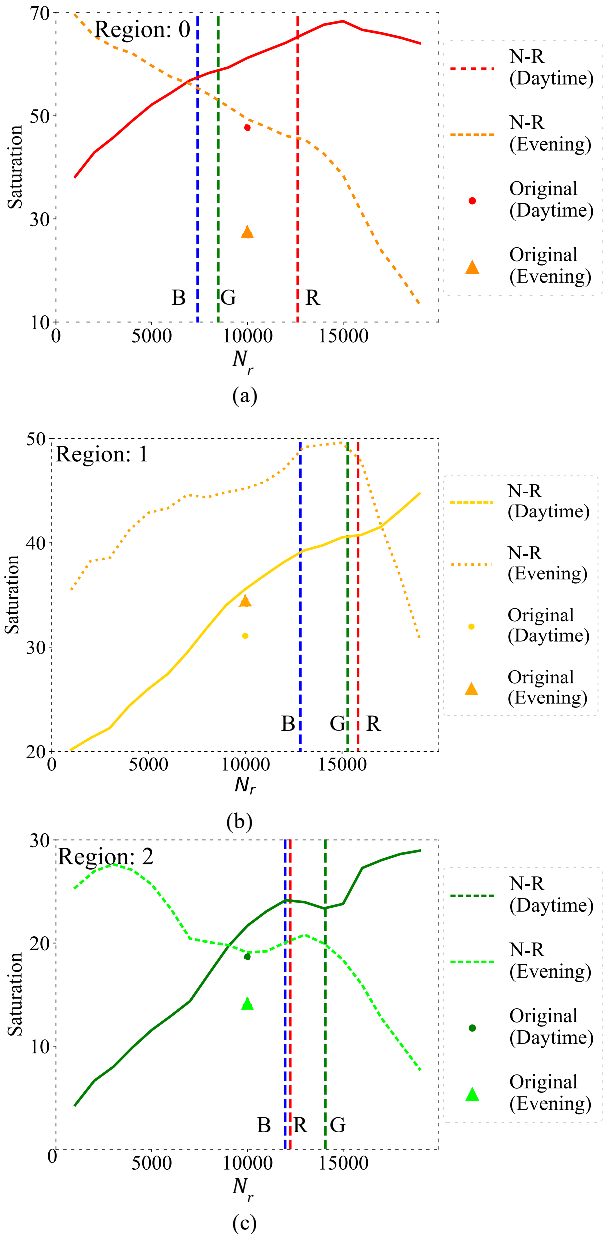

Fig. 6. Relationship between $\boldsymbol{N_r}$ and the saturation of the output image. (a)(b) and (c) show the relationship in regions 0, 1, and 2 (shown in Fig. 4), respectively. The vertical dashed lines represent the position in the cumulative histogram of the target region. The color of the lines indicates the corresponding color channel.

was deviated significantly from this value, the difference could be large.

Fig. 6 shows the relationship between N_r and the saturation. The saturation of the N-R C/S retinex tended to be higher than that of the original retinex, depending on the value of I_h. A lower value of saturation could lead to instability of the hue.

4. Conclusion

In this study, we proposed a color constancy algorithm by combining the N-R equation and the C/S retinex model. We evaluated the effects of a parameter in the N-R equation on the color constancy performance. The results suggested that the color constancy performance can be improved by setting I_h to an appropriate value. Further study is required for finding the method for setting an appropriate value of I_h.

Acknowledgements

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