Novel Method of Color Histogram Equalization: Binding the Colors with Brightness

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Abstract— Histogram equalization (HE) is the simplest and most commonly used nonlinear technique to enhance grayscale images. It stretches the image histogram into a uniform histogram and becomes a more difficult task when dealing with color images, because of the need to take into account the correlation between color components, and also the color perception by humans. There are three key types of HE for color images, including: (i) the application of grayscale histogram equalization separately to the color components; (ii) 3-D histogram equalization in the RGB space, and (iii) equalization of the intensity component in the HSI or YCbCr space (since hue is the most basic attribute of color and changing it results in unacceptable color artifacts). Each of them has own advantages and disadvantages. For example, when applying the equalization method on color components of the RGB image, it may yield dramatic changes in the image's color balance since the relative distributions of the color components change as a result of applying the algorithm, or transforming from one color space to another and processing in these spaces usually generates a gamut problem, i.e., values of the variables may not be in their respective intervals. There is a need to develop new color image enhancement algorithms that preserve the color information content while enhancing the contrast. This paper presents a new color image enhancement concept. We illustrate the advantages of this concept using the histogram equalization for color images in the RGB model. The primary colors are processed together with the brightness at each pixel. In other words, the colors associated with their brightness (the gray as the average of colors can also be considered). The color image plus brightness are map to the grayscale image and the histogram equalization of grays is computed. Then, the new colors of the image are reconstructed from the histogram equalization. The proposed method is simple, fast, and the preliminary experimental examples show that the method is effective for color image enhancement without undesirable color artifacts. The new equalized images were compared to the performance of well-known color histogram equalization methods on both synthetic and natural images.

Index Terms - Color image enhancement, histogram equalization, image contrast, color enhancement measure.

1 Introduction

In many applications of imaging, including medical imaging, underwater imaging, feature extraction and object recognition, it is important to enhance images of low quality [1]-[6], which usually is estimated visually, as well as by using different measures to characterize the quality of images [26]-[31]. Different methods of image enhancement were developed when processing images not only in the spatial domain, but also in the frequency domain when using different transforms, such as the discrete Fourier transform (DFT) [28], elliptical DFT [36][57], cosine transform [34], signal-induced heap transforms [32][33], wavelets [35], and morphological transformations [37]. For grayscale images, one of the most popular methods of image enhancement in the spatial domain is the histogram equalization (HE) [7]. This method belongs to the class of image enhancement with a lookup table; it is simple and makes the histogram of the processed image to be approximately flat. The HE has many modifications and specifications, since it does not preserve the mean value of the image and may produce some undesirable image artifacts, noise amplification, and edge effect [30]. We mention the effective gradient-based HE [9], methods of bi-HE, multi-HE, HE with segmentation of the image, dynamic HE, and monotonic sequences, unsharp masking, contrast entropy, and others [10]-[14]. More than 45 different methods of HE are reported in the study of [8] and they work well for many images; there is no such a method of HE that can be used to enhance all types of images. In color imaging, the known algorithms of the HE can be applied for each color component of the image [16][17], if it is considered for instance in the RGB model, or only to the intensity component, if the image is transformed to the HSI or HSV color models [21]-[25]. It is the simple approach to enhance color images. The distribution functions of three primary colors are calculated and used separately for each color, which means that the correlation of colors is not considered. The method of HE with intensity and saturation components of color images has been also proposed [18]. It is known that the color HE may result in color artifacts. Therefore, new methods of color HE were developed, including the novel concept of homomorphic ratio of colors in HE [15] and 3-D color histogram [18]-[21].

It should be noted that the methods of image enhancement, such as the mentioned above HE in color HSI model, and method of color HE with average histogram in the RGB model, as well as the effective methods of alpha-rooting by the 2-D quaternion discrete Fourier transforms (QDFT) [38][39], use the grayscale image composed from the color channels in the first stage of computing. The grayscale image contains a mixed information of colors and appears to be a very useful concept to preserve in some degree the interconnection of colors. As illustration of usefulness the grayscale image in color image enhancement, we consider the color image "Lena" of size 512×512. Figure 1 shows this image in part (a) and the HE performed separately on color components of the image in part (b). The result of HE of the intensity component of thee image after transforming to the HSI color model is shown in part (c). The color HE of the image, when each color equalized by the histogram of the average histograms of colors is shown in part (d). And finally, the α-rooting by the 2-D QDFT and α=0.88 is shown in part (e). One can notice that the last three methods work well when comparing with the result of component-wise HE. The α-rooting in the quaternion algebra [41]-[46] processes three colors together with the gray as one unit, and this method belongs to another class of image enhancement methods in the frequency domain [40][47], which require computing the complex transforms, and was given above only to demonstrate the importance of using the colors together in the process of color image enhancement and color imaging in general. The effectiveness of this approach is also clear when comparing the methods of alpha-rooting with the known retinex method [53]-[55].

