Gray World based Color Correction and Intensity Preservation for Image Enhancement

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***Abstract*—Images captured by digital cameras are vulnerable to quality degradations due to non-ideal illumination conditions such as dominated lighting source colors, where images so obtained may not faithfully reproduce the scene chromatics accurately. While it is a complicated process to control the scene illumination, color correction used as a post-processing procedure, is becoming an attractive solution. This research has developed an approach for color correction based on a modified implementation of the gray world assumption. The image color is adjusted by employing a gamma correction to satisfy the gray world assumption and avoid color saturation as encountered in the conventional approach. In order to further improve the image visual quality, an intensity preservation criterion is adopted as an additional means to produce the resultant image. With the normalization of intensity in accordance with the original image, an enhanced image both in color and intensity, is finally obtained. A collection of color images are used in an experiment to verify the proposed algorithm. Results have indicated that the proposed method is effective in producing enhanced images in the context of color enhancements.**

I. Introduction

With the advancement of digital imaging technology, a large number of photographs are being captured in our daily livings. On the other hand, the development of sophisticated cameras has also made a substantial contribution to industrial automation. One of the crucial pre-requisites in making use of the captured images rests on a faithful reproduction of the chromaticity of the captured scene in addition to an accurate representation of the scene illumination. To this end, color constancy provided by means of a variety of color correction schemes is becoming a necessity.

For armature photography, one always realizes the importance of color harmony such that the captured image can provide a sense of pleasant viewing [1]. Moreover, harmonizing colors in an image also improves its contrast perception [2]. In order to accomplish color harmony or to make the image suitable for computer process such as object segmentation [3], it frequently requires methods to establish color constancy so that the image would represent the scene as if it is illuminated under ambient natural lighting. There have been many methods developed to provide color constancy, for example, the widely used gray world assumption hypothesizes that the average scene captured in an image is gray [4]. Interested readers may also refer to the recent survey [5] on the computational aspects of color constancy.

The computation of color constancy also leads to the possibility of estimating the color of illumination [6] that shines on the object when it is captured by a camera. This concept is well suitable to restore colors that are absent due to the lack of controllable lightings [7]. Similar researches also address issues concerned with color balancing. In the work reported in [8], image statistics were used in obtaining casted areas under different illuminations, then colors of these areas were adjusted to provide a balance over the complete image. Another approach [9] was independently developed in the context of global and local color correction. The local correction concept had also been proven to be effective in contrast enhancement [10] for color images.

A branch of techniques employed in color constancy restorations is related to white balance. As with the gray world assumption, white is treated as the maximum value of gray. It is believed that the brightest point in an image would be white. For example, white balance is obtained automatically by manipulating multiple frames of images [11]. One possible approach was reported in [12] where the color components in an image are adjusted by multiplying by appropriate scale factors.

Processes based on the widely used gray world assumption also adopt scaling the color channels, for example red, green and blue, by a scale factor. In order to initiate the process, gray points in the image were extracted and the illumination color estimated [13]. This information was then used to restore the image color to that of illuminated by natural ambient light. In the work reported in [14], automatic white balancing was achieved by using a quadratic weighting among scales obtained from the gray world assumption and the Retinex

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theory. The result had shown a closer match to natural scenes. Furthermore, when determining the scale factors, statistical information such as the standard deviations of the color channels were used [15]. A collective review of the white balancing or color correction algorithms was given in [16] where an evaluation was made on the basis of restoring faded images. In the regard of color correction methods, it had been reported in [17] that this process could well contribute to an enhancement of the image in terms of its information content.

In this work, further investigation into the color correction process is made and a new approach is proposed. Noticeably, alternation in the values of color values would introduce a change in the image intensity [18]. Simply scaling the color channels inevitably may also drive the color content to beyond its permissible magnitude for display or transmission. On the other hand, the choice of scaling reference may not be unique for different images. Here, we propose to make use of the gamma correction method to adjust each color channel magnitude thus ensuring the display will not be saturated. In addition, the mean value of each color channel is adjusted to the mean of the image intensity. This procedure preserves intensity information conveyed by the image irrespective of the change in color magnitudes.

