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COLOR CONTRAST ENHANCEMENT USING AUTOMATIC WEIGHTING MEAN-SEPARATED HISTOGRAM EQUALIZATION WITH SPHERICAL COLOR MODEL

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Abstract. *Histogram equalization (HE) is one of the most effective technique for image contrast enhancement. However, it is not suitable to be implemented directly in consumer electronics (digital TV, camera, etc.) because this method tends to produce an output with saturation effects. Therefore, Automatic Weighting Mean-separated Histogram Equalization (AWMHE) was proposed to overcome this weakness for gray-scale images in our recent work. Although AWMHE method performs well in the gray-scale images, it cannot be applied to most consumer electronic products that produce color images. This article proposes a novel enhancement scheme by using the spherical color model and the AWMHE method to improve the quality of color images. The effectiveness of the spherical color model for color contrast enhancement is verified by comparing with other state-of-the-art color models with HE and AWMHE methods. Furthermore, experimental results show that the proposed enhancement scheme can generate better enhancement images than those using the state-of-the-art enhancement schemes.*
Keywords: Color contrast enhancement, Histogram equalization, Spherical color space

1. **Introduction.** Over the last few decades, contrast enhancement techniques have been actively developed to improve the image quality. This can facilitate the performance of image processing systems, such as video surveillance systems [1, 2], digital photography [3, 4], medical imaging systems [5, 6] and low power display systems [7]. Moreover, contrast enhancement has become widely available to improve the representation of digital images with software and hardware environments, including Adobe Photoshop, mobile devices, digital TVs, digital cameras, and so on [8, 9, 10, 11, 12, 13, 14, 15].

Contrast enhancement methods can be broadly categorized into two major classes: direct and indirect methods [16]. Direct methods [17, 18] try to improve the image quality using the definition of a contrast measure. Indirect methods [19, 20] exploit the under-utilized dynamic range of digital images to improve the contrast without defining a specific contrast term. According to the related literature [16], the most popular contrast enhancement methods almost fall into the second class.

One of the most popular indirect methods is histogram equalization (HE) due to its simplicity and effectiveness [21]. The basic idea of HE method is to re-map the gray levels of the input image using a transformation function with the cumulative distribution of the input image. HE method stretches the dynamic range of the image histogram to improve the overall contrast of the original image. However, HE method is unsuitable for the consumer electronic applications because the calculated transformation function may extremely change the original brightness of the input image.

To overcome this problem, several researchers have studied the preservation of the image brightness in HE-based enhancement methods. In 1997, Brightness preserving Bi-Histogram Equalization (BBHE) [10] was proposed to generate two sub-histograms using the mean gray-level for the independent sub-histogram equalization. Later, Wang et al. [11] proposed Dualistic Sub-Image Histogram Equalization (DSIHE) to separate the histogram based on the median value instead of the mean value in BBHE [10]. Sim et al. [12] proposed Recursive Sub-Image Histogram Equalization (RSIHE) by extending DSIHE [11]. In RSIHE [12], the median-based histogram separation is applied several times to get local median values, whereas DSIHE [11] only applies it once.

As mentioned before, these previous HE-based methods [10, 11, 12] preserve the mean brightness of the original image by using local histogram equalization with several histogram separation procedures. However, some over-enhancement and other artifacts (noise, block artifacts, etc.) still exist in the equalized images. This is because these methods cannot determine the optimum number of sub-images and cannot calculate the suitable threshold values. Therefore, we proposed a new histogram equalization algorithm with the optimum sub-image number and its corresponding threshold calculation [22] to generate better enhancement results than those using the compared methods [10, 11, 12, 21].

Although all HE-based works [10, 11, 12, 21, 22] have good performances with gray-scale images, they cannot be applied to most consumer electronic products (digital TV, camera, etc.) which produce color images [23]. Therefore, an enhancement scheme should be further developed for enhancing color images. This article serves as an extension work of our recent literature [22]. We present several possibilities of Automatic Weighting Mean-separated Histogram Equalization (AWMHE) [22] implementation for the color images. Therefore, not only is an overview of popular color models given in this article, but also a spherical color model is proposed to facilitate the color contrast enhancement using the AWMHE method [22] as well.

