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Study on Wavelet Transform Adjustment Method with Enhancement of Color Image

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Abstract. *Low contrast and poor quality images are the major problems in the image processing field. In order to make the color of image more distinct and sensory, this article uses the special structure of image data after wavelet transformation to organically combine wavelet analysis and traditional enhancement methods and put forward the new method of color image enhancement based on wavelet transformation. Through wavelet decomposition of the luminance component, it deals with the high frequency coefficients with the nonlinear unsharp masking method of different enhancement coefficients, and deals with the low frequency coefficients with the method of nonlinear function reflecting wavelet coefficients or the method of image saturation component model. Experiments show that the improved wavelet transformation algorithm is effective for color image enhancement, and it has good visual effect.*
Keywords: Color image enhancement, Special structure, Wavelet decomposition, Color saturation enhancement

1. **Introduction.** A visual image is rich in information and many real world images are acquired with low contrast and poor quality, sometimes unsuitable for human eyes to read such remote sensing imagery. At present, there are many ways to improve the image resolution. Wavelet analysis technique is a newly developed technology to enhance image based on remote sensing image[1-3]. Among them, the complex wavelet transformation has improved the resolution of satellite image; it proves that technology is feasible to enhance the resolution of satellite image with high frequency sub image interpolation based on dual tree complex wavelet transformation (DT-CWT)[4-6]. Saadiquebasha[7] presented a novel approach which addressed contrast enhancement in color images. The wavelet transformed decomposes an image into bands that varied in spatial frequency and orientation. Malek [8] proposed a numerical strategy to define a multi-scale analysis for color and multi-component images based on the representation of data on a graph, which consisted in computing the graph of an image using the psychovisual information and analyzing it by using the spectral graph wavelet transform. Huang[9] presented a novel image enhancement method, named CLAHE-discrete wavelet transform, which combined the contrast limited adaptive histogram equalization (CLAHE) with discrete wavelet transform (DWT). Zhang[10] proposed homomorphism decomposition-wavelet enhancement algorithm based on the basic principle of Wavelet Transform and separated the

incidence component and reflection component of the image by homomorphism decomposition. As we all know, image enhancement is a classical problem in image processing and computer vision. However, such characteristics as relatively dark color image, low contrast, less prominent local details and noise not only affect the visual effect, but also make the aims in some images hard to recognize and distinguish. Therefore, before the image processing, we often need to enhance the color image.

Motivation:

Color images are a special kind of images and are very important for diagnosis and correct interpretation. But images can be blur or may be of low contrast and poor quality. In such cases it will be difficult for researchers to take the decisions. The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific observer. Enhanced remote sensing images are desired by researchers to assist in diagnosis and interpretation. The result is more suitable than the original image for certain specific applications.

Contribution:

This paper uses the characteristics of wavelet to put forward the algorithm to enhance the color image based on wavelet decomposition; color image is transformed from RGB space into HSV space, and then it decomposed the wavelet of the brightness component of color image; it uses human visual characteristics to enhance the images according to the different characteristics of high frequency and low frequency respectively. Finally enhanced image is obtained by subtractions the sharpened image from original image. So we get the enhanced image which is visually appealing and with high PSNR value and low RMSE.

The remainder of the paper is organized as follows. In section 2, we introduce the process of wavelet transformation of color images. In section 3, we give the processing of the high frequency coefficients of the brightness component of images. Section 4 introduces processing of the low frequency coefficients of the luminance component of image. In section 5, we conduct experiments and illustrate processing of saturation component of image. In section 6, a conclusion is given.

2. **The process of wavelet transformation of color images.** The wavelet theory[11,12] is a way to independently change the frequency window and spatial window, and to locate spatial frequency, and compared with the Fourier theory, it has a better spatial frequency window. Assuming that $\phi(x)$ is the scaling function of one-dimensional wavelet analysis, $\varphi(x)$ is the corresponding wavelet function, then the relation between two dimensional scaling function and orthogonal wavelet function, according to equation, can be defined as follows.

$$\begin{cases} \phi(x,y) = & \phi(x)\cdot\phi(y) \\ \varphi^1(x,y) = & \phi(x)\cdot\varphi(y) \\ \varphi^2(x,y) = & \varphi(x)\cdot\phi(y) \\ \varphi^3(x,y) = & \varphi(x)\cdot\varphi(y) \end{cases} \tag{1}$$

In this equation, where $\phi(x,y)$ is a two dimensional scaling function, and $\varphi^1(x,y)$, $\varphi^2(x,y)$, $\varphi^3(x,y)$ are three two-dimensional wavelet functions. The definition of multi-scale two-dimensional discrete wavelet is as follows: $f(x,y)$ is the signal of black and white images, $S_jf(n,m)$ is the low frequency component of $f(x,y)$. $W_j^1f(n,m)$, $W_j^2f(n,m)$ and $W_j^3f(n,m)$ are the high frequency components of Vertical, diagonal and horizontal of $f(x,y)$ respectively, and they can be calculated by equation (2):

$$\begin{cases} S_j f(n,m) = & \int\int_{R^2} 2^{2j}\phi_j(x-2^{-j},n,y-2^{-j}m)dxdy \\ W_j^1 f(n,m) = & \int\int_{R^2} 2^{2j}\varphi_j(x-2^{-j},n,y-2^{-j}m)dxdy \\ W_j^2 f(n,m) = & \int\int_{R^2} 2^{2j}\varphi_j(x-2^{-j},n,y-2^{-j}m)dxdy \\ W_j^3 f(n,m) = & \int\int_{R^2} 2^{2j}\varphi_j(x-2^{-j},n,y-2^{-j}m)dxdy \end{cases} \tag{2}$$

$$c_j(k>1) = \begin{cases} c_j^H \\ k \times c_j^L \end{cases} \tag{3}$$

The algorithm is to enhance color image based on wavelet decomposition. In the computation of two dimensional discrete wavelet transformations, set the low-frequency components of color image as vertical components, the high frequency components as diagonal and horizontal component. Among them, low frequency component represents the contour of black and white image, while the high frequency component represents its details. The low contrast of color image is mainly represented by three less frequency components. And it will make the details of images blurry, so we can make the details information clear by adding the three high frequency components. When the equation (3) is established, which means the high frequency components of image are larger, the image looks clearer. In this equation, c_j is wavelet coefficients of image. c_j^L is the high frequency wavelet coefficients of image, c_j^H is the low frequency wavelet coefficients of image. k is the high frequency components of image. j is the solution of horizontal wavelet components solution. However, this method may cause the increase of the high frequency components or decrease of the low frequency components, and parts of the images we get may be bright or blurry and the contrast may be low, so the image resolution needs to be further strengthened by color processing. The definition of wavelet function is as function (4).

$$\begin{cases} \varphi(t) = & \Sigma_