Contrast Enhancement of RGB Color Images by Histogram Equalization of Color Vectors' Intensities

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Abstract. The histogram equalization (HE) is a technique developed for image contrast enhancement of grayscale images. For RGB (Red, Green, Blue) color images, the HE is usually applied in the color channels separately; due to correlation between the color channels, the chromaticity of colors is modified. In order to overcome this problem, the colors of the image are mapped to different color spaces where the chromaticity and the intensity of colors are decoupled; then, the HE is applied in the intensity channel. Mapping colors between different color spaces may involve a huge computational load, because the mathematical operations are not linear. In this paper we present a proposal for contrast enhancement of RGB color images, without mapping the colors to different color spaces, where the HE is applied to the intensities of the color vectors. We show that the images obtained with our proposal are very similar to the images processed in the HSV (Hue, Saturation, Value) and L*a*b* color spaces.

Keywords: Color characterization · Histogram equalization · RGB images

1 Introduction

Color image processing has not been studied so exhaustive, relatively, because the color representation demands significant computational resources [1, 2]; but given the technological advances, the development of techniques for color image processing have been incentivized [3–7]. Several of the techniques employed for color image processing are extended versions of techniques designed for grayscale images [8–12]. But they do not always success because the nature of the chromaticity data is not considered; such techniques focus on to process, mainly, the intensity of colors. Hence, it is necessary to develop new techniques or update the current techniques to process adequately the color.

There are several models to represent colors, but the RGB space is the most employed because the image acquisition hardware uses this space to represent colors.

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Despite the RGB space is accepted by most of the image processing community to represent colors, such space is not suitable for color processing because the color differences cannot be computed using the Euclidean distance [13, 14].

One of the classic techniques for image processing is the HE for contrast enhancement. Usually, for RGB color images, the HE is applied in the three color channels separately [15, 16], but given the high correlation between the color channels, the chromaticity of colors is modified.

Different works overcome this problem by mapping the colors from the RGB space to a different color space where the intensity is decoupled from the chromaticity, such as the HSV and L*a*b* spaces; the HE is performed in the intensity channel and finally the colors are mapped back to the RGB space [17–19]. However, the computational load of color mapping between the RGB space and other color spaces may be high because most of the mathematical operations are not linear [1].

Therefore, the contribution of this work is a proposal of how to apply the HE for contrast enhancement of RGB color images using the colors' intensities, without mapping the colors to other color spaces and without suffering undesired chromaticity changes. The intensities of the colors are obtained by computing the magnitudes of the color vectors, creating an intensity channel; on this intensity channel the HE is applied, then, the magnitudes of the color vectors are updated. The resulting images are very similar to the images obtained if a different color space is employed to process the image.

The rest of the paper is organized as follows: in Sect. 2 the histogram equalization technique and the features of the RGB space are presented, but also, our proposal of contrast enhancement of color images is introduced. The experiments performed and the resulting images are shown in Sect. 3; but also, we compare the images obtained with our approach with respect to the images obtained using the well-known color spaces HSV and L*a*b*, where the HE is applied in their respective intensity channels. In Sect. 4 the results are discussed and their respective accumulative intensity histograms are analyzed. Conclusions in Sect. 5 close the paper.

2 Proposed Approach

The HE is an image processing technique developed for grayscale images to process the intensity of the pixels; the goal of the HE is that all the intensity levels are employed and also, all the intensity levels have the same occurrences.

For color images, the HE is applied to the intensity channel of the color space employed to represent colors. There are different color spaces where the intensity of colors is decoupled from the chromaticity. As we state before, the RGB space is often employed to model colors because the image acquisition hardware employs this space to represent colors. Thus, if the colors are planned to be processed in a different color space, then the colors must be mapped to the desired space before processing; it implies to perform, most of them, non-linear mathematical operations that may represent an important computational load. Because of space constraints within the paper, we do not show such non-linear operations, but the reader can find them in reference [1].