The remainder of this article is divided into Sections 2 – 5. Because this article is an extension of the AWMHE method [22], a description of AWMHE is presented in Section 2. Section 3 presents the state-of-the-art color spaces, including the spherical color model, as well as enhancement schemes based on the AWMHE method for all color spaces. Section 4 shows some experimental results of the color contrast enhancement using the proposed enhancement scheme as well as the comparison with some previous arts [24]. Section 5 serves as the conclusion of this article.

2. Automatic Weighting Mean-separated Histogram Equalization.

For contrast enhancement of gray-scale images, AWMHE method was proposed to enhance the contrast between the interesting region and the other parts of an image.

Before the equalization process of AWMHE, an input image is separated into several sub-images. This separation procedure is similar to the RSIHE method [12]. However, the optimum number of sub-images can be determined precisely by using the global and local histogram information of AWMHE. Therefore, the details in the interesting region can be brought out and revealed to the observers after enhancing the image contrast based on AWMHE.

In general, there are two significant stages involved in AWMHE. The basic description of these stages are described as follows:

1. Automatic Histogram Separation: Separating the input image based on a combination of the weighting mean function and the automatic determination of the number recursion level.

2. Piecewise Transform Function: Achieving contrast enhancement by equalizing the sub-histograms in small-scale detail.

2.1. **Automatic histogram separation.** After the Cumulative Distribution Function (CDF) of an input image W is generated, the weighting mean value X_r^t can be calculated by using the weighting mean function, which is expressed as follows:

$$X_r^t = \frac{\sum_{l=a}^{b}(l \times CDF(l))}{\sum_{l=a}^{b}(CDF(l))}, \tag{1}$$

where $[a, b]$ represents the sub-interval of the histogram, l represents the corresponding gray-level, r is the index of mean values in each level, and t represents the recursion level. Notice that the sub-interval $[a, b]$ is initialized as [0, 255] and t is initialized as 1.

In order to accurately determine the appropriate number of sub-images, the existing sub-histograms is defined over a gray-level range $[X_r^{t-1}, X_{r+1}^{t-1} - 1]$ at the recursion level $t-1$ $(0 \leq r \leq t-1)$. Suppose that the boundary $[X_0^t, X_t^t]$ is set at [0, 256] and the range $[a, b]$ is defined as $[X_r^{t-1}, X_{r+1}^{t-1} - 1]$ for the corresponding sub-image. We then calculate each new mean value X_r^t for dividing the histogram by using the weighting mean function (1). The optimum recursion level of histogram separation can be found out when the calculated maximum mean value X_r^t equals 255.

2.2. **Piecewise transform function.** After the ideal weighting mean values are determined, the optimum number of sub-images is directly determined as follows:

$$W_k = \{W(x, y) | X_k \leq W(x, y) < X_{k+1}, \forall W(x, y) \in W\}, \tag{2}$$

where W_k represents each sub-image, and $k = 0, 1, 2, \ldots, t-1$.

Then the relationship between gray-level G and each sub-image W_k is defined as the respective Probability Density Function PDF_k.

$$PDF_k(G_h) = \frac{n_h}{\Sigma n_h}, \tag{3}$$

where $h = X_k, X_k + 1, \ldots, X_{k+1} - 1$, and n_h denotes the number of pixels that correspond to the value h. Notice that $PDF_k(G_h)$ is associated with the histogram of the k-th sub-image, which represents the frequency of a specific input gray-level G_h. In the next step, the respective CDF_k is defined for each sub-image based on the respective PDF_k:

$$CDF_k(G_h) = \sum_{j=X_k}^{h}(PDF_k(G_j)). \tag{4}$$

Finally, the piecewise transform function is used to map the equalized image. This is characterized by utilizing CDF_k of sub-image W_k for k segments. The transform function T_k is defined as below:

$$T_k(G_h) = X_k + (X_{k+1} - X_k) \times CDF_k(G_h), \tag{5}$$

where $k = 0, 1, \ldots, t-1$ and $h = X_k, X_k + 1, \ldots, X_{k+1} - 1$. More details of this method can be found in the literature [22].

