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CONTRAST ENHANCEMENT OF COLOR IMAGES BASED ON WAVELET TRANSFORM AND HUMAN VISUAL SYSTEM

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ABSTRACT

This paper proposes a new method for enhancing the contrast of color images based on Wavelet Transform and human visual system. The RGB (red, green, and blue) values of each pixel in a color image are converted to HSV (hue, saturation and value) values. To the V (luminance value) components of the color image, Wavelet Transform is applied so that the V components are decomposed into the approximate components and detail components. The obtained coefficients of the approximate components are converted by a grey-level contrast enhancement technique based on human visual system. Then, inverse Wavelet transform is performed for the converted coefficients so that the enhanced V values are obtained. The S components are enhanced by histogram equalization. The H components are not changed, because changes in the H components could degrade the color balance between the HSV components. The enhanced S and V together with H are converted back to RGB values. The effectiveness of the proposed method is demonstrated experimentally.

KEY WORDS

Image processing, color enhancement, human visual system, HSV color space, wavelet transform

1. Introduction

Image enhancement is a technology to improve the quality of an image in terms of visual perception of human beings. With the growing quality in image acquisition, image enhancement technologies are more and more needed for many applications.

Images are categorized into grey-level images and color images. Each pixel of the grey-level image has only one grey-level value as opposed to color images' pixels; therefore, there have been many algorithms for contrast enhancement for grey-level images. The main techniques for image enhancement such as contrast stretching, slicing, histogram equalization, for grey-level images are discussed in many articles and books. On the other hand, since each pixel of color images consists of color information as well as grey-level information, these typical techniques for grey-level images cannot be applied to color images. Thus, compared with grey-level images, the enhancement of color images is more difficult, and there are much more points to be researched.

Some color enhancement methods were proposed. Based on histogram equalization, as the well-known contrast enhancement methods, Buzuloiu et al.[1] proposed an adaptive neighbourhood histogram equalization method, and Trahanias et al.[2] proposed a 3D histogram equalization method in RGB cube. Thomas et al. [3] proposed an enhancement method by considering the correlation between the luminance and saturation components of the image locally. A method for enhancing the color contrast in xy-chromaticity diagram was proposed by Lucchese et al. [5]. Shyu et al. [6] suggested a genetic algorithm approach in which the enhancement problem is formulated as an optimization problem. In recent years, multi-scale technologies have been widely used in image processing. For example, Toet [7] proposed a schema by representing the original luminance and saturation components of a color image at multiple spatial scales. Lu [8] proposed a contrast enhancement method based on multi-scale gradient transformation. Brown [9] proposed an adaptive strategy for wavelet based image enhancement. The multi-scale methods mainly enhance the edge information of the image.

The related research mentioned above is useful for color image enhancement. However, color shifting problem is hardly considered. A color enhancement method should not convert, for example, a red color to a yellow color. Even if in some special cases such a conversion is needed, the color shifting should also be controlled. It is the hue component that indicates the color. Therefore, it is critical to consider hue in color enhancement method.

The color shift problem has been considered in some research. For instance, Gupta et al. [4] suggested a hue preserving contrast stretching scheme for a class of color images. Naik et al.[11] proposed a hue preserve color image enhancement method without gamut problem. Their methods keep hue preserved and avoid color shifting problem. However, there is also another essential problem. They hardly consider the features of human visual system. In all kinds of practical applications, most images are viewed by humans. Thereby, it is necessary to consider the human visual system in color image enhancement.

To solve the two problems mentioned above, color shifting and human visual system, we propose a hue-preserve algorithm, with the human visual system considered, to enhance color images. The wavelet transform is applied to decompose the luminance information to approximate components and detail components. Then, a contrast enhancement technique for grey-level images based on the human visual system is applied to enhance approximate component. For the S components, a histogram equalization is applied for contrast enhancement. Then, inverse Wavelet transform is applied so that contrast enhanced color image is obtained.

This paper is organized as follows. In Section 2, the basic idea of our method is described. Section 3 elaborates on our proposed method. Experimental results are shown in Section 4. Section 5 concludes this paper.

2. Basic Idea

2.1 Color Space

If the visible portion of the light spectrum is divided into three components, the predominant colors are red, green and blue. These three colors are considered the primary colors of the visible light spectrum. The RGB color space, in which color is specified by the amount of Red, Green and Blue present in the color, is known as the most popular color space.

RGB is an additive and subtractive model, respectively, defining color in terms of the combination of primaries, whereas HSV color space encapsulates information about a color in terms that are more familiar to humans. In HSV color space, the color is decomposed into hue, saturation and luminance value similar to the way humans tend to perceive color. Ledley's research shows that the performance of HSV color space is good in color improving [10].

