2006－CVIM－155 (6)
2006／9／8

ウェーブレット分析に基づくカラー画像強調研究

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あらまし 画像強調、特にカラー画像強調は画像処理研究の一つの重要な分野である。ウェーブレット分析は信号処理と画像処理に広範に応用されている。ウェーブレット変換、ウェーブレット逆変換と強調処理を使用し、私たちは HSV カラー空間でのカラー画像強調方法を提案する。即ち、カラー画像の輝度成分に対してウェー ブレット変換を施し、得られる近似成分の係数に対して、輝度成分用のコントラスト強調を施すことにより得られる修正係数を用いて逆ウェーブレット変換を行う。色彩成分に対して Saturation に対してヒストグラム平坦化を施す。カラー画像に本提案手法の施す実験を行い、提案手法の有効性の見通しを得た。

キーワード 画像処理、ウェーブレット分析、画像強調、カラー画像強調

Study of Color Image Enhancement Based on Wavelet Analysis

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Abstract Image enhancement, especially color image enhancement is a critical area in image processing research. The wavelet analysis is widely used in signal processing and image processing. By using wavelet transform, wavelet inverse transform and an enhancement processing between the two transforms, we propose a color image enhancement method in HSV color space. More specifically, Wavelet transform is applied to the luminance component. The coefficients for the approximation components are enhanced by a gray-level image contrast enhancement technique, and then using the enhanced coefficients, the inverse Wavelet transform is performed. To the saturation component, the histogram equalization is applied. Promising results are obtained by applying the proposed method to some color images. The experimental result showed that the enhancement method can improve the performance of color images.

Keyword Image Processing, Wavelet Analysis, Image Enhancement, Color Image Enhancement

1. Introduction

1.1. Image Enhancement

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

In the recent years, the multi-scale technologies based on wavelet are widely used in image processing. For example, Lu proposed a contrast method based on multi-scale gradient transformation [1]. Brown proposed an adaptive strategy for wavelet based image enhancement [2]. Their methods mainly enhance the edge information of the image. Compared with gray-level images, color images include color information besides gray-level information. Color contrast enhancement should improve the color information to make the image more vivid and legible without unexpected problems such as color balance. It is important to choose an appropriate color space for color contrast enhancement.

1.2. 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 which is 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 [3].

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, hue should not be changed for any pixel [4]. 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 improving only to luminance and saturation. In Yang's research, they have paid attention to the effect of luminance and saturation to color image enhancement [5]. Therefore, we chose HSV color space for our enhancement method and apply a wavelet-based algorithm on luminance component to enhance the color images. The experiment showed that our method successfully enhanced the color images.

1.3. Wavelet Analysis

A wavelet is a wave which has its energy concentrated in time to give a tool for the analysis of transient, nonstationary or time-varying phenomena. It still has the oscillating wave-like characteristic but also has the ability to allow simultaneous time and frequency analysis with a flexible mathematical function.

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, Donoho et al [6] proposed a denoising method based on wavelet coefficients. Xu et al[7] developed a noise filtration method based on the spatial correlation between wavelet coefficients over adjacent scales . An improved version is proposed by Pan et al[8].

In our research, we take advantage of the characteristic that wavelet transform can decompose the signals into approximate component and detail component and enhance the approximate component to improve the color image by increasing the contrast radius.

2. Algorithm

2.1. Color Space Conversion

As mentioned before, we apply our enhancement method in HSV color space. However, the input color image is presented in RGB color space. Therefore the first step is to convert RGB color space to HSV color space.

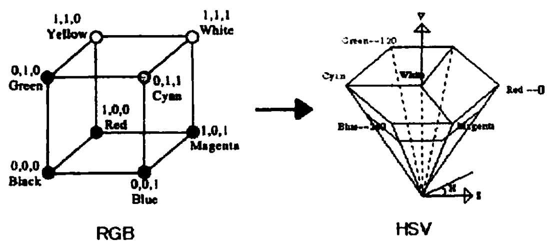


Fig.1 RGB Color Space and HSV Color Space

The conversion algorithm is shown in Fig.2. MAX is the maximal value in R, G, B of all the pixels in the image, and MIN is the minimal one.

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

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

$$V = MAX$$

Fig.2 RGB to HSV

After the enhancement processing in HSV color space, we need to convert back to RGB color space to save the processing result. The inverse conversion algorithm is shown in Fig.3.

$$Hi = \lfloor \frac{H}{60} \rfloor \bmod 6$$

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

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

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

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

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.3 HSV to RGB

2.2. Luminance Contrast Enhancement

The luminance processing is to enhance V component, the brightness value in HSV color space. The wavelet transform can decompose the luminance into approximate component and detail component. We apply the transform method to the approximate component and then reconstruct the brightness information. Thus, the processing consists of three steps: Wavelet Transform, contrast enhancement and Inverse Wavelet Transform.