The rest of this paper is organized as follows. In Section II, common procedures in gray world based color corrections are reviewed and their limitations discussed. The approach taken to correct the color and preserve the intensity is presented in Section III. The experiments are described in Section IV and a conclusion is given in Section V.

II. Color Correction

In gray world based color correction algorithms, scaling factors are derived on the basis of referencing to one of the color channels. A commonly chosen reference is the green channel in the red-green-blue (RGB) color space [14].

A. Simple Correction using Green Channel

Consider a given image in the RGB space,

$$\mathcal{I} = \{R_{uv}\ G_{uv}\ B_{uv}\}, \tag{1}$$

where u, v are the pixel coordinates in width-by-height.

In the simple gray world based correction, two scale factors α_r and α_b are derived as ratios depending on the green channel, i.e.,

$$\alpha_r = \bar{G}/\bar{R},\ \alpha_b = \bar{G}/\bar{B}, \tag{2}$$

where $\bar{R},\ \bar{G},\ \bar{B}$ denote the mean values of the color channels. The corrected color is obtained as a scaling of the original color magnitudes. We have,

$$\hat{R} = R \times \alpha_r,\ \hat{G} = G,\ \hat{B} = B \times \alpha_b. \tag{3}$$

The green channel is frequently assumed having the smallest magnitude; however, this assumption may be violated for images captured under different illumination conditions.

Figure 1 shows two test images where the green color magnitude is the smallest (Fig. 1(a)) and the other with the green color is not the smallest (Fig. 1(b)). The resultant color corrected images are shown in figures 1(c) and 1(d) respectively. It is observed that the color tone has been changed but the intensity are different where the simple gray world based color correction may not hold in general.

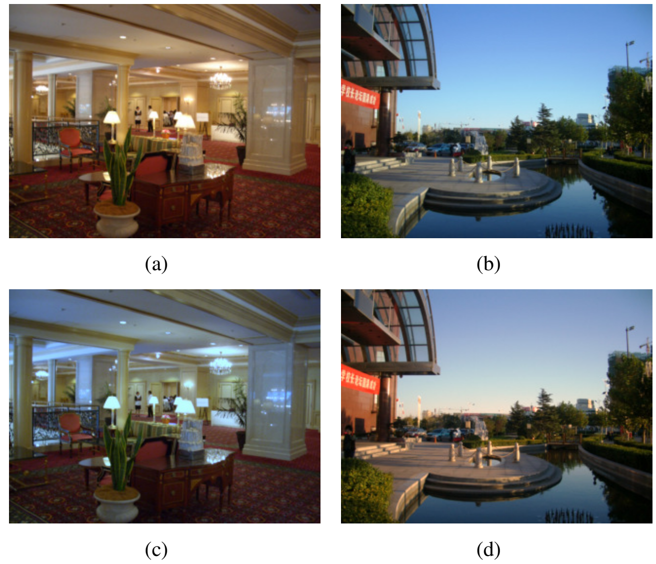

Fig. 1. Effect of simple color correction; (a) original image 1, (b) original image 2, (c) resultant image 1, (d) resultant image 2.

B. Color Channel Compression

In order to discover alternative scaling approaches in color correction, an attempt is made to use the channel with minimum mean magnitude as the reference. In this case, we have

$$\alpha_r = \bar{Z}_{min}/\bar{R},\ \alpha_g = \bar{Z}_{min}/\bar{G}, \alpha_b = \bar{Z}_{min}/\bar{B}, \tag{4}$$

where $Z_{min}(m) \in \{R, G, B\}$, $m = \text{argmin}\{\bar{R}, \bar{G}, \bar{B}\}$, is the color channel having the smallest mean magnitude. Using this reference, the scale factors are less than unity or at most equal to unity for the referenced channel. Consequently, the corrected color magnitude will be less than or at most equal to their original value. The overall effect is a reduction in the image intensity. Figure 2 shows the results from the same test images.