We claim that the contrast of RGB color images can be enhanced using the HE technique on the intensity of colors, without mapping the colors to other space; but it is important to consider the disadvantages of such space for color processing. For instance, the intensity is not decoupled from the chromaticity; that is, there is not an intensity channel. However, it is possible to build the intensity channel by computing the magnitudes of the color vectors, and then to apply the HE technique to such intensity channel, without modifying the chromaticity of the colors.

Our proposal consists on the following steps:

1. Build the intensity channel with the magnitudes of the color vectors,
2. All the color vectors are normalized,
3. The HE is applied to the intensity channel,
4. All the normalized vectors are multiplied by the corresponding scalar value obtained after HE.

Next, in this section, we explain in detail the mathematical operations of the proposed approach; but also, we give a brief explanation about the color representation in the RGB space and their features, and the HE technique.

2.1 RGB Color Space

The RGB space is based in a Cartesian coordinate system where colors are points defined by vectors that extend from the origin, where black is located in the origin and white in the opposite corner to the origin, see Fig. 1.

The color of a pixel p is written as a linear combination of the basis vectors red, green and blue, that is:

$$\phi_p = r_p\hat{\imath} + g_p\hat{\jmath} + b_p\hat{k}. \tag{1}$$

Where r_p, g_p and b_p are the red, green and blue components, respectively. The colors have two features: the chromaticity or hue, and the intensity or brightness. It is important to remark that the orientation and magnitude of a color vector defines the chromaticity and the intensity of the color, respectively [1].

In order to explain the difference between chromaticity and intensity, consider the Fig. 2, we state the color of squares (a) and (b) of Fig. 2 is green because both squares have the same chromaticity although the square (a) is brighter than square (b); therefore, the color vectors of both squares have the same orientation but with different

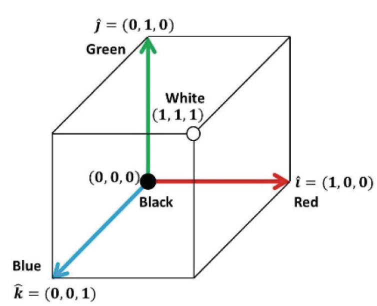

Fig. 1. RGB color space (Color figure online)

magnitude. On the other hand, we claim the colors of squares (c) and (d) are different because the chromaticity of both squares are different despite the intensities are the same; that is, the color vectors have different orientation but with the same magnitude.

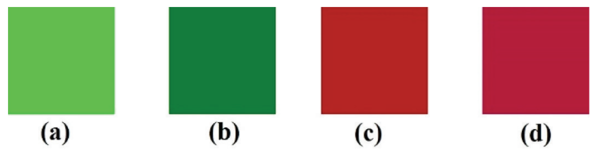

Fig. 2. Color of squares (a) and (b) with the same chromaticity but with different intensities; color of squares (c) and (d) with different chromaticity but with the same intensity (Color figure online)

2.2 Histogram Equalization Technique

The HE is an image processing technique for contrast enhancement of images. The purposes of the HE are [1]:

1. employ all the intensity levels,
2. distribute the number of intensities in all the pixels of the image, in other words, all the intensity levels have the same occurrences within the image.

The HE is computed with the following equation [1]:

$$\lambda(k) = \frac{L-1}{N}\sum\nolimits_{i=0}^{k} h(i). \tag{2}$$

Where $h(i)$ is the occurrence of intensity level i of the image to process, L is the number of intensity levels, N is the number of pixels of the image, $k = I(x, y)$ is the intensity value of the pixel located at (x, y) of the image I, and $\lambda(k)$ is the value of the equalized intensity level k.

This technique is developed for grayscale images, so, usually $L = 256$; for RGB color images, the pixel's intensity is represented by the magnitude of the vector that characterizes the pixel's color. Thus, the number of intensity levels is different; the value of L is computed as we explain in the following Sect. 2.3.

2.3 Contrast Enhancement Proposal

As mentioned before, in RGB color images the color channels cannot be processed separately; because of the high correlation between the components, the chromaticity of colors may be modified. In order to avoid undesired chromaticity changes, the color of every pixel is processed as a vector.