According to orthonormal wavelet transform, the luminance values are decomposed by Eq. (1):

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

Here 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, each Aj is in the range [0,255] (the same as the range of luminance value).

According to the human vision theory, light stimuli are received by receptive fields on the retina. 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 [9]. 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 described by Eq. (2):

$$R(I) = \log \frac{I - K_1}{K_2 - I} \qquad (2)$$

In Eq. (2), I indicates the input and R indicates the output result. Parameters K1 and K2 are parameters. K1 must be less than the minimum of input I and K2 must be larger than the maxium 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 improving algorithm of the approximate component:

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

$$R' = \frac{R - Rmin}{Rmax - Rmin} \qquad (3)$$

The Rmax and Rmin are the maxium and the minium value of all the R got by Eq. (2) in step 1.

3. Convert them to the appropriate range and get the new approximate coefficients A'. In our method, the output range is [m, M], the same as the input range. As the range of R' is [0, 1], it is convenient to get A' by Eq. (4).

$$A' = R' * (M - m) + m \qquad (4)$$

The reconstruction is done by using the inverse wavelet transform as indicted by Eq. (5):

$$F'(x,y) = \sum_{j=0}^{n-1} A'_j \, \phi_{jn}(x,y) + \sum_{j=0}^{n-1} \sum_{k=0}^{n} D_{jk} \, \psi_{jk}(x,y) \qquad (5)$$

The mapping diagram is shown in Fig.4.

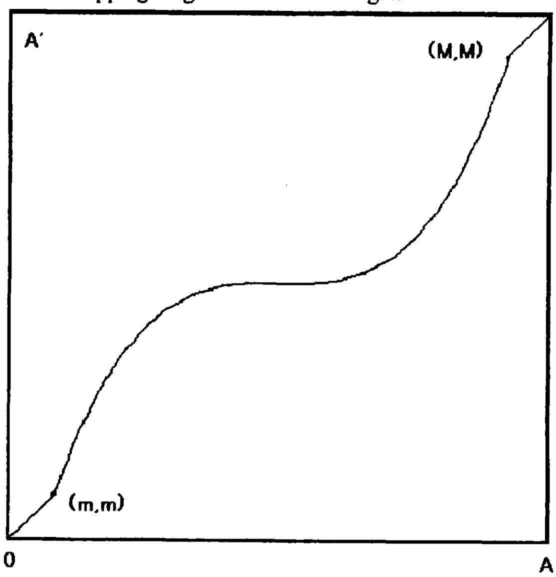


Fig.4 Coefficient Conversion Mapping

2.3. Saturation Enhancement

The purpose of saturation adjustment is to make the color image soft and vivid. An analysis by Strickland et al. [10] 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 mainly tried two methods: histogram equalization and inverse-S transformation.

The inverse-S transform includes two steps:

1. Count a temp value T for S component of each pixel by Eq.(6):

$$T(S) = \log \frac{S - K_3}{K_4 - S} \quad (6)$$

2. Orthonormalize R by Eq. (7):

$$S' = \frac{T - Tmin}{Tmax - Tmin} \quad (7)$$

As the output range S' is just [0, 1], there is no need for any additional step.

2.4. Processing Flow

According to our method, we can compute the color contrast images by means of 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 wavelet transform to V component
5. Apply the contrast enhancement method 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

3. Automatic Parameter Determination

The value of parameter K1, K2, m and M in contrast enhancement straightly affects the performance of the processing result. Thus, it is critical to assign them as available value.

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

The manual assignment is to simply assign the parameters as certain constants. The straight 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. This point is the problem in Manual Assignment. The coefficients out of the range [m, M] are not converted.

2. The range [m, M] should not be too small. If the range is too small, even if most coefficients are in the range and converted, they do not change clearly because the results are also in [m, M].

The computing algorithm includes the following three steps:

1. Assign two constant m0, M0, which satisfy $0 <= m0 < M0 <= 255$, and $M0 - m0 > 150$. For instance, m0= 30, M0 = 200.
2. Compute m1 and M1 which 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 median value and few are near maximal or minimal value, the contrast efficiency is low. In this situation, Automatic Adaptation algorithm shows its advantage.

4. Experiment and Evaluation

To test the performance of our method, we apply our method to a low contrast radium color image and a dark color image.

To evaluate the contrast enhancement performance of our method, we count the following two evaluation parameters mentioned in [11]:

$$C = \frac{\sigma out - \sigma in}{\sigma in} \quad (8)$$

$$L = \frac{\bar{I}out - \bar{I}in}{\bar{I}in} \quad (9)$$

Here σout, Īout are the variance and average of the luminance value of the output image and σin, Īin are those of the input image.