3. **Color Contrast Enhancement.** Color information is a significant feature of the color image processing systems. According to [25], the input image is acquired and displayed with the RGB color model due to its well-known popularity of the electronic equipments.

For the input color image W, each pixel is presented by R (red), G (green) and B (blue) channels. We assume that each output pixel is presented by R', G' and B' after the contrast enhancement.

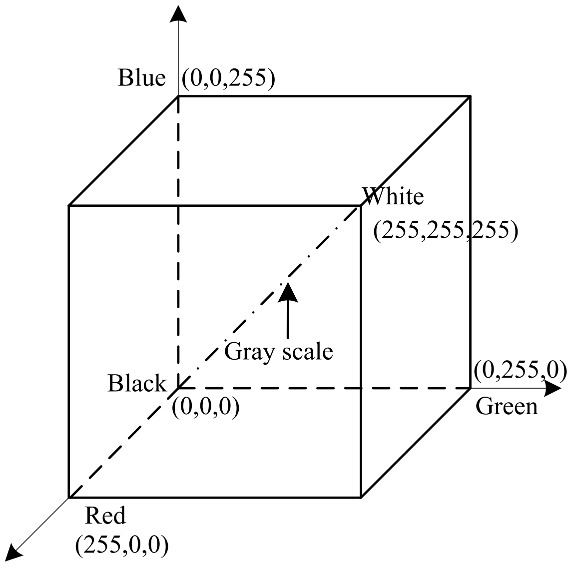


Figure 1. RGB color cube

This section presents five enhancement schemes by using the state-of-the-art color models and AWMHE for color image processing. These enhancement schemes are explained in the following subsections.

3.1. **AWMHE with RGB color model.** Based on a Cartesian coordinate system, RGB color model is represented by a three-dimensional cube with R, G and B channels at the corners on each axis. Each pixel of a color image can be represented by using eight bits per color channel to generate the range of values from 0 to 255.

Figure 1 shows the RGB cube with all values of R, G and B, which are respectively assumed to be in the interval of [0 255]. Note that black is at the origin, and white is at the corner farthest from the origin.

This color model is usually one of the popular spaces for color image processing [26]. With a combination of AWMHE method and RGB color model, each channel of RGB space is independently processed using AWMHE for color contrast enhancement.

3.2. **AWMHE with only *G* channel.** This enhancement scheme is an extension of Subsection 3.1 [24]. Due to G channel is a good estimate of the luminance signals, only G channel is processed with AWMHE to generate the enhanced G' channel. The R' and B' channels can be calculated by using the following equations:

$$R' = \begin{cases} 0, & \text{if } \alpha < 0 \\ \alpha, & \text{if } 0 \leq \alpha \leq 255 \\ 255, & \text{if } \alpha > 255 \end{cases}, \tag{6}$$

$$B' = \begin{cases} 0, & \text{if } \beta < 0 \\ \beta, & \text{if } 0 \leq \beta \leq 255 \\ 255, & \text{if } \beta > 255 \end{cases}, \tag{7}$$

where $\alpha = G' + (R - G)$ and $\beta = G' + (B - G)$.

3.3. **AWMHE with HSV color model.** Normally, a digital color image is composed of R, G and B chromatic channels. According to [27], HSV color model can be used for color contrast enhancement. This color model can perceive the relationship between the achromatic and chromatic information of the original RGB color image.