So as to equalize the intensity histogram of RGB color images, the range of intensity levels must be defined; in other words, the magnitudes of the smallest and largest color vectors must be computed. As shown in Fig. 1, the vector with the lowest magnitude corresponds to the black color; that is, let $\phi_b = [0, 0, 0]$ be the color vector of black color, therefore $||\phi_b|| = 0$. While the largest vector represents the white color, this vector extends from the origin to the opposite corner of the cube, see Fig. 1. Considering that the usual range of the red, green and blue components is $[0, 255]$, the vector representing white color is $\phi_w = [255, 255, 255]$, therefore $||\phi_w|| = 255\sqrt{3}$. So, the range of the intensity values is $\left[0, 255\sqrt{3}\right]$.

Note that L of Eq. (2) is an integer number, and the highest intensity value is $255\sqrt{3} \approx 441.673$; hence, only the integer part of this number is employed, thus $L = 441$. The magnitude of the color vectors can be modified by multiplying the respective scalar value obtained after the HE. Before this mathematical operation is performed, the color vectors must be normalized; in this way all the vectors have the same intensity without modifying their orientation that represents the chromaticity. In other words, our proposal consists on performing the following mathematical operations:

1. Let $\Phi = \{\phi_1, \ldots, \phi_N\} \subset \mathbb{R}^3$ be the set of color vectors of a given image; all the color vectors are normalized with $\hat{\phi}_i = \phi_i / \|\phi_i\|$.
2. The intensity histogram $h(i)$ of the image is computed as follows

$$h(i) = \#\{k | f(\|\phi_k\|) = i, \forall \phi_k \in \Phi\}. \quad (3)$$

   Where # denotes the cardinality of the set, $f : \mathbb{R} \to \mathbb{Z}$ is a function that extracts the integer part of a real number.
3. Equalize the histogram using Eq. (2), where $L = 441$.
4. The normalized color vectors are multiplied by their respective scalar value computed with Eq. (2). That is:

$$\varphi_j = \lambda(k) \cdot \hat{\phi}_j, j = 1, \ldots, N. \quad (4)$$

   Where $k = f\left(\left\|\phi_j\right\|\right)$, $\lambda(k)$ is computed with Eq. (2) and φ_j is the color vector of the resulting image.
5. Replace the color vector ϕ_j by the color vector φ_j.

With this proposal the contrast of the RGB color image is enhanced without modifying the chromaticity of the colors. In Sect. 3 we present the experiments and the resulting images using our approach.

3 Experiments and Results

In this section we show the images obtained using our proposal. In previous works where the images are processed using other color spaces, the histogram of the intensity channel is equalized and then the image is mapped back to the RGB space.

We compare the images obtained with our approach and the images processed in the HSV and L*a*b* color spaces, because these color spaces are often employed for color processing [1]; but also, we show the images obtained by equalizing the histogram of each color channel of RGB color images. First column of Fig. 3 shows the input images. The images selected for experiments are extracted from the Berkeley segmentation database (BSD) of the Berkeley computer vision group[1], which is becoming the standard benchmark to test color image processing algorithms; the BSD is a database of natural images that contains 500 color images of size 481 × 321 pixels; because of space constraints within the paper, we have selected 6 images from the BSD, but we consider the resulting images show evidence our proposal is worthy.