Fig.5 shows the experimental result of the low contrast radium image. (a) is the original image, (b) is the result obtained by the proposed method with saturation histogram equalization and (c) is the proposed method with saturation inverse-S transform.

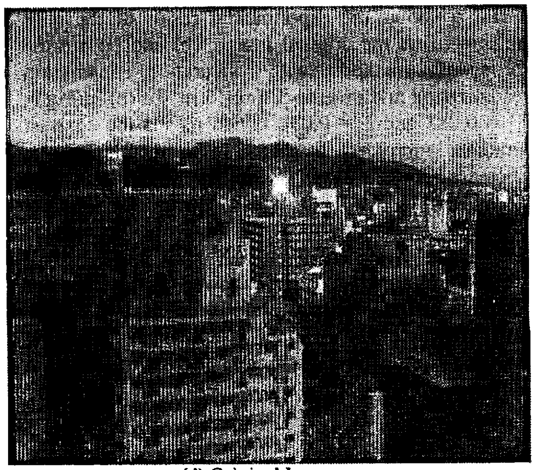
To (b) in Fig.5, C = 0.073 and L = 0.022 which means the contrast gradient increased by 7.3% and the luminance increased by 2.2% are given. To (c) in Fig.5, C = 0.083 and L = 0.022 which means the contrast gradient increased by 8.3% and the luminance increased by 2.2% are given.

(a) Original Image

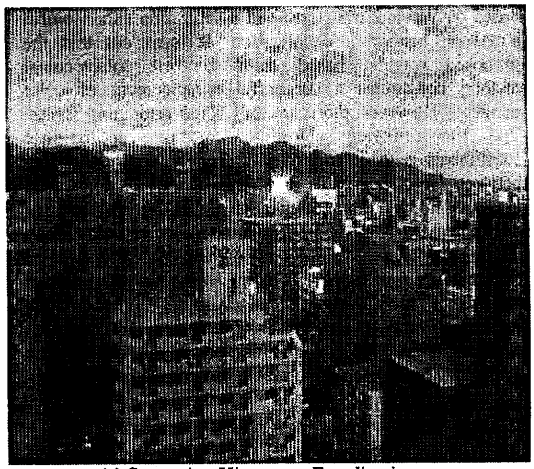
(b) Saturation Histogram Equalization

(c) Saturation Inverse-S Transform

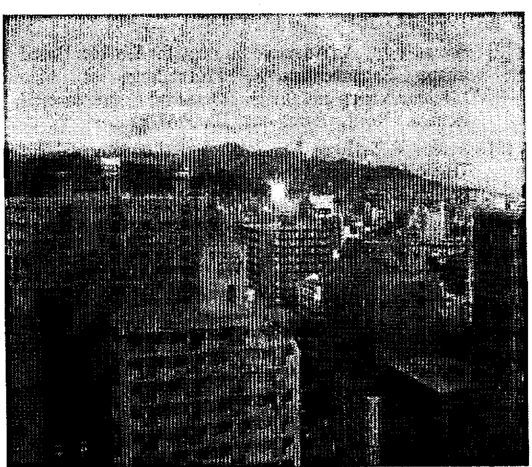
Fig.5 Experiment of Low Contrast Image



(d) Original Image



(e) Saturation Histogram Equalization



(f) Saturation Inverse-S Transform

Fig.6 Experiment of Dark Image

Fig.6 shows the experimental result of the dark image. (d) is the original image, (e) and (f) are the proposed method with saturation histogram equalization and inverse-S transform. To (e) in Fig.6, C = 0.083 and L = 0.032 which means the contrast gradient increased by 8.3% and the luminance increased by 3.2% are given. To (f) in Fig.6, C = 0.081 and L = 0.032 which means the contrast gradient increased by 8.1% and the luminance increased by 3.2% are given.

The experimental result showed that our color contrast method can successfully enhance the color image. However, we cannot assert which makes the better performance, saturation histogram equalization or inverse-S transform.

5. Conclusion

This paper has proposed a color contrast enhancement method that uses a luminance component enhancement based on Wavelet transform and a saturation enhancement based on histogram equalization. It turns out that the proposed wavelet based color contrast enhancement method constitutes a successful enhancement of color images. However, there are still some remaining issues. The transformation algorithm for the approximate coefficients is to be improved. Secondly, the relationship between luminance value and saturation is not considered in the method. And 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 different algorithm or different parameters to different areas. Another topic is that sometimes the color contrast enhancement requires changing color and the hue component should also be adjusted. These issues are our next research topics.

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