C. Color Channel Expansion

In order to mitigate the drawback of reduced intensity, an attempt is made to use the channel with the largest mean value as the reference. We have,

$$\alpha_r = \bar{Z}_{max}/\bar{R},\ \alpha_g = \bar{Z}_{max}/\bar{G}, \alpha_b = \bar{Z}_{max}/\bar{B}, \tag{5}$$

where $Z_{max}(x) \in \{R, G, B\}$, $x = \text{argmax}\{\bar{R}, \bar{G}, \bar{B}\}$, is the color channel having the smallest mean magnitude. In contrary, the scale factors are at least equal to unity for the reference color. The other scale factors are larger than unity and produce an amplification effect on the resultant image. The consequence is a possible over-saturation of the display device. Test results are shown in Fig. 3 where the amplification effect is evident.

(a) (b)

Fig. 2. Effect of compressive color correction; (a) resultant image 1, (b) resultant image 2.

(a) (b)

Fig. 3. Effect of expansive color correction; (a) resultant image 1, (b) resultant image 2.

(a) (b)

Fig. 4. Effect of color correction referred to the color channel with intermediate mean magnitude; (a) resultant image 1, (b) resultant image 2.

D. Reference to Intermediate Magnitude Channel

It has been demonstrated that the choice of the reference color channel in deriving the scale factors are crucial to the quality of the color corrected image. A further evaluation is conducted where the channel with intermediate mean magnitude is taken as the reference. In this test, we have

$$\alpha_r = \bar{Z}_{mid}/\bar{R},\ \alpha_g = \bar{Z}_{mid}/\bar{G}, \alpha_b = \bar{Z}_{mid}/\bar{B}, \qquad (6)$$

where $Z_{mid}(d) \in \{R, G, B\}$, $d = \text{argmid}\{\bar{R}, \bar{G}, \bar{B}\}$, is the color channel having the intermediate mean magnitude. Here, the scale factors may have values less than, greater than or equal to unity which corresponds to the reference color channel. Figure 4 shows the test results. It is illustrated that for test image 1 (Fig. 4(a)), the resultant intensity is restored close to the original image. However, for test image 2 (Fig. 4(b)), the resultant intensity is still higher than the original image due to excessive amplification on the color channel with a higher color magnitude.

III. Intensity Preservation

In the previous section, evaluations and tests of possible scaling factor derivations had been made. It is shown that these approaches in general suffer from a reduction in the resultant image intensity or there are possibilities of large resultant intensities leading to display saturation. These limitations may be caused by simply multiplying the color channel magnitudes with the scale factors. In this section, a non-linear adjustment of the color magnitudes is proposed. Specifically, the gamma correction approach is adopted and the proper choice of gamma value ensures that the gray world assumption is satisfied and the image intensity is preserved.

A. Intensity Reference

In order to preserve the intensity of the original image, a reference to the intensity is firstly made. First, the RGB image is converted to the hue-saturation-intensity (HSI) color space where the image intensity is given by the I-channel as a gray level image. That is

$$HSI \leftarrow RGB,\ I = (R + G + B)/3 \qquad (7)$$

The mean value of the I-component is denoted as the reference and that all color channels, R, G, and B have to be adjusted to this value. Because of the resultant equal mean values of each color channel, their gray equivalent matches to that of the original image. This also guarantees that the color corrected image will satisfy the gray world assumption.