In HSV, H (hue), S (saturation) and V (value) are three properties to describe color as tint, shade and tone by the artists, respectively. Moreover, HSV color model is closer than RGB color model to the way in which people experience and describe color sensations. After each channel of RGB color model is normalized as the range of [0 1], the color transformation from RGB to HSV can be described as follows:

$$H = \begin{cases} 0, & \text{if } L_b = L_s \\ \frac{\pi(G-B)}{3(L_b-L_s)}, & \text{if } L_b = R \text{ and } G \geq B \\ 2\pi + \frac{\pi(G-B)}{3(L_b-L_s)}, & \text{if } L_b = R \text{ and } G < B \\ 2\pi/3 + \frac{\pi(B-R)}{3(L_b-L_s)}, & \text{if } L_b = G \\ 4\pi/3 + \frac{\pi(R-G)}{3(L_b-L_s)}, & \text{if } L_b = B \end{cases}, \tag{8}$$

$$S = \begin{cases} 0, & \text{if } L_b = 0 \\ \frac{L_b-L_s}{L_b}, & \text{otherwise} \end{cases}, \tag{9}$$

$$V = 255 \times L_b, \tag{10}$$

where $L_b = \max(R, G, B)$ and $L_s = \min(R, G, B)$ for each pixel.

After H, S and V components are obtained, only V channel is processed using AWMHE. The inverse color transformation from HSV to RGB is described as follows:

$$h = \lfloor \frac{3H}{\pi} \rfloor \bmod 6, \tag{11}$$

$$f = \frac{3H}{\pi} - h, \tag{12}$$

$$p = V' \times (1 - S), \tag{13}$$

$$q = V' \times (1 - f \times S), \tag{14}$$

$$t = V' \times (1 - (1 - f) \times S), \tag{15}$$

$$(R', G', B') = \begin{cases} (255V', 255t, 255p), & \text{if } h = 0 \\ (255q, 255V', 255p), & \text{if } h = 1 \\ (255p, 255V', 255t), & \text{if } h = 2 \\ (255p, 255q, 255V'), & \text{if } h = 3 \\ (255t, 255p, 255V'), & \text{if } h = 4 \\ (255V', 255p, 255q), & \text{if } h = 5 \end{cases}, \tag{16}$$

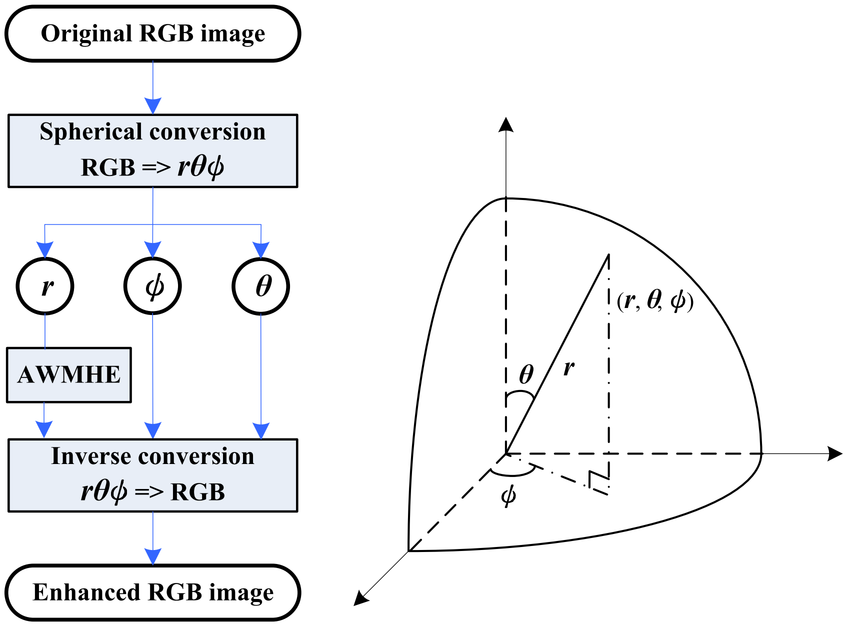
where V' channel is normalized as [0 1].