(a) (b) (c) (d) (e)

Fig. 1. (a) The color image, (b) the component-wise HE, (c) the image after HE in the HSI model, (d) HE by the average histogram, and (e) the 0.88-rooting by the 2-D QDFT.

In this work, we present a new model for color histogram equalization, wherein the original color image is binding to the brightness of colors. Therefore, the color image is presented as 4-component data, or image, and then, these data are processed not as a 4-D image; the data are transformed to a grayscale image of twice larger size. On this stage, we consider the HE of the grayscale image with the following transformation back to the new color image. Images are considered in the original RGB color model, without transforming them to other models, such as the HSI or HSV models, and then back to the RGB model. Many mentioned above algorithms of histogram equalization can be applied on such a grayscale image, but we will stand only on the traditional HE. The method of binding colors with the brightness is analyzed and compared with the HE accomplished component-wise. The examples of color HE on different color images are given and the results are analyzed.
The quality of color images is estimated by the enhancement and visibility measures [40][56].

2. Histogram Equalization of Images

In this section we consider a grayscale image $f_{n,m}$ of size $N \times M$ with the range of intensities $[r_0, r_1]$, which in many cases is the integer interval [0,255]. The histogram of the image $f_{n,m}$ gives us the information of the number (cardinality) of pixels of the image with the given level of intensity r,

$$h(r) = \text{cardinality}\{(n,m);\ f_{n,m} = r, n = 0:(N-1),\ m = 0:(M-1)\}.$$

The histogram is normalized as $h(r) = h(r)/(NM)$, so that $0 \leq h(r) \leq 1$, when $r \in [r_0, r_1]$.

In the method of histogram equalization [5], a monotonic increasing grayscale transformation T is used to straighten approximately the curve of the histogram in the desired range of intensities $[T_{\min}, T_{\max}]$,

$$T: r = f_{n,m} \to g_{n,m} = T(r) = T_{\min} + [T_{\max} - T_{\min}]F(r).$$

Here, the distribution function, $F(r)$, of image intensity is calculated by

$$F(r) = h(r_0) + h(r_0 + 1) + \cdots + h(r),\ r \in [r_0, r_1].$$

For the range $[r_0, r_1] = [T_{\min}, T_{\max}] = [0,255]$, the histogram equalization of the image is calculated by the transformation

$$T(r) = Q[F(r)] = Q\left[255 \sum_{k=0}^{k} h(k)\right], k = 0,1,\ldots,255.$$

where Q is a rounding operation.

3. Color Images as 2-D Grayscale Images

In this section, we consider the transformation of the color image into a grayscale image which allows for processing the three color channels of the image together with the brightness as one unit in each pixel in the spatial domain. The RGB color model is considered, when the image $f_{n,m}$ is described by the red, green, and blue components

$$f_{n,m} = (r_{n,m}, g_{n,m}, b_{n,m}), n = 0:(N-1), m = 0:(M-1).$$

The grayscale image presenting the brightness of this image is calculated by

$$i_{n,m} = 0.3 r_{n,m} + 0.59 g_{n,m} + 0.11 b_{n,m}. \qquad (3)$$

Now, we consider the image $f_{n,m} = (i_{n,m}, r_{n,m}, g_{n,m}, b_{n,m})$. This 4-component image can be mapped to a grayscale image in different ways, for instance, to the image of size twice larger, $(2N) \times (2M)$, by using the scheme shown in Fig. 2.

Fig. 2. Mapping the 4-component image into the grays.

Thus, in this model of transformation of the color image into the grayscale image $a_{n,m}$, the image is calculated as

$$a_{n,m} = \begin{cases} i_{k,l}, & k = 0:(N-1), l = 0:(M-1), \\ r_{k,l-M}, & k = 0:(N-1), l = M:(2M-1), \\ g_{k-N,l}, & k = 0:(2N-1), l = 0:(M-1), \\ b_{k-N,l-M}, & k = N:(2N-1), l = M:(2M-1). \end{cases}$$

We call this model the (2×2) model. The histogram of this grayscale image $a_{k,l}$, $k = 0:(2N-1), l = 0:(2M-1)$, can be referred to as the histogram of the color image $f_{n,m}$ with the brightness $i_{n,m}$. This grayscale image can be processed $a_{n,m} \to T(a)_{k,l}$ and then transformed back to the four components of size $N \times M$ each,

$$T(a)_{k,l} \to \hat{q}_{n,m} = (\hat{i}_{n,m}, \hat{r}_{n,m}, \hat{g}_{n,m}, \hat{b}_{n,m})$$

These components are calculated by

$$\hat{i}_{n,m} = T(a)_{n,m},\ \hat{r}_{n,m} = T(a)_{n,m+M},\ \hat{g}_{n,m} = T(a)_{n+N,m},$$
$$\hat{b}_{n,m} = T(a)_{n+N,m+M},$$

for $n = 0:(N-1), m = 0:(M-1)$.