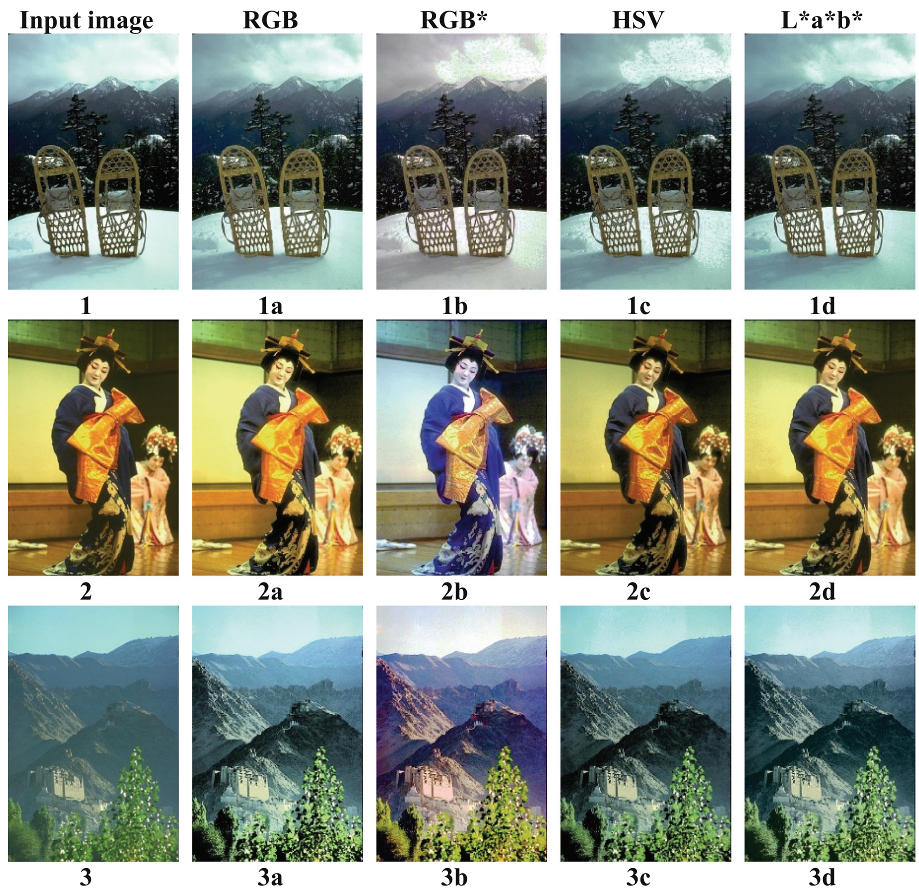

Fig. 3. First column shows the images employed for experiments; column RGB shows the images obtained by processing them with our proposal; column RGB* show the resulting images by applying the HE to each color channel; columns HSV and L*a*b* show the images obtained by using HE to the intensity channels of the respective color space. Input images and resulting images

[1] www2.eecs.berkeley.edu/Research/Projects/CS/vision/bsds/.

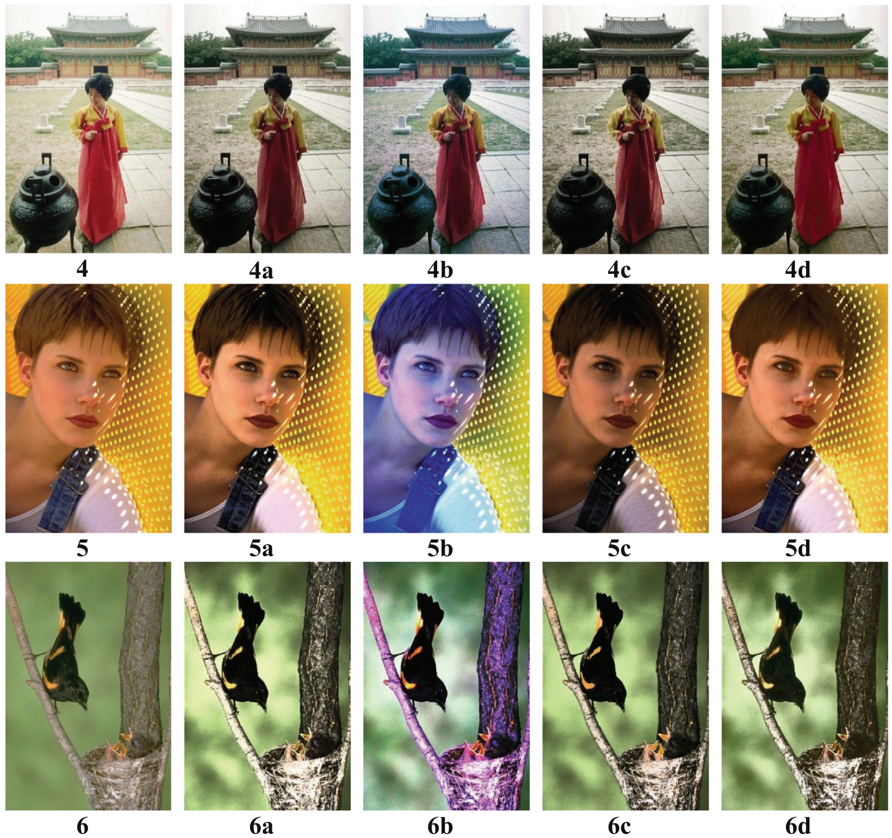

Fig. 3. (*continued*)