3.4. **AWMHE with YUV color model.** In the PAL (Phase Alternate Line) and NTSC (National Television System Committee) systems, YUV color model is used for composite color video standards. In this model, RGB colors are divided into luminance (Y) and chrominance (U, V) parts. The color transformation from RGB to YUV is described as follows:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{17}$$

For the enhancement scheme with AWMHE and YUV color model, only Y channel is processed using AWMHE after we obtained Y, U and V components. The inverse color transformation from YUV to RGB is described as follows:

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.140 \\ 1 & -0.395 & -0.581 \\ 1 & 2.032 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix} \tag{18}$$



(a) (b)

Figure 2. The enhancement scheme with AWMHE and spherical color model: (a) is the proposed flowchart and (b) is the spherical coordinate system

Actually, our previous work also uses YUV color model for color contrast enhancement [28].

3.5. **AWMHE with spherical color model.** In mathematics, spherical coordinate system represents a three-dimensional space where the position of a point is specified by three numbers, including the radial distance (r), the inclination angle (θ) and the azimuth angle (ϕ). According to [29], the spherical coordinate system is used to reduce color artifacts by using an adaptive filter based on the noise estimation method.

In this article, a unique enhancement scheme with a combination of AWMHE and spherical color model is proposed to smoothly enhance the color contrast. This is the first enhancement scheme by using the spherical coordinate system. The flowchart of the proposed enhancement scheme and the spherical coordinate system are shown in Figure 2. The color transformation from RGB color model to spherical color model is given in the following equations:

$$r = \sqrt{(R^2 + G^2 + B^2)}, \tag{19}$$

$$\theta = \cos^{-1}\left(\frac{B}{r}\right), \tag{20}$$

$$\phi = \tan^{-1}\left(\frac{G}{R}\right). \tag{21}$$

In the proposed enhancement scheme, only r channel of spherical color model is processed using AWMHE for color contrast enhancement. The inverse color transformation

FIGURE 3. The "Street" color image: (a) is the original image; the remaining five images are the enhanced images using HE with (b) RGB color model [26], (c) G channel of RGB [24], (d) YUV color model [28], (e) HSV color model [27] and (f) spherical color model

from spherical color model to RGB color model is given in the following equations:

$$R' = r' \sin\theta \cos\phi, \tag{22}$$

$$G' = r' \sin\theta \sin\phi, \tag{23}$$

$$B' = r' \cos\theta. \tag{24}$$

4. **Experimental Results.** In order to demonstrate the benefits of the proposed enhancement scheme, the enhancement results are produced and analyzed by using some natural color images in three ways:

1. Evaluating the effectiveness of each color model for color contrast enhancement.
2. Comparing the generated enhancement quality by using the proposed enhancement scheme and the other state-of-the-art enhancement scheme [24].
3. Analysing the computational complexity of the enhancement schemes based on Bachmann-Landau notation.

4.1. **Color model analysis.** According to the analysis approach in [24], we use the original color image "Street" to test five enhancement schemes with the traditional HE and different color models as shown in Figure 3. Here we can see that the image contrast and overall brightness are insufficient in the original image Figure 3(a).

For the first enhancement scheme by using the RGB color model [26], each channel is equalized to attain the enhanced color image. However, we can easily observe the serious color distortion in Figure 3(b) due to it cannot perceive the relationship between the achromatic and chromatic information by enhancing the color contrast.

