Color Image Enhancement Based on Land's Color Constancy Algorithm

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Abstract

Color image enhancement to restore natural color by excluding the effect of ambient illumination is important in recent image processing. In this paper, a color image enhancement method based on Land's color constancy is proposed. Since the color constancy processing preserves only hue while reducing the dynamic range of lightness and saturation, the technique of dynamic range increase in the IHS coordinate system is used to compensate them. The proposed method increases lightness and saturation simultaneously.

Introduction

Image enhancement is the technique of making an image more vivid for human vision. Since color has more information than black and white and most natural images are color, the technique of color image enhancement is required to meet the increasing demands for applications.

The object color can be perceived by the characteristics of light such as reflection, permeance, and absorption. The surface color is the product of light reflection and illumination, and it can be widely varied by illumination itself and the characteristic of reflecting surface[1], etc. For example, the same object can be viewed differently under different illuminations such as incandescent or fluorescent lamp. However, human has color constancy which-is the subjective color perception of the objects, so that he cannot perceive the variation of object color though there is the variation of illumination and surroundings, etc. Exclusion of the effect of ambient light can be obtained by considering the color constancy.

In this paper, we proposed color image enhancement based on Land's color constancy. The illuminant component of an image can be eliminated by considering the global mean of each frame, i.e., red, green, and blue frame, because the global mean can be thought as the illuminant component by Land's color constancy algorithm[1]. Color constancy algorithm preserves hue and depresses the dynamic range of lightness and saturation[2]. To improve the quality of an image, the dynamic range of lightness and saturation was increased in the IHS coordinate system.

Land's Color Constancy Algorithm

Color constancy is that human can perceive the original color of an object by excluding the effect of illuminants based on the surface reflectance of an object. Three bands of red, green, and blue are considered independently in Land's Retinex theory. Three quantized values, L_k, of receptors which receive reflected light from the scene can be expressed by spectral reflectance, S_k, and illuminant, E_k

$$L_k(x, y) = E_k(x, y) \times S_k(x, y), k = R, G, B \tag{1}$$

where k means each color receptor.

Human can exclude the effect of illuminants by the fact that the movement of an eyeball can provide the spatial average of the scene. Therefore, it can be said that the average values of three frames represent the illuminating color. The red, green and blue without illuminating effect can be calculated by using the averages of three frames as

$$r = \frac{R}{W_R} \qquad g = \frac{G}{W_G} \qquad b = \frac{B}{W_B} \tag{2}$$

where W_R, W_G, and W_B mean average values of each frame. True color without illuminating effect can be obtained in this stage, but the dynamic range of each frame is decreased. To solve this problem, the method increasing the dynamic range of saturation and lightness while preserving hue is required.

Image Enhancement in IHS Coordinate System

Any arbitrary chromaticity $\vec{C}$ can be expressed by the proper combination of three primary vectors, R, G and B, as

$$
\begin{aligned}
\vec{C} &= r\angle 0 + g\angle(2\pi/3) + b\angle(4\pi/3) \\
&= \frac{2r - g - b}{2} + j\frac{\sqrt{3}(g-b)}{2} \\
&= S\angle H,
\end{aligned}
\tag{3}
$$

where r, g, and b are the magnitudes of three primary color vectors. S means the magnitude of color in the complex domain, and H, the phase angle. The IHS color coordinate system[3-4] having equal weights to red, green, and blue can be expressed using r, g, and b as

$$
\begin{cases}
I = \frac{1}{3}(r+g+b), & 0 \le I \le 255 \\
H = atan2(\sqrt{3}(g-b), 2r-g-b), & -\pi \le H \le \pi \\
\quad = atan2\left(\sqrt{3}, 2\left(\frac{r-g}{g-b}+1\right)\right) & \\
S = \sqrt{r(r-g)+g(g-b)+b(b-r)}, & 0 \le S \le 255
\end{cases}
\tag{4}
$$

The I, H, and S mean lightness, hue, and saturation, respectively. The dynamic range of r, g, and b is depressed because the averaged component are eliminated by Land's constancy algorithm. To compensate this problem, we can increase the saturation and lightness. Linear stretching of lightness histogram was used[5]. The stretched lightness, I_s, can be expressed by original lightness, I_o, global maximum lightness, I_{max} and minimum lightness, I_{min} as

$$
I_S = 255 \times \frac{I_O - I_{min}}{I_{max} - I_{min}}
\tag{5}
$$

3×3 median filter was applied to lightness component to reduce the effect of noise, and 3×3 average filter was applied to saturation component for the continuity of the image. Then adjusted red, green, and blue, i.e, r_a, g_a, and b_a, can be expressed by median-filtered lightness, I_{med}, and saturation, S, as

$$
\begin{aligned}
r_a &= I_{med} + \frac{S_{avg}(2r-g-b)}{3S} \\
g_a &= I_{med} + \frac{S_{avg}(-r+2g-b)}{3S} \\
b_a &= I_{med} + \frac{S_{avg}(-r-g+2b)}{3S}
\end{aligned}
\tag{6}
$$

where S_{avg} means averaged saturation of 3×3 window. The relationship between r_a, g_a, and b_a from (4) to obtain the increased saturation while preserving hue and lightness can be expressed as

$$
\begin{aligned}
r_e - g_e &= \alpha(r_a - g_a) \\
g_e - b_e &= \alpha(g_a - b_a)
\end{aligned}
\tag{7}
$$

where α is a scaling factor and r_e, g_e, and b_e are designed enhanced red, green, and blue, respectively.