B. Color Adjustment by Gamma Correction

In order to provide satisfactory color corrected images, a non-linear scaling scheme, namely, the gamma correction approach is adopted. Consider a color channel, for example, the red channel with the commonly used magnitude range $R \in [0,\ 255]$. This magnitude is normalized such that $\tilde{R} \in [0,\ 1]$. Now the normalized magnitude is raised to the power of γ, that is, $\hat{R} = \tilde{R}^{\gamma}$. Since the maximum of $\tilde{R}$ is limited to unity, then $\hat{R}$ is also limited to unity. On the other hand, when $\tilde{R} = 0$, the gamma corrected magnitude is also zero. Thus, the range $[0,\ 1]$ is maintained while the average magnitude is changed in accordance to particular values of the parameter γ. In the case that $\tilde{R} \in [0,\ 1]$, the resultant mean magnitude will increase for $\gamma < 1$. Similarly, the mean magnitude decreases for $\gamma > 1$. This process is applied to the other two color channels.

C. Determination of the γ Value

There could be a variety of methods to determine a proper γ value. Here, we use the bi-sectional search method for its implementation simplicity. A pair of minimum γ_{min} and maximum γ_{max} values is arbitrarily assigned from some pilot experiments. The number of sectors γ_N is also specified, for example, $\gamma_n = 5$. Then we have a set of γ values given by

$$\gamma_i \in [\gamma_{min},\ \gamma_{max}],\ i = 1, \cdots, \gamma_N, \qquad (8)$$

where subscript i is used as an index to each γ element in the set and arranged such that $\gamma_{i-1} < \gamma_i < \gamma_{i+1}$. For each of these

γ_i values, it is applied to change the color channel magnitude. Furthermore, the average of the gamma corrected channel is calculated and compared to the mean of the reference I-component. If the minimum discrepancy among the γ_i's is less than a threshold $\tau = 1$ (for 1 magnitude step in the commonly used 255 magnitude range), the adjustment process is terminated.

Alternatively, if the matching criterion to the reference intensity is not satisfied, the gamma correction process is repeated with a new set of γ-values. Two cases have to be considered. First, if the γ_i is within the initial range $\gamma_i \in [\gamma_{min},\ \gamma_{max}]$, then the two neighboring gamma values, γ_{i-1} and γ_{i+1} are used as the new minimum and maximum range. That is

$$\gamma_{min} \leftarrow \gamma_{i-1},\ \gamma_{max} \leftarrow \gamma_{i+1}, \tag{9}$$

while the number γ_N is kept the un-altered. On the other hand, if the γ_i that gives the minimum discrepancy to the reference intensity lies on the two ends of the gamma range, the new gamma range is obtained from scaling the previous range by a factor of 2. For example, when $i = 1$ (the smallest γ), then we have the new lower bound given as $\gamma_{min} \leftarrow \gamma_1/2$. On the other hand, if γ_{γ_N} gives the least difference to the reference intensity, then set $\gamma_{max} \leftarrow \gamma_{\gamma_N} \times 2$.

When the gamma-correction process is completed, we have the averages of each color channel equal to the reference intensity, thus accomplishes color correction and satisfies the gray world assumption. Algorithm 1 summarizes the proposed color correction procedure based on gamma-corrections.

Algorithm 1 Gamma correction algorithm

Given color image $\mathcal{I} = \{\mathbf{RGB}\}$ of 3 color channels
Convert to HSI space and assign I as intensity
Calculate mean intensity $\bar{I}$
for each color channel, e.g., R channel, **do**
    Assign initial γ_{min}, γ_{max} and γ_N
    repeat
        for each $\gamma_i \in [\gamma_{min}, \gamma_{max}]$, $i = 1, \cdots, \gamma_N$ **do**
            Find gamma corrected channel $R_i^* = R_i^{\gamma_i}$
        end for
        Calculate mean of gamma corrected image $\bar{R}_i^*$
        Calculate absolute difference $\delta R_i = |\bar{R}_i^* - \bar{I}|$
        Find $i^* = \text{argmin}_i\{\delta R_i\}$
        if $\delta R_{i^*} > \tau$ **then**
            if $i^* = 1$ (smallest γ) **then**
                $\gamma_{min} \leftarrow \gamma_1/2$ **else** $\gamma_{min} \leftarrow \gamma_{i^*-1}$
            end if
            if $i^* = \gamma_N$ (largest γ) **then**
                $\gamma_{max} \leftarrow \gamma_{\gamma_N} \times 2$ **else** $\gamma_{max} \leftarrow \gamma_{i^*+1}$
            end if
        end if
    until $\delta R_{i^*} \le \tau$
end for
Return gamma corrected image $\mathcal{I}_{i^*}$