The histogram equalization of the color image $f_{n,m}$ is considered to be the image $\hat{f}_{n,m} = (\hat{r}_{n,m}, \hat{g}_{n,m}, \hat{b}_{n,m})$. The color image processing $f_{n,m} \to \hat{f}_{n,m}$ is called the color-brightness binding histogram equalization, or simply the color histogram equalization (CHE); its diagram is shown in Fig. 3.

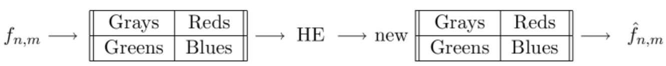


Fig. 3. Diagram of color histogram equalization.

The mapping of the 4-component image $q_{n,m}$ into the grayscale image $a_{k,l}$, as written in Fig. 2 and Eq. 4, is convenient for better visualization. We can also simply record each four components in sequence from pixel to pixel. The way these four components are recorded in a grayscale image is not important for the histogram equalization. It matters for other than lookup table transformations, for instance, when processing the composed grayscale image in the frequency domain. In the proposed CHE, the three primary colors are binding with the brightness and this four is treated as a whole or unit at each pixel of the image. We do consider that the colors are dependent and such a binding of colors with brightness guarantees to some extent that the colors will not be greatly scattered after processing and there will not be any color artifacts.

To describe the process of CHE, we consider the histogram of the grayscale image $a_{k,l}$. Let $\tilde{h}_a$, $\tilde{h}_r$, $\tilde{h}_g$, $\tilde{h}_b$, and $\tilde{h}_i$ be the non normalized histograms of images $a_{k,l}$, $r_{n,m}$, $g_{n,m}$, $b_{n,m}$, and $i_{n,m}$,respectively. The corresponding normalized histograms will be denoted without the symbol tilde. For instance, $h_a = \tilde{h}_a/(4NM)$ and $h_r = \tilde{h}_r/(4NM)$. The distribution function of the image $a_{k,l}$ can be written as

$$F_a(r) = \frac{1}{4NM}\sum_{k=0}^{k}\tilde{h}_a(k)$$
$$= \frac{1}{4NM}\sum_{k=0}^{k}\left[\tilde{h}_r(k)+\tilde{h}_g(k)+\tilde{h}_b(k)+\tilde{h}_i(k)\right]$$
$$= \frac{1}{4}\sum_{k=0}^{k}\frac{1}{NM}\left[\tilde{h}_r(k)+\tilde{h}_g(k)+\tilde{h}_b(k)\right]+\frac{1}{4}\sum_{k=0}^{k}\frac{1}{NM}\tilde{h}_i(k)$$
$$= \frac{1}{4}\sum_{k=0}^{k}\left[h_r(k)+h_g(k)+h_b(k)\right]+\frac{1}{4}\sum_{k=0}^{r}h_i(k)$$

and, therefore,

$$F_a(r) = \frac{3}{4}\frac{F_r(r)+F_g(r)+F_b(r)}{3}+\frac{1}{4}F_i(r),$$

where $r \in [0, r_1]$. Here, $F_r(r)$, $F_g(r)$, $F_b(r)$, and $F_i(r)$ denote the distribution functions of the red, green, blue, and brightness components of the image, respectively. Then, considering the average color distribution as $F_c(r) = [F_r(r)+F_g(r)+F_b(r)]/3$, one can write that the distribution function of the grayscale image $a_{k,l}$ is the arithmetic mean $F_a(r) = 3/4F_c(r) + 1/4F_i(r)$. We can generalize this result, by writing this mean as

$$F_a(r) = a_1F_c(r) + a_2F_i(r), \qquad (5)$$

where a_1 and a_2 are two non negative numbers such that $a_1 + a_2 = 1$. The case when $a_1 = 1$ corresponds to the HE by the average histogram, which is illustrated for "Lena" image in Fig. 1 in part (d).