Among the three components of HSV color space, hue is the attribute of a color, which decides which color it is. For the purpose of enhancing a color image, it is to be seen that hue should not change for any pixel. If hue is changed then the color gets changed, thereby distorting the image [11]. Compared with other perceptually uniform such as CIE LUV color space and CIE Lab color space, it is easier to control the Hue component of color and avoid color shifting in the HSV color space.

In our method, we keep hue preserved and apply the enhancement only to luminance and saturation. In Yang's research, they have paid attention to the effect of luminance and saturation to color image enhancement [12]. Therefore, we chose HSV color space for our enhancement method.

2.2 Luminance Enhancement

We apply wavelet transform and Reverse-S-Shape transform obtained from human visual system to enhance the luminance component.

The wavelet transform, or wavelet expansion is to express a signal or function as a linear decomposition based on a group of certain functions. Wavelet analysis, a new mathematics branch developed in recent years, is a perfect combination of harmonic analysis, function analysis, Fourier analysis and numerical analysis. Wavelet analysis has been applied to various research areas. For example, Xu et al [13] developed a noise filtration method based on the spatial correlation between wavelet coefficients over adjacent scales. Pan et al [14] proposed an improved schema.

In our approach, we exploit the characteristic that wavelet transform can decompose the signals into approximate components and detail components, and the approximate component is enhanced by increasing the contrast.

According to the human visual theory, receptive fields on the retina receive light stimuli. Rod cells and cone cells process them. Receptive fields are very common in the retina of many species, and the same arrangement is found in second and higher order neurons. Kobayashi et al. [15] analyzed the feature of human visual system and proposed a Reverse-S-Shape transform to enhance the grey-level image. To obtain the result, we generalize the method to color image processing and applied the transform to the luminance component of the color image.

3. Algorithm

3.1 Color Space Conversion

As mentioned before, we apply our enhancement method in HSV color space. In general, color images are represented by RGB color space. Therefore the first step is to convert RGB color space to HSV color space.

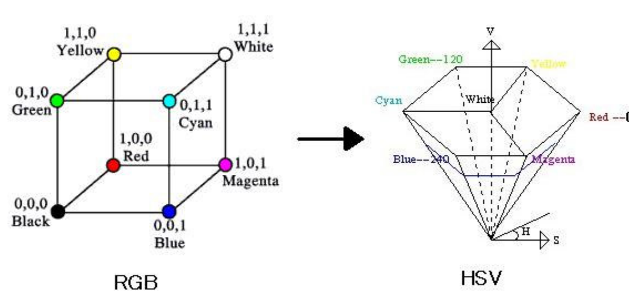


Fig.1 RGB Color Space and HSV Color Space

The conversion algorithm is shown in Eq. (1). MAX is the maximal value in R, G, B of all the pixels in the image, and MIN is the minimal one.

$$H = \begin{cases} \text{undefined}, & \text{if } MAX = MIN \\ 60 \times \frac{G-B}{MAX-MIN} + 0, & \text{if } MAX = R \\ & \text{and } G \geq B \\ 60 \times \frac{G-B}{MAX-MIN} + 360, & \text{if } MAX = R \\ & \text{and } G < B \\ 60 \times \frac{B-R}{MAX-MIN} + 120, & \text{if } MAX = G \\ 60 \times \frac{R-G}{MAX-MIN} + 240, & \text{if } MAX = B \end{cases}$$

$$S = \begin{cases} 0, & \text{if } MAX = 0 \\ 1 - \frac{MIN}{MAX}, & \text{otherwise} \end{cases}$$

$$V = MAX$$

(1)

After performing the enhancement in HSV color space, we need to convert back to RGB color space to save and/or display the processing result. The inverse conversion algorithm is shown in Figure 2.

$$Hi = [\frac{H}{60}] \bmod 6$$

$$F = \frac{H}{60} - Hi$$

$$P = V(1 - S)$$

$$Q = V(1 - FS)$$

$$T = V(1 - (1 - F)S)$$

Hi	R	G	B
0	V	T	P
1	Q	V	P
2	P	V	T
3	P	Q	V
4	T	P	V
5	V	P	Q

Fig.2 HSV to RGB

3.2 Luminance Contrast Enhancement

The luminance value, V component in the HSV color space, is enhanced. The wavelet transform can decompose the luminance into approximate component and detail component. We apply a contrast enhancement method for grey-level images to the approximate component and then reconstruct the brightness information by applying inverse Wavelet transform. Thus, the above mentioned process consists of three steps: Wavelet Transform, contrast enhancement and Inverse Wavelet Transform.

According to orthonormal wavelet transform, the luminance values are decomposed by Eq. (2):

$$F(x, y) = \sum_{j=0}^{n-1} A_j \phi_{j\,n}(x, y) + \sum_{j=0}^{n-1} \sum_{k=0}^{n} D_{j\,k} \psi_{j\,k}(x, y) \quad \textbf{(2)}$$

where ϕ is the scale function and ψ is the wavelet function. The former component of the decomposition is the approximate component and the latter one is the detail component. Aj are approximate coefficients and Djk are detail coefficients. As the transform is an orthonormal transform, each Aj is in the range [0,255] (same as the range of luminance value).