Columns RGB, RGB*, HSV and L*a*b* of Fig. 3 shows the images obtained by processing the input images. The column RGB shows the resulting images using our proposal; the column RGB* shows the images obtained by equalizing the histogram of each color channel separately; columns HSV and L*a*b* show the resulting images by applying HE in the intensity channels of the HSV and L*a*b* spaces, respectively.

It is easy to appreciate that the colors of the images of the column RGB* suffered chromaticity changes; perhaps, the most notable are images 2b, 3b, 5b and 6b. The images obtained with our proposal are very similar to the resulting images of the columns HSV and L*a*b*. The intensity ranges of the images processed using the HSV and L*a*b* color spaces are $[0, 255]$ and $[0, 100]$, respectively.

4 Discussion

The discussion of the results has been divided in three parts: in Sect. 4.1 we perform the qualitative analysis of the images' appearances; in Sect. 4.2 we show and discuss the accumulative histogram (AH) of each resulting images, previously transformed to grayscale, so as to analyze the contrast objectively; in order to reduce the computational of our approach, in Sect. 4.3 we propose to change the formula to compute the color vectors' magnitude, the resulting images change slightly with respect to the input images shown in Fig. 3.

4.1 Qualitative Evaluation

As mentioned before, the contrast enhancement using the HE technique for HSV and L*a*b* color images is applied to the intensity channel, where the chromaticity of colors does not change. One of the most important features of the HSV and L*a*b* spaces is the chromaticity is decoupled from the intensity. In the RGB space there is not an intensity channel; however, with our proposal it is possible to modify the intensity of colors without altering the chromaticity.

It is easy to appreciate that the images of column RGB*, Fig. 3, suffered chromatic changes in their colors. The colors of all the images are more saturated; note that the images obtained with our approach are very similar to the images processed with the L*a*b* space; however, there are small differences. In images 1a, 1c and 1d, the shape of the clouds is different. In image 2a the colors of the person's clothes of the background and person's face of the front ground are brighter than the corresponding parts of images 2c and 2d.

The images 3a and 3d are almost the same; in image 3c the details of the mountains are slightly less clear. In image 4d, the red part of the woman's dress is brighter than in the other images obtained; note that the house's roof in the background is clearer than in the original image.

The images 5a and 5c are the most similar between them; the image 5d is the brightest, it is easy to appreciate it in the hair, clothes and lips of the woman. Between the images 6a, 6c and 6d the differences are minimal; in the image 6a the branches where the bird and the nest are set, are darker than in the original images; besides, the intensity differences in the background are more notable.

4.2 Accumulative Histogram Analysis

In grayscale images, the AH of intensities is employed to analyze the contrast of the images. The shape of an image's AH with contrast enhanced is a straight line at 45°, approximately. For color images, it is not possible to compute the AH because the number of intensity levels of the color spaces is different between them. As we state before, the number of intensity levels is 441 with our proposal, while for HSV and L*a*b* spaces the number of intensity levels is 256 and 101, respectively.