For the second enhancement scheme using only the G channel of RGB [24], only the G channel is equalized to attain the color contrast enhancement due to G channel is a good luminance estimation. As can be observed in Figure 3(c), the serious color distortion in

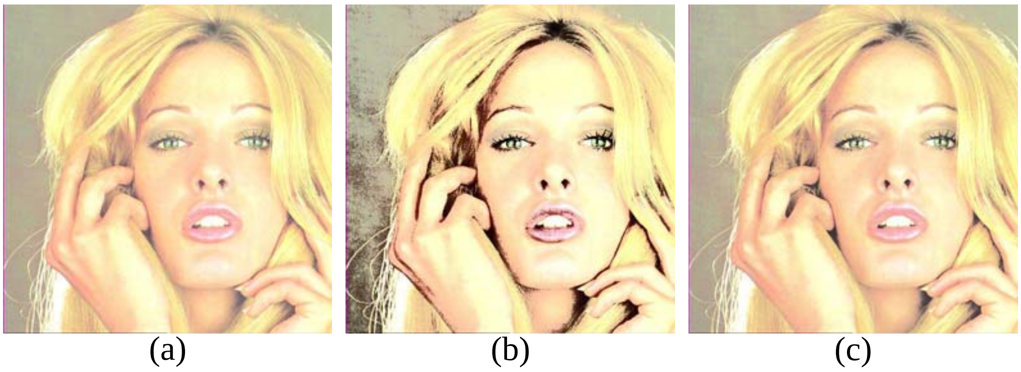


FIGURE 4. The "Tiffany" color image: (a) is the original image; the remaining two images are the enhanced images using (b) Kong's enhancement scheme [24] and (c) the proposed enhancement scheme

the sky can be reduced with a simple modification from the first one [26]. However, the chromatic information is still not enough in the circled brick buildings and manhole cover.

For the third enhancement scheme using YUV color model [28], the luminance channel is simply obtained from the array calculation. Again, the serious color distortion in the sky can be reduced while only equalizing the luminance channel Y as shown in Figure 3(d). However, some chromatic information is still insufficient in the circled region.

Compared with the simple array calculation of YUV color model [28], the geometry of RGB color space can be effectively rearranged to perceive the achromatic information in the HSV color model [27]. Therefore, there is no color distortion in the enhanced image as shown in Figure 3(e). Unfortunately, some block artifacts still occur in the circled region of Figure 3(e).

Figure 3(f) shows the enhanced image by using HE and the proposed spherical color model. After enhancing the image contrast and overall brightness, there are no color distortion and block artifacts due to the r channel in spherical color model can represent the more accurate luminance signal with the discrete interval [0 442] than those with the discrete intervals [0 255] in HSV and YUV color models [27, 28]. In other words, the discrete luminance signals of r channel are smoother than those of V channel in HSV and Y channel in YUV after all discrete intervals are normalized as [0 1].

4.2. **Quality comparison.** In order to further verify the effectiveness of the proposed enhancement scheme, we present a further enhancement comparison between the proposed enhancement scheme and Kong's enhancement scheme [24]. Experimental results are carried out by using two color images, "Tiffany" and "Baboon", respectively.

Figure 4 shows the original "Tiffany" color image (Figure 4(a)) and the contrast enhancement results using Kong's enhancement scheme [24] and our proposed enhancement scheme, respectively (Figures 4(b) and 4(c)). According to Figure 4(a), the non-uniform contrast, poor tint and shade can be easily observed in the original "Tiffany" color image.

After Figure 4(a) is enhanced using Kong's scheme [24], the original color features are seriously distorted in the enhanced image Figure 4(b). This is because the enhancement method of Kong's scheme [24] only uses the local maximum intensity to equalize the local histogram. This method may cause local over-enhancement and other artifacts, including noise, block artifacts, and so on. On the other hand, Kong's scheme only enhances the G channel of the RGB color model for fitting the color image enhancement. Therefore, the achromatic and chromatic information can not be effectively processed using this enhancement scheme [24].