3.1. Preliminary Experimental Results of CHE

In this section, we consider a few examples of the CHE of color images. The results of CHE are compared with the traditional method of component-wise HE to which we refer as the 3-color HE. The visual appearance of images is considered together with quantitative measures of enhancement, the Michelson color construct measure, the image sharpness measure, the average entropy and color square-root gradient, that will be defined in a moment.

$$T(a) = \text{new}\begin{bmatrix}\text{Grays} & \text{Reds}\\ \text{Greens} & \text{Blues}\end{bmatrix} \longrightarrow \hat{f}_{n,m} = \left[\{\text{new Red, new Green, new Blue}\}_{n,m}\right]$$

Fig. 4. Color image composition from the new grayscale image.

First, we describe one example of CHE in detail. Figure 5 shows the grayscale image $a_{k,l}$ of size 2048×1536 in part (a) that is composed from the original color "girl Anoush" image $f_{n,m}$ of size 1024×768. The histogram equalization $T(a)_{k,l}$ of the grayscale image is shown in part (b).

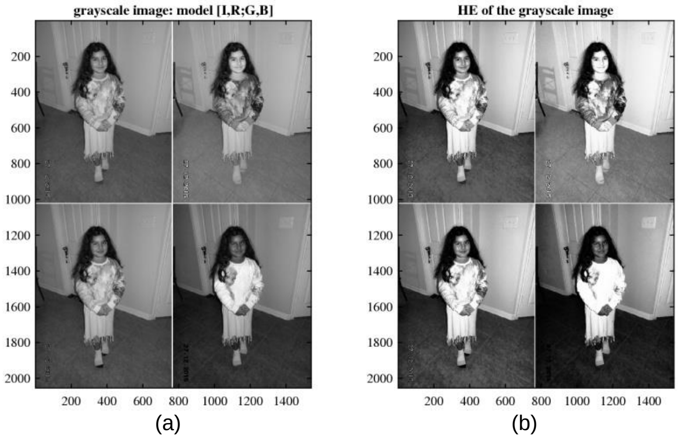


Fig. 5. (a) The 4-component grayscale image and (b) its histogram equalization.

The color image $f_{n,m}$ is shown in Fig. 6 in part (a) and the histogram of the grayscale image $a_{k,l}$ in part (b). This image has the full range of intensities [0,255]. The graph of distribution function $F_a(r)$ is shown in part (c). The grayscale transformation for the HE is calculated as $T(r) = 255F(r)$, $r = 0{:}255$. The color histogram equalization is shown in part (d); this image is composed from three parts of the 4-component grayscale image in Fig. 5(b), as shown in Fig. 4.

Fig. 7 shows the histograms of the color components of the image before and after processing by the CHE.

Figure 8 shows the original color image in part (a), the color enhancement image in part (b), and the image processed by the histogram equalization of each color component separately in part (c). One can notice that the HE, which is accomplished component-wise, results in false colors at many pixels of the image, for instance, in the floor.

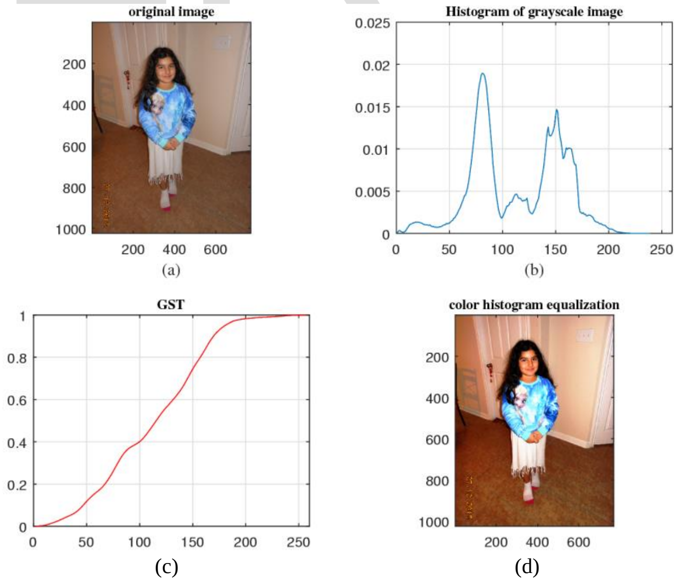


Fig. 6. (a) The image, (b) the histogram of the image, (c) the distribution function, and (d) the color histogram equalization of the image.