In our method, we assign two thresholds m and M (0<m<M<255) and divide the range of Aj into three parts:[0, m], [m, M], (M, 255). If Aj < m or Aj > M, we do not convert and simply set A'j = Aj. Otherwise, we use the transform model represented by Eq. (3):

$$R(I) = \log \frac{I - K_1}{K_2 - I} \quad \textbf{(3)}$$

In Eq. (3), I indicates the input and R indicates the output result. Parameter K1 should be less than the minimum of input I, and parameter K2 should be larger than the maximum of input I. As input $I \in [m, M]$, we can simply assure the validity of the equation by setting K1 < m < M < K2.

The following steps show the contrast enhancement algorithm of the approximate component:

1. Compute R for each approximate coefficient A in range [m, M] by Eq. (3).
2. Normalize R by Eq. (4):

$$R' = \frac{R - Rmin}{Rmax - Rmin} \quad \textbf{(4)}$$

The Rmax and Rmin are the maximal and the minimal values of all the R obtained by Eq. (3) in step 1.

3. Convert them to the appropriate range and get the new approximate coefficients A'. As the range of A' is [m, M] and the range of R' is [0, 1], it is convenient to get A' by Eq. (5).

$$A' = R' * (M - m) + m \quad \textbf{(5)}$$

The image is reconstructed by using the inverse wavelet transform as indicted by Eq. (6):

$$F'(x, y) = \sum_{j=0}^{n-1} A'_j \phi_{j\,n}(x, y) + \sum_{j=0}^{n-1} \sum_{k=0}^{n} D_{j\,k} \psi_{j\,k}(x, y) \quad \textbf{(6)}$$

The mapping diagram is shown in Figure 3.

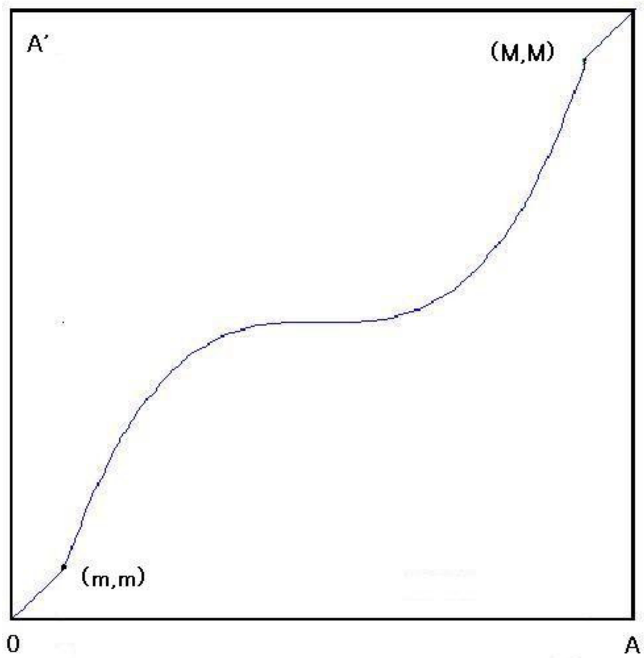


Fig.3 Coefficient Conversion Mapping Diagram

To assign the threshold m and M, we tried two ways. One is "Manual Assignment", the other is "Automatic Adaptation".

The manual assignment is to simply assign the parameters as certain constants. The manual assignment is simple but there is a problem. From the wavelet decomposition equation, we get a set of approximate coefficients. If most of the coefficients are near the maximal value, we need to set a larger threshold otherwise most coefficients are not changed which leads to an ineffective enhancement. The situation is similar when most of the coefficients are near the minimal value. To solve the problem, we use Automatic Adaptation.

Automatic Adaptation is to compute the parameters according to the information of the input image. So we compute the threshold m and M to assure:

1. Most of the coefficients are between m and M. The coefficients out of the range [m, M] are not converted.
2. The range [m, M] should not be too small. Otherwise, even if most coefficients are in the range and converted, the effect of the contrast enhancement is not significant, because the results are also in [m, M].

The computing algorithm includes the following three steps:

1. Assign two constants m0 and M0, which satisfy $0 <= m0 < M0 <= 255$, and $M0 - m0 > 150$. For instance, $m0 = 30$, $M0 = 200$.
2. Compute m1 and M1, satisfy that there are just 5% of approximate coefficients (Aj) are less than m1 and 5% of Aj larger than M1.
3. Set m = min (m0, m1), M = max (M0, M1).

The algorithm assures that at least 90% coefficients are converted and the conversion range is large enough.