IV. Experiment

A collection of digital images taken under a diversified illumination conditions are used in the experiment to verify the proposed approach. Results from the proposed procedures are shown in figures 5 and 6 respectively. In Fig. 5, an outdoor image was taken where the illumination condition had given the image in a bluish tone. A histogram of the original image is depicted in Fig. 5(b) where the domination by blue colored pixels is obvious. Limitations in performance as resulted from simple, compressive, expansive and intermediate magnitude referenced results are shown in figures 5(c) to 5(f). In Fig. 5(g), the result from the proposed gamma correction based correction and its associated hue histogram is illustrated in Fig. 5(h). It is noticeable that the final result has preserved the intensity of the original image and is able to clearly show more details of the scene, for example, the texture of the pavement. The hue histogram also illustrates a more evenly distribution of colors. An additional test had been conducted and the original and resultant images are shown in Fig. 6. The test image is taken indoor and carries a yellowish tone. Results from the proposed method had shown that white patches in the image are properly corrected. In contrary, the yellowish tone as a combination of red and green has not been completely corrected in other correction procedures.

V. Conclusion

A color correction approach, based on the gray world assumption, has been presented in this paper. The proposed method makes use of an non-linear gamma correction magnitude scaling to mitigate drawbacks from over saturation. The determination of a proper gamma is accomplished by using an efficient bi-sectional search procedure. When color channels are adjusted to the mean intensity of the original image, the resultant image is able to preserve this important feature. Experiments using real-world images had verified the effectiveness of the method and promising results were obtained.

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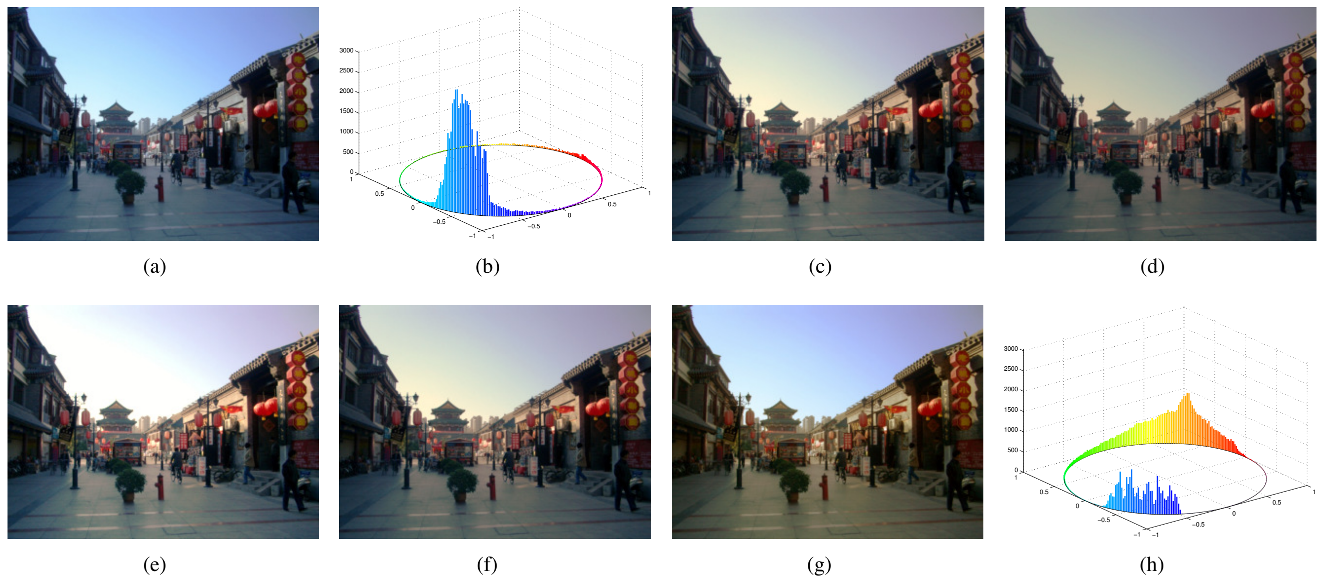