The lightness is linearly stretched from 0 to 255, and the value of α should be obtained so that the corrected value does not exceed the valid coordinate gamut. Enhanced red, green, and blue values should be adjusted within the range from 0 to 255 when they are quantized into 8 bits to avoid overflow. Therefore, the values in (6) should be within the range from 0 to 255 as stated above, and proper α can be obtained from (5), (6), and (7) as

$$
\begin{aligned}
&\frac{-255(r_m+g_m+b_m-3I_{min})}{(I_{max}-I_{min})(2r_m-g_m-b_m)} \le \alpha \le \frac{-255(r_m+g_m+b_m-3I_{max})}{(2r_m-g_m-b_m)(I_{max}-I_{min})} \\
&\frac{-255(r_m+g_m+b_m-3I_{min})}{(I_{max}-I_{min})(-r_m+2g_m-b_m)} \le \alpha \le \frac{-255(r_m+g_m+b_m-3I_{max})}{(-r_m+2g_m-b_m)(I_{max}-I_{min})} \\
&\frac{-255(r_m+g_m+b_m-3I_{min})}{(I_{max}-I_{min})(-r_m-g_m+2b_m)} \le \alpha \le \frac{-255(r_m+g_m+b_m-3I_{max})}{(-r_m-g_m+2b_m)(I_{max}-I_{min})}
\end{aligned}
\tag{8}
$$

where r_m, g_m and b_m are three primary values of the maximum saturation point in the image.

There exist several solutions for (8). We can take α between 3rd and 4th values in Figure 1.

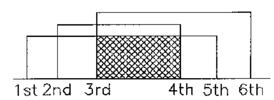


Figure 1. The possible range of a

To increase the saturation maximally, α can be taken as the 4th value. Since excessive α, however, causes the image unnaturally saturated, selecting the 4th value of α causes somewhat oversaturated image. Therefore, proper scaling of α is needed and based on the fact that the lightness of a pixel seldom exceeds 80% of its possible maximum value[6]. Thus α is selected as 200 in the case of 8-bit quantization. The rescaled scaling factor ß can be expressed by the frame averages as

$$
\beta = \alpha \times \frac{W_R + W_G + W_B}{600}
\tag{9}
$$

The r_e, g_e and b_e satisfying (6) are

$$
\begin{aligned}
r_e &= \frac{85(r_a+g_a+b_a-3I_{min})}{I_{max}-I_{min}} + \frac{\beta(2r_a-g_a-b_a)}{3} \\
g_e &= \frac{85(r_a+g_a+b_a-3I_{min})}{I_{max}-I_{min}} + \frac{\beta(-r_a+2g_a-b_a)}{3} \\
b_e &= \frac{85(r_a+g_a+b_a-3I_{min})}{I_{max}-I_{min}} + \frac{\beta(-r_a-g_a+2b_a)}{3}
\end{aligned}
\tag{10}
$$

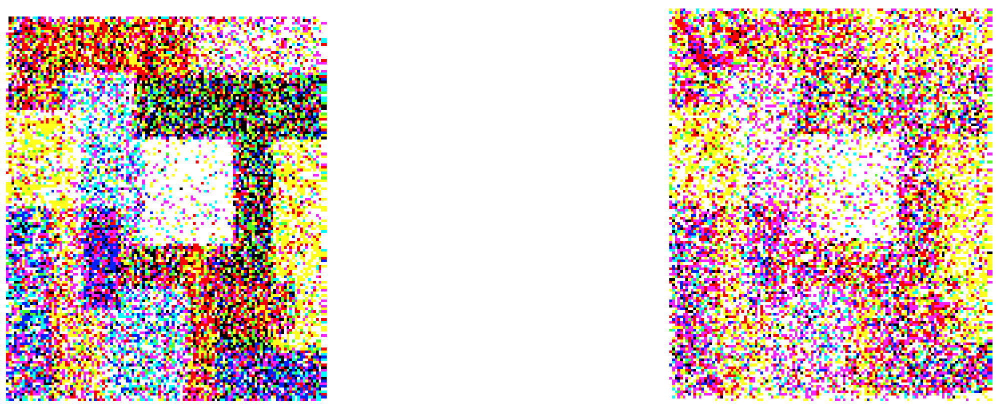
When the lightness value is very low or high, the enhanced values can exceed the valid coordinate gamut. In this case, the related values are adjusted by using (8).