However, it is possible to analyze the AH of the images if all the resulting images are converted to grayscale. From Figs. 4, 5, 6, 7, 8 and 9 the AHs of the respective images obtained in Fig. 3 are shown; the histograms are obtained by converting

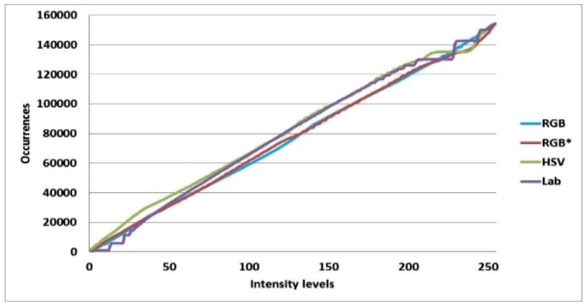

Fig. 4. Accumulative histogram of image 1

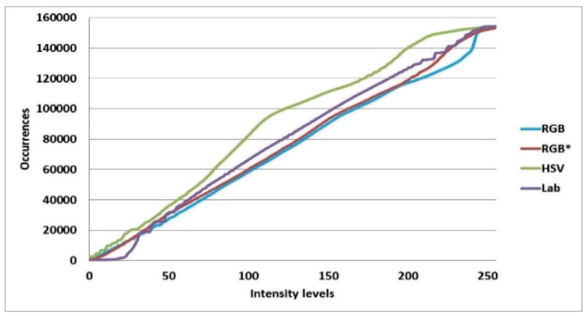

Fig. 5. Accumulative histogram of image 2

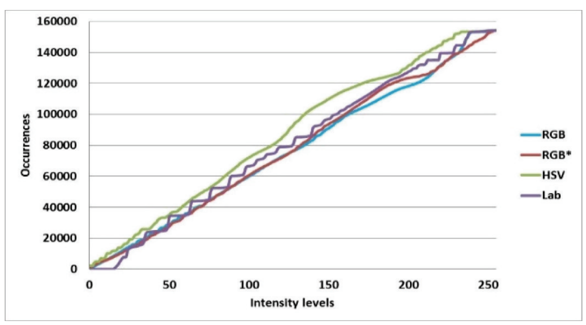

Fig. 6. Accumulative histogram of image 3

previously the images to grayscale. The blue lines represent the AHs of the images obtained with our proposal; the lines in red, green and purple represent the AHs of the images shown in the columns RGB*, HSV and L*a*b* of Fig. 3, respectively.

The AH obtained from the image processed with our proposal, shown in Fig. 4, is the straightest from the other AHs; the AHs of the other images have several peaks in the highest intensity levels.

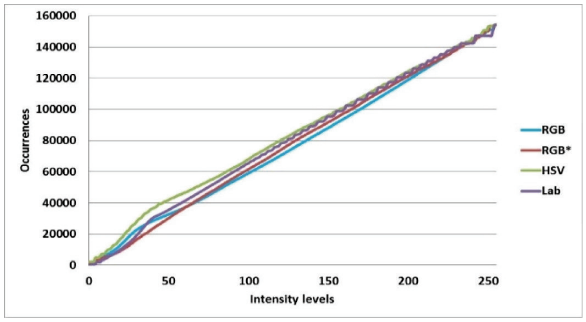

Fig. 7. Accumulative histogram of image 4

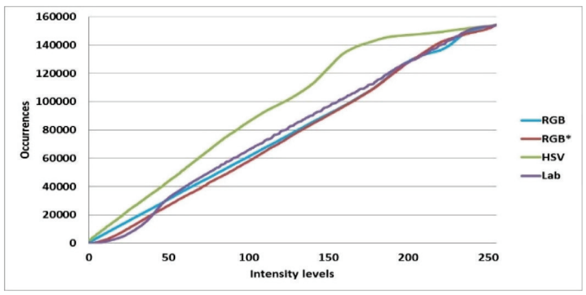

Fig. 8. Accumulative histogram of image 5

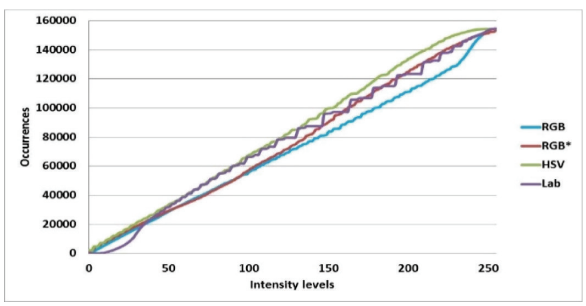

Fig. 9. Accumulative histogram of image 6

In Fig. 5 the straightest AHs are obtained with the images processed with our proposal and RGB*; it is easy to appreciate that in the other histograms there are several parts with curves. It is notorious that all the AHs shown in Fig. 6 have peaks and/or curves; however, the straightest AH is obtained with our proposal. In Fig. 7 is easy to observe that the shape of all the AH is straight, but in the lowest and highest intensity levels there are peaks and curves; nevertheless, the AH obtained with our proposal have less pronounced curves.