Fig. 5. Test image 3 (bluish tone dominance); (a) original image, (b) original color histogram, (c) simple gray world color correction, (d) compressive correction, (e) expansive correction, (f) intermediate referenced correction, (g) gamma correction result, (h) hue histogram of gamma corrected image.

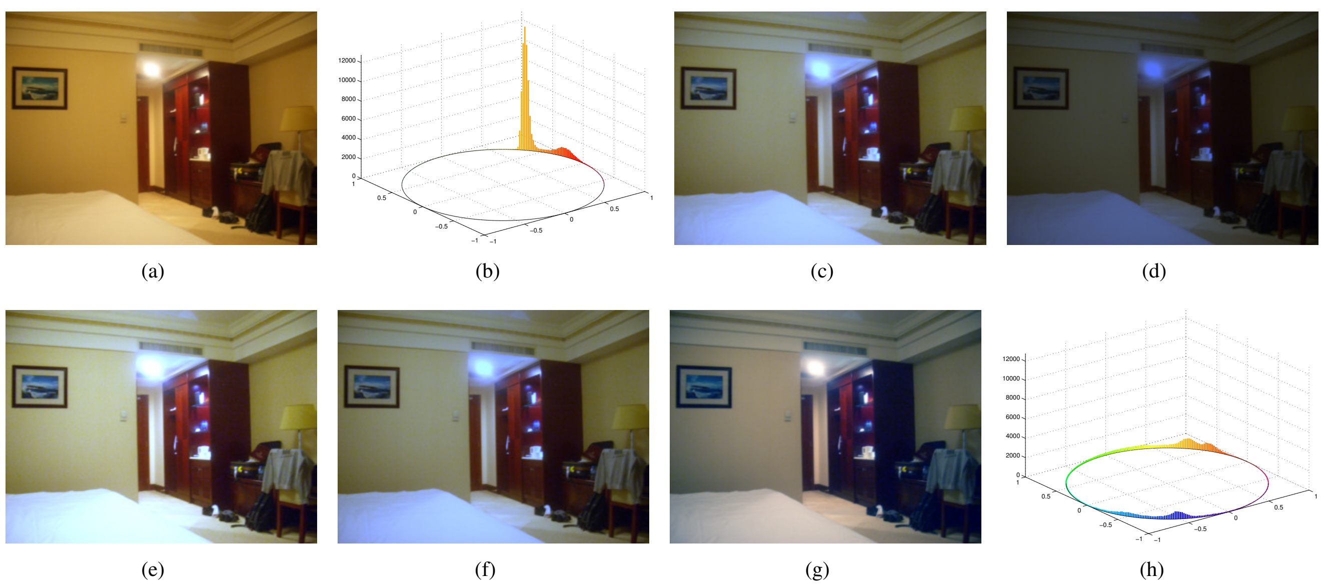

Fig. 6. Test image 4 (yellowish tone dominance); (a) original image, (b) original color histogram, (c) simple gray world color correction, (d) compressive correction, (e) expansive correction, (f) intermediate referenced correction, (g) gamma correction result, (h) hue histogram of gamma corrected image.

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