Experimental Results

Mondrian color patch image is used in the experiment. Figure 2 is the original image under the fluorescent and incandescent lamp. In Figure 2(a), saturation and contrast are degraded due to the blue component of the fluorescent lamp. In Figure 2(b), hue component was severely changed and the contrast was degraded due to the yellow component of the incandescent lamp. The same scene seems to be different under different illuminants. By the proposed algorithm, the degradation of the image can be compensated effectively as shown in Figure 3. Contrast and saturation were increased enough and hue component was adjusted. The x-y chromaticity plane in Figure 4 shows the processed results.

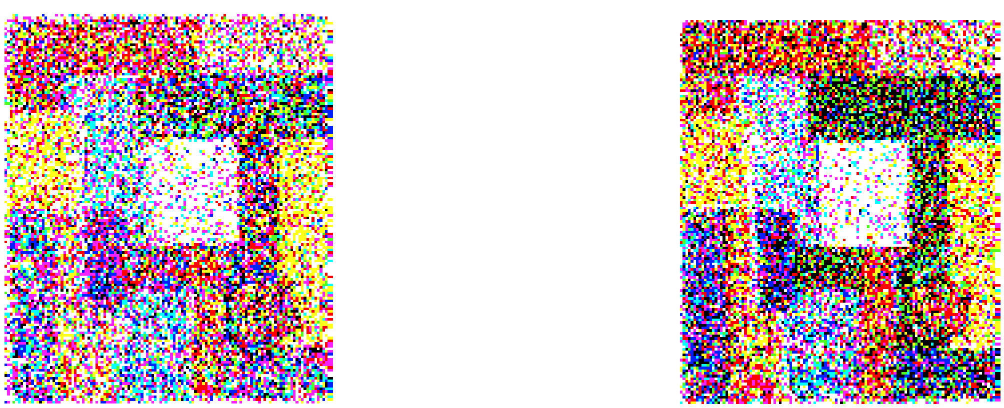
Conclusion

Ambient illuminants can change the image characteristics such as lightness, hue, and saturation. This problem can be solved by adopting the color constancy. The proposed algorithm increases saturation and contrast as well as corrects hue in the processed images. Due to the white-dependency, it is difficult to apply color constancy to the cases of total reflection by the mirror or metal and no white-component or nonuniform illumination. In these cases, the saturation can be increased enough, but hue component varies widely. To solve these problems, more elaborate algorithm should be considered in the further study.



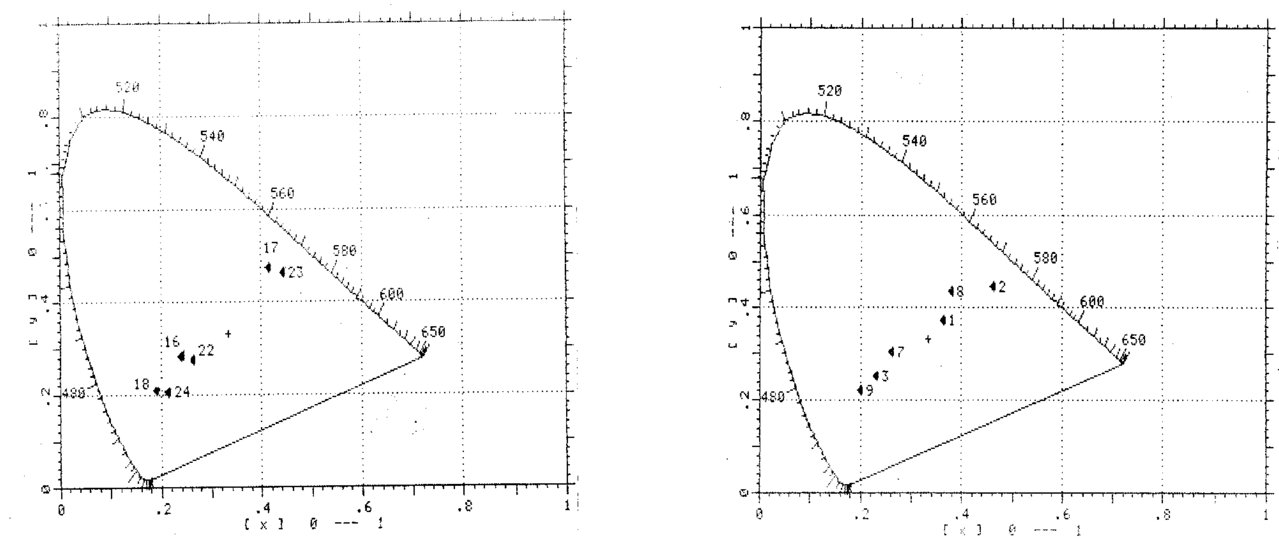
(a) fluorescent lamp *(b) incandescent lamp*

Figure 2. Color images taken under fluorescent and incandescent lamps



(a) in the case of fluorescent lamp *(b) in the case of incandescent lamp*

Figure 3. Enhanced results of Mondrian color patches



(a) in the case of fluorescent lamp (before processing: 16; white, 17; yellow, 18; blue after processing: 22; white, 23; yellow, 24; blue)

(b) in the case of incandescent lamp (before processing: 1; white, 2; yellow, 3; blue after processing: 7; white, 8; yellow, 9; blue)

Figure 4. x-y Chromaticity diagram of correcting effect

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