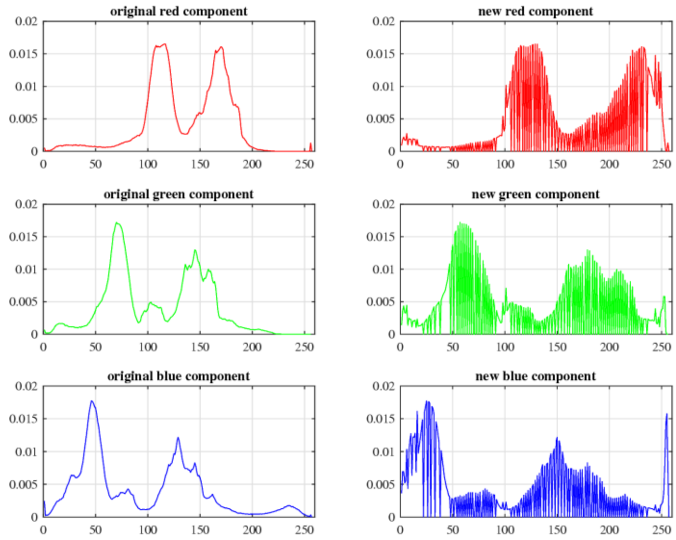
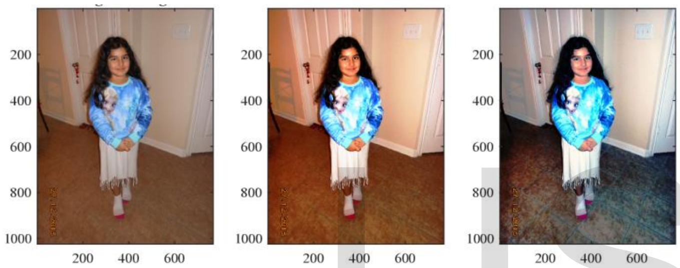


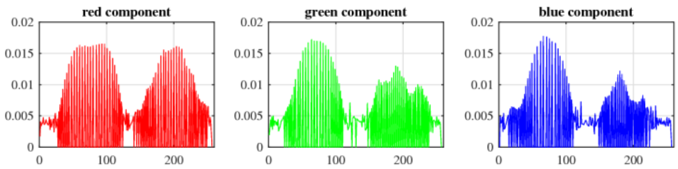
Fig. 7. The histograms of color components of the original image (the left column) and the color enhancement (the right column).



(a) (b) (c)

Figure 8: (a) The original color image "girl Anoush," (b) the CHE, and (c) the component-wise HE.

For this image, Fig. 9 shows the histograms of the red, green, and blue colors in parts (a), (b), and (c), respectively. We can analyze visually the difference in these histograms and the corresponding histograms that are given in Fig. 7. For instance, for the red component, the first main cup in Fig. 9(a) has been shifted to the left, while the CHE almost preserves the range of this cup (see Fig. 7).



(a) (b) (c)

Fig. 9. Histograms of (a) red, (b) green, and (c) blue components of the image after processing component-wise by the HE.

3.2 Measures of Color Image Enhancement

To measure the quality of color images, first we consider the described in [5][38][40] quantitative measure of image enhancement that is based on the ratio of the maximum and minimum of colors in the logarithm scale. A color image $f_{n,m}$ of size $N \times M$ is divided by blocks, for instance of 5×5 each. The number of such blocks in the first direction is $k_1 = [N/5]$, and $k_2 = [M/5]$ in the second direction. Here, the rounding operation is denoted by $[\cdot]$. The enhancement measure of the color image $f_{n,m}$ is estimated as

$$EMEC(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[\frac{\max_{k,l}\{r,g,b\}}{\min_{k,l}\{r,g,b\}} \right]. \quad (6)$$

The maximum and minimum values of the image in the (k,l)-th block are calculated as $\max(f) = \max(r,g,b)$ and $\min(f) = \min(r,g,b)$ of colors, respectively.

When processing a grayscale image $x_{n,m}$, the enhancement measure, EME, is calculated by [26]-[29]

$$EME(x) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[\frac{\max_{k,l}(x)}{\min_{k,l}(x)} \right]. \quad (7)$$

Here, $\max_{k,l}(x)$ and $\min_{k,l}(x)$ respectively are the maximum and minimum of the grays in the (k,l)-th block.

For images in Fig. 8, the EMEC of the original color image is 16.1870, and 26.7246 for the color histogram equalization. The EMEC of the color image, which is obtained by the component-wise HE, is 17.2067. It should be noted that the EME of the 4-component grayscale image $a_{n,m}$ in Fig. 4(a) is 3.9522 and after HE this measure is 6.3285.