According to the AH shown in Fig. 8, the image processed in the HSV space has the lowest contrast because the shape of the AH is a pronounced curve. The other histograms are straighter, but the AH obtained with our proposal is the straightest. In Fig. 9 the AH obtained with our proposal is perhaps the straightest, although it has several small peaks, the AH of the L*a*b* image has the most enhanced peaks; the AH of the HSV image has a pronounced curve in the highest intensity levels, the AH of the RGB* image is perhaps the straightest histogram but it slope is higher than 45°.

4.3 Alternative Metric to Compute the Vectors' Magnitude

As we claim previously, mapping the colors between the RGB space and the HSV and L*a*b* spaces may become a huge computational load. With our proposal the mathematical operations do not represent a high computational load; due to in our proposal the Euclidean distance is employed to compute the magnitude of the color vectors, the square root operation is perhaps the mathematical operation that may demand the highest computational resources.

In order to reduce the computing resources the Euclidean distance demands, it is common to find that the magnitude of vectors is approximated by computing the average of the vector's components [1, 6]; that is, let $\phi = [r, g, b]$ be a RGB color vector:

$$\|\phi\|^{*} = \frac{r+g+b}{3} \quad (5)$$

Figure 10 shows the images obtained by processing the input images of Fig. 3 and using Eq. (5) as metric; note that the range of intensity levels is $[0, 255]$. The images shown in Fig. 10 do not suffer significant changes with respect to the images obtained

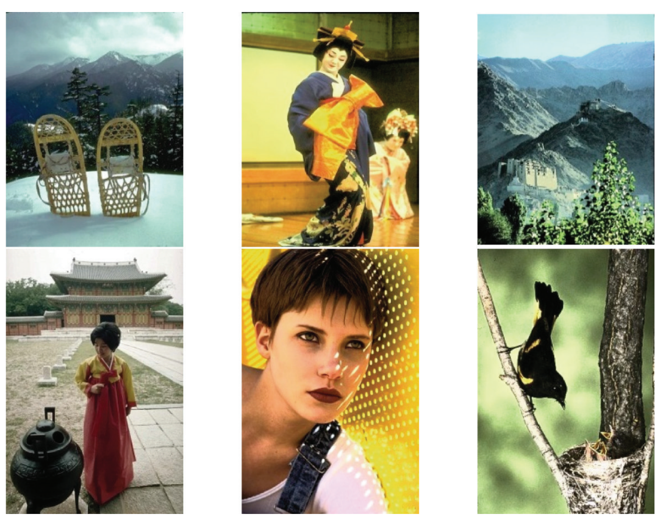

Fig. 10. Image obtained by processing the input images of Fig. 3 using as metric the Eq. (5)

with our proposal, using the Euclidean distance as metric, both in chromaticity and intensity of the colors. It is easy to appreciate that the contrast of the images does not vary significantly.

5 Conclusions and Future Work

We have introduced a proposal for contrast enhancement of RGB color images, without mapping the colors to a different color space that decouples the intensity from the chromaticity. In our proposal the magnitudes of the vectors are extracted and an intensity channel is computed, the histogram equalization is applied to this intensity channel the new intensity values are multiplied with their respective color vectors, previously normalized. The resulting images with our approach are compared with images processed in the HSV and L*a*b* spaces, where the histogram equalization is performed in their respective intensity channels. The images obtained are very similar between them, particularly the images obtained with our approach and the images processed under the L*a*b* space.

The computational load is low because it is not necessary to map the colors to a different space; the computational load may be reduced if Eq. (5) is employed as metric to compute the magnitude of vectors. The resulting images are almost the same to the images obtained using the Euclidean metric. The images obtained with our approach are evidence that the contrast of RGB color images can be enhanced.