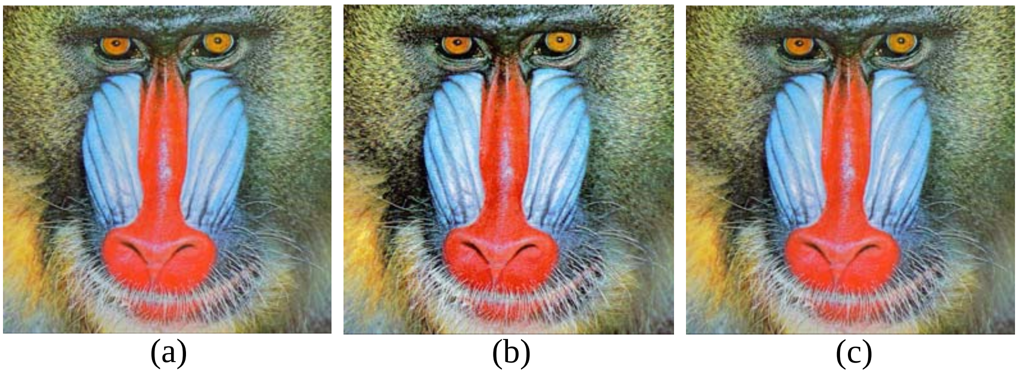


FIGURE 5. The "Baboon" color image: (a) is the original image; the remaining two images are the enhanced images using (b) Kong's enhancement scheme [24] and (c) the proposed enhancement scheme

Compared with Kong's scheme [24], our proposed enhancement scheme slightly improves the contrast on the girl's eyes, skin, and hair without losing the original color features shown in Figure 4(c). This is because the accurate luminance signal of spherical color model can facilitate the color contrast enhancement using the AWMHE method [22].

Figure 5 shows the original "Baboon" color image (Figure 5(a)) and the contrast enhancement results using Kong's enhancement scheme [24] and our proposed enhancement scheme, respectively (Figures 5(b) and 5(c)). With enough tint and shade, a uniform contrast exists in the original "Baboon" color image Figure 5(a). However, the over-enhancement still exists in the enhanced image (Figure 5(b)) by using Kong's scheme [24]. We can see that the tint and shade of baboon's nose and cheeks are distorted. Finally, there are no tint and shade distortion exist in the enhanced image (Figure 5(c)) by using our proposed enhancement scheme, while the original image has acceptable color features.

In gray-scale images, the well-known AMBE metric (absolute mean brightness error) has been widely used for measuring the brightness preserving effectiveness [24]. However, there are no useful metrics can be carried out for quantitative evaluation of color contrast enhancement [24]. Therefore, this article only provides the qualitative evaluation of the enhancement results based on the same evaluation approach in [24].

4.3. **Computational complexity.** The computational complexity of our proposed spherical color model, both in terms of space and time, is $O(MN)$, where MN is the image resolution. To complete our analysis, we report the time consumption of the proposed spherical color model for each test color image in Figures 3 – 5. Note that timings have been obtained by prototype implementations in C programming language on a laptop with Pentium(R) M 1.73 GHz CPU and 1 GB RAM, running Windows 7 operating system, and the excluded I/O. According to the time consumption analysis, the execution time is about 0.0613 seconds for the "Street" image. The execution time is about 0.0521 seconds for the "Tiffany" image. The execution time is about 0.0533 seconds for the "Baboon" image. As a result, the proposed spherical color model can handle an average of 0.0556 seconds in real-time at typical resolutions.

5. **Conclusions.** This article has presented a compact overview and experimentations between gray-scale and color image processing. First, we have presented a compact description on the AWMHE method. Second, several color models have explored to facilitate the color image processing by using the AWMHE method. Moreover, we have proposed a

novel enhancement scheme with the AWMHE method and the spherical color model for enhancing the color image contrast. This is the first enhancement scheme that uses the spherical coordinate system. Based on our color model analysis, we have demonstrated that spherical color model can effectively facilitate the color contrast enhancement without losing the original color features when compared to other state-of-the-art color models. According to the visual inspection method, experimental results show that the proposed enhancement scheme generates better enhancement images than those using the state-of-the-art enhancement schemes.

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