It may be considered that it is simpler to manually assign m = 0 and M = 255 to meet with the two requirements. However, if most coefficients are near 128, and few are near maximal or minimal value, the contrast efficiency is low. In this situation, Automatic Adaptation algorithm shows its advantage.

3.3 Saturation Enhancement

The purpose of saturation adjustment is to make the color image soft and vivid. An analysis by Strickland et al. [16] has shown that the saturation component often contains more high frequency spectral energy, i.e. image detail, than its luminance counterpart. In our research, we use histogram equalization.

3.4 Processing Flow

Our method is represented by the following steps:

1. Load a color image
2. Read (r, g, b) values for each pixel
3. Convert RGB color space to HSV color space
4. Apply the wavelet transform to V component
5. Apply the Reverse-S-Shape transform to the approximate coefficient of Eq. (1)
6. Reconstruct V by inverse wavelet transform
7. Apply the saturation enhancement
8. Convert HSV color space to RGB color space
9. Store the color image

4. Experimental Result

To test the performance of our method, we apply our method to a low contrast color image and a dark color image and compare the results with histogram equalization in RGB color space.

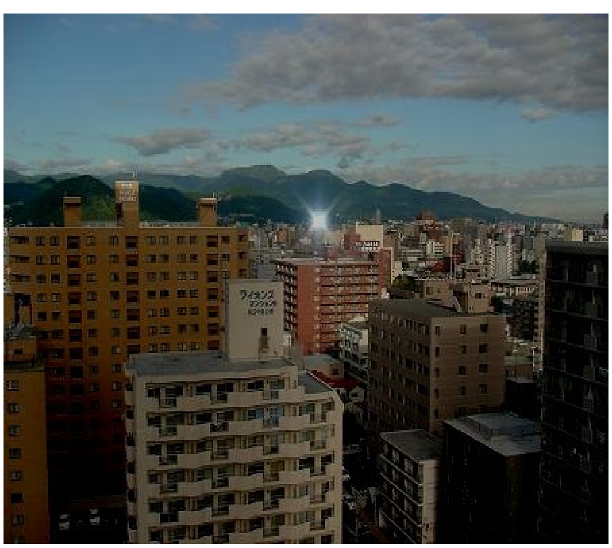
Figure 4 shows the experimental result of the low contrast image. (a) is the original image, (b) is the result obtained by the histogram equalization in RGB color space and (c) is the result obtained by our proposed method. Figure 5 is the experimental result of the dark image, where (a), (b), and (c) indicate the original image, the result of histogram equalization in RGB and the result of our proposed method, respectively.

(a) Original Image

(b) Histogram Equalization on RGB Color Space

(c) Proposed Method

Fig.4 Experiment of Low Contrast Image



(a) Original Image

(b) Histogram Equalization on RGB Color Space

(c) Proposed Method

Fig.5 Experiment of Dark Image

To evaluate the contrast enhancement performance of our method, we count the following two evaluation parameters mentioned in [17]:

$$C = \frac{\sigma out - \sigma in}{\sigma in} \quad \textbf{(7)}$$

$$L = \frac{\bar{I}out - \bar{I}in}{\bar{I}in} \quad \textbf{(8)}$$

where σout, $\bar{I}out$ are the variance and average of the luminance value of the output image and σin, $\bar{I}in$ are those of the input image.

From (b) in Figure 4, C = 0.073 and L = 0.022, which means the contrast increased by 7.3% and the luminance increased by 2.2%, are obtained. Similarly, the values for C and L for (c) in Figure 4, (b) in Figure 5, and (c) in Figure 5 are C = 0.083 and L = 0.022, C = 0.083 and L = 0.026, and C = 0.081 and L = 0.032, respectively.

The experimental result shows that our color contrast method can successfully enhance the color image. According to Figure 4 (c) and Figure 5 (c), the results of our method neither lose useful information nor cause gamut problem shown in Figure 4 (b) and Figure 5 (b).

5. Conclusion

This paper has proposed a color contrast enhancement method that uses a luminance component enhancement based on wavelet transform: more specifically, Reverse-S-Shape enhancement based on human visual system for the approximate component coefficients obtained by the Wavelet transform. The Saturation components are enhanced by histogram equalization.

It turns out that the proposed wavelet based color contrast enhancement method can achieve a successful enhancement of color images which are dark or with low contrast. However, there are still some remaining issues. The transformation algorithm for the approximate coefficients is to be improved and the enhancement of detail coefficients may also be effective. The relationship between luminance value and saturation is not considered in the method. The method is a global transformation of a certain image but the performance might be better if we divide the image into some certain areas according to some certain rules and apply a different algorithm or different parameters to different areas. Another topic is that sometimes the color contrast enhancement requires changing color; that is, the hue component should also be adjusted. These issues are our next research topics.

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