As future work, more experiments are needed using the images of the Berkeley segmentation database; also, compare the resulting images with the images obtained with different techniques proposed in related works. Look in the state of the art for a metric, if exists, to evaluate quantitatively the contrast of the images.

References

1. Gonzalez, R.C., Woods, R.E.: Digital Image Processing, 2nd edn. Prentice Hall, Upper Saddle River (2002)
2. Jahanirad, M., Wahab, A.W.A., Anuar, N.B.: An evolution of image source camera attribution approaches. Forensic Sci. Int. **262**, 242–275 (2016)
3. Nnolim, U.A.: An adaptive RGB colour enhancement formulation for logarithmic image processing-based algorithms. Opt. Int. J. Light Electron Opt. **154**, 192–215 (2018)
4. Jun, H., Inoue, K., Hara, K., Urahama, K.: Saturation improvement in hue-preserving color image enhancement without gamut problem. ICT Express (2017). https://doi.org/10.1016/j.icte.2017.07.003
5. Qian, X., Han, L., Wang, Y., Wang, B.: Color contrast enhancement for color night vision based on color mapping. Infrared Phys. Technol. **57**, 36–41 (2013)
6. Zhang, H., Friits, J.E., Goldman, S.A.: Image segmentation evaluation: a survey of unsupervised methods. Comput. Vis. Image Underst. **110**(2), 260–280 (2008)
7. Agarwal, M., Mahajan, R.: Medical image contrast enhancement using range limited weighted histogram equalization. Procedia Comput. Sci. **125**, 149–156 (2018)
8. Rajinikanth, V., Couceiro, M.S.: RGB histogram based color image segmentation using firefly algorithm. Procedia Comput. Sci. **46**, 1449–1457 (2015)

9. Pare, S., Kumar, A., Bajaj, V., Singh, G.K.: A multilevel color image segmentation technique based on cuckoo search algorithm and energy curve. Appl. Soft Comput. **47**, 76–102 (2016)
10. Zhou, Z., Sang, N., Hu, X.: Global brightness and local contrast adaptive enhancement for low illumination color image. Opt. Int. J. Light Electron Opt. **125**(6), 1795–1799 (2014)
11. Xiao, B., Tang, H., Jiang, Y., Li, W., Wang, G.: Brightness and contrast controllable image enhancement based on histogram specification. Neurocomputing **275**, 2798–2809 (2018)
12. Tang, J.R., Isa, N.A.M.: Bi-histogram equalization using modified histogram bins. Appl. Soft Comput. **55**, 31–43 (2017)
13. Ong, S., Yeo, N., Lee, K., Venkatesh, Y., Cao, D.: Segmentation of color images using a two-stage self-organizing network. Image Vis. Comput. **20**(4), 279–289 (2002)
14. Paschos, G.: Perceptually uniform color spaces for color texture analysis: an empirical evaluation. IEEE Trans. Image Process. **10**(6), 932–937 (2001)
15. Rong, Z., Li, Z., Dong-nan, L.: Study of color heritage image enhancement algorithms based on histogram equalization. Opt. Int. J. Light Electron Opt. **126**(24), 5665–5667 (2015)
16. Li, X., Fang, M., Zhang, J.J., Wu, J.: Learning coupled classifiers with RGB images for RGB-D object recognition. Pattern Recognit. **61**, 433–446 (2017)
17. Grupt, B., Agarwal T.K.: New contrast enhancement approach for dark images with non-uniform illumination. Comput. Electr. Eng. (2017). https://doi.org/10.1016/j.compeleceng.2017.09.007
18. Ghani, A.S.A., Isa, N.A.M.: Automatic system for improving under water image contrast and color through recursive adaptive histogram modification. Comput. Electron. Agric. **141**, 181–195 (2017)
19. Gu, Z., Ju, M., Zhang, D.: A novel retinex image enhancement approach via brightness channel prior and change of detail prior. Pattern Recognit. Image Anal. **27**(2), 234–242 (2017)