The mean of the EMEs of colors is the image sharpness measure [48],

$$UISM(f) = \lambda_r EME(r) + \lambda_g EME(g) + \lambda_b EME(b)$$

with coefficients $\lambda_r = 0.299$, $\lambda_g = 0.587$ and $\lambda_b = 0.114$ [1].

The measure for image contrast can also be defined with the Michelson visibility ratio [40][49], which is for the red component $r_{n,m}$ is calculated by

$$MVR_{k,l}(r) = \left[\frac{\max_{k,l}(x) - \min_{k,l}(x)}{\max_{k,l}(x) + \min_{k,l}(x)} \right],$$

and similarly for the green and blue components of the image. The Michelson enhancement measure for one color component is calculated by

$$MEM(c) = -\frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} MVR_{k,l}(c) \log_{10}[MVR_{k,l}(c)].$$

The color image contrast measure is defined as the average

$$UICM(f) = [MEM(r) + MEM(g) + MEM(b)]/3.$$

The information function in the form of average of entropies of three colors can also be considered [50],

$$ACE(f) = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \frac{1}{3} \left(\sum_{c=r,g,b} c'_{n,m} \log_2 c'_{n,m} \right).$$

Here, the normalized coefficients $c'_{n,m} = c_{n,m}/A(c)$, and $A(c)$ are the areas of the color components $c_{n,m}$.

To analyze the information carrying the image gradients, we consider the average color square-root gradient [51],

$$ACG(f) = \frac{1}{NM} \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \frac{1}{3} [G(r)_{n,m} + G(g)_{n,m} + G(b)_{n,m}],$$

where, for each color component $c = r$, g, and b, the gradient measure at pixel (n,m) is calculated by

$$G(c)_{n,m} = \sqrt{[G_x(c)_{n,m}]^2 + [G_y(c)_{n,m}]^2}.$$

Here, G_x and G_y are the gradient operators along the X- and Y-directions, respectively. For instance, the Sobel gradient operators with the 3×3 and 5×5 masks can be used [2]. For the color image in Fig. 8(a) before and after processing by the HEs, the values of EMEC and other mentioned above measures are given in Table 1.

Table 1
Measure of the "girl Anoush" image before and after enhancement.

"girl Anoush"	EMEC	ACE	ACG	UICM	UISM
original	16.19	19.43	4.68	3.83	3.61
enhanced	**26.72**	19.28	6.71	6.37	6.06
enhanced by CHE	15.85	19.29	8.92	7.59	7.54

The preliminary experimental results show that the CHE is effective; it gives good quality enhanced images. Figure 10 shows the color "pentagon" image in part (a) and the CHE of the image in part (b).

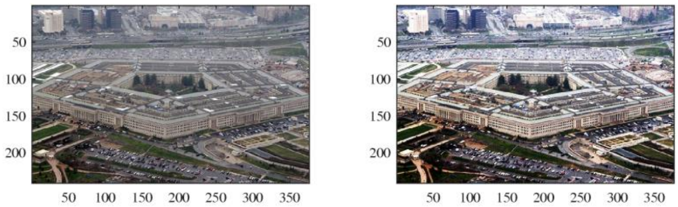


Fig. 10. (a) The original "pentagon" image and (b) the CHE of the image.

Figure 11 shows the original "couple" image in part (a), the color image enhancement of this image in part (b). The component-wise HE of the color image is shown in part (c). Both results of the HE are of high quality. One can note the change of color palette in the image of the 3-color HE.

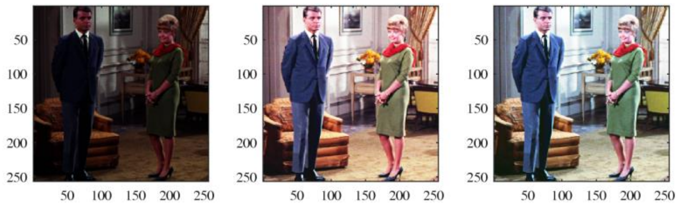


Fig. 11. (a) The original "couple" image, (b) the CHE of the image, and (c) the color-wise HE of the image.

Examples of processing more images are shown in Figs. 12 and 13 and the values of measures are given in Table 2.

The following observation can be made from this table. The images enhanced by the CHE have the high EMEC measure. The exception is the "couple image;" it should be mentioned that for some images the minimums (not only maximums) of EME result in the image enhancement. By entropy characteristic, ACE, the propose method is not inferior to the 3-color HE; the small increase in entropy can be seem for the images. The information of gradient measure, ACG, is high for the 3-color HE, except the "pentagon" image. Also, one can see good results for CHE when comparing two measures related to the contrast and sharpness, UICM and UISM.

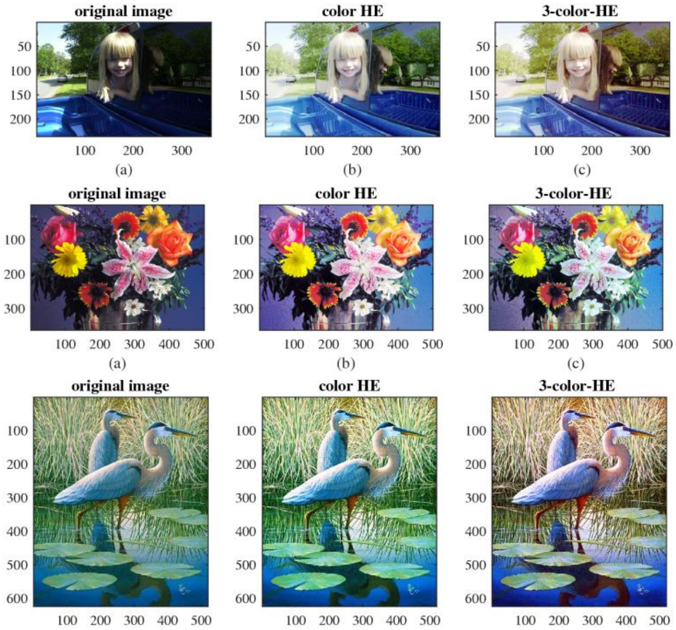


Fig. 12. (a) The original color images, (b) the CHE of images, and (c) the color-wise HE of images.

Table 2
Measure Of Images Before And After Enhancement

Image	EMEC	ACE	ACG	UICM	UISM
"pentagon"	24.63	16.34	24.99	21.05	20.96
enhanced by CHE	**39.56**	16.19	**40.93**	**34.16**	**33.93**
enhanced by 3-HE	33.96	16.18	41.18	26.72	26.80
"couple"	40.01	15.38	9.10	25.33	25.30
enhanced by CHE	**23.35**	15.75	22.04	14.85	14.81
enhanced by 3-HE	29.33	15.71	23.75	18.68	17.49
"girl"	38.92	15.65	12.84	19.02	18.94
enhanced by CHE	**43.99**	16.09	18.19	**21.27**	**19.40**
enhanced by 3-HE	27.56	16.08	18.91	13.42	13.57
"flowers"	26.41	17.12	14.63	13.72	14.32
enhanced by CHE	**31.97**	17.18	19.66	**16.08**	**17.15**
enhanced by 3-HE	29.48	17.18	20.69	15.97	16.59
"blue cranes"	35.44	18.07	26.82	18.50	18.01
enhanced by CHE	**51.89**	18.00	34.04	**29.83**	**26.74**
enhanced by 3-HE	40.48	18.01	35.34	24.36	24.30
"Lena"	24.44	17.88	9.20	7.37	8.76
enhanced by CHE	**36.80**	17.75	12.00	11.84	**13.60**
enhanced by 3-HE	20.52	17.70	15.36	22.23	11.34

The last image "blue cranes" in Fig. 12 and "Lena" image in Figs. 1 and 13 show a well essential difference between the CHE and 3-color HE. We believe that there are color artifacts in the images that are shown in parts (c). We can also analyze the difference of these images relative to the mean peak-signal-noise ratio (PSNR), which is calculated as

$$\text{mean}[PSNR] = 1/3[PSNR(r) + PSNR(g) + PSNR(b)],$$

where the PSNRs for the primary colors $c = r$, g, and b are calculated by

$$PSNR(r) = 20\log_{10}\left(\frac{255}{\varepsilon(c)}\right),$$

where

$$\varepsilon(c) = \frac{1}{NM}\sum_{n=0}^{N-1}\sum_{m=0}^{M-1}\left(c_{n,m} - \hat{c}_{n,m}\right)^2.$$

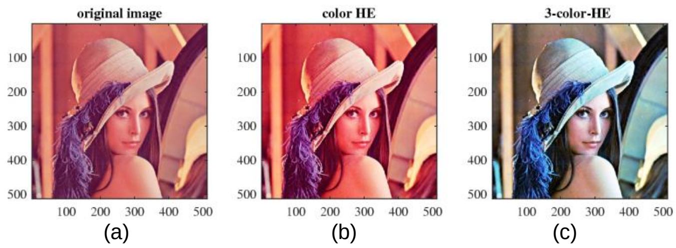


Figure 13: The original "Lena" image, (b) the CHE of the image, and (c) the color-wise HE of the image.

The data of PSNR for the images are given in Table 3. The mean PSNR for both images has highest value when processing images by the color HE. Relative to the green and blue colors, the PSNR of the red channel has the smallest value for both images, when processing the color independently. There is not a wide range of values of the PSNR of colors for the proposed method of CHE.

Table 3
PSNR of Images

"blue cranes"	mean[PSNR]	PSNR(red)	PSNR(green)	PSNR(blue)
enhanced by CHE	**21.09**	22.32	20.00	20.95
enhanced by 3-color HE	19.02	17.55	19.98	19.54
"Lena"	mean[PSNR]	PSNR(red)	PSNR(green)	PSNR(blue)
enhanced by CHE	**22.43**	22.47	22.27	22.56
enhanced by 3-color HE	14.58	12.44	16.79	14.52

To demonstrate the effectiveness of proposed method, we also consider a few images from the cite by the address: https://hypjudy.github.io/2017/03/19/dip-histogram-equalization/. The images are shown in Fig. 14 in the part (a). The corresponding color histogram equalizations of these images are shown in part (b), and the result of the independent histogram equalization are shown in par (c).

4 Conclution

A new method of histogram equalization for color images in the RGB model is presented. The three primary colors are processed together with the brightness at each pixel. The color image plus brightness are map to the grayscale image and histogram equalization of grays is computed and then, the new colors of the image are reconstructed from the HE. The preliminary experimental examples with different images show that the described color histogram equalization is effective and can be used in color imaging for color image enhancement. It should be noted that the model of color image processing described in this paper for the HE can also be used for different modifications of the HE of grayscale image processing, including the techniques of bi-HE, multi-HE and unsharp masking. For instance, for the "Lena" image, Figure 15 shows the direct application of the method called the range limited weighted histogram equalization (RLWHE) [51] to each color component in part (a). The application of the proposed method with the RLWHE is shown in part (b), and for comparison, the color HE of this image in part (c).

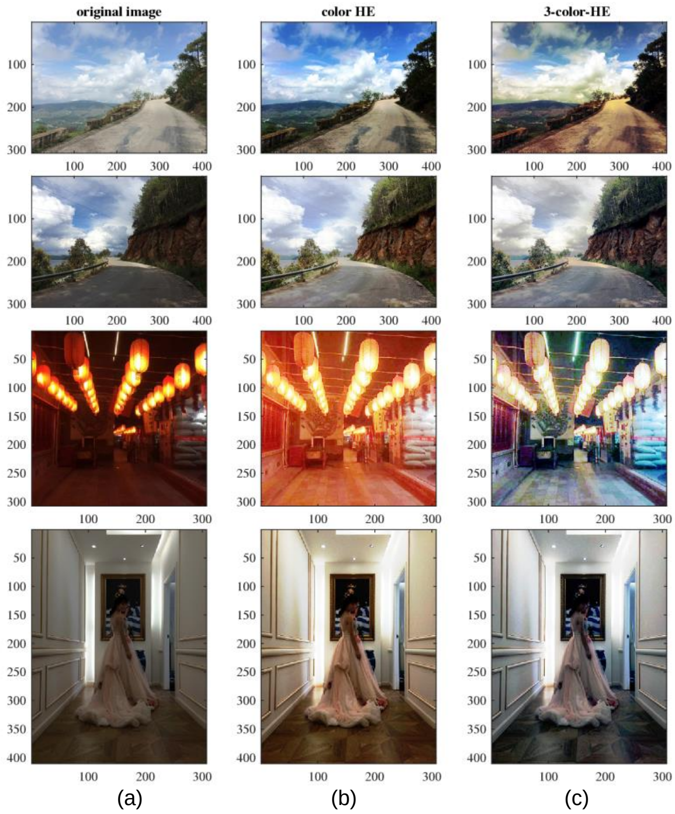


Fig. 14. (a) The original color images, (b) the CHE of images, and (c) the color-wise HE of images.

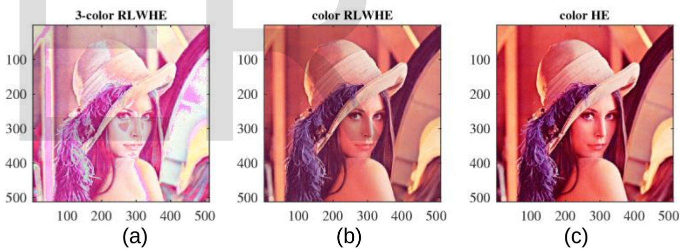


Fig. 15. (a) The color-wise RLWHE, (b) the color RLWHE, and (c) the color HE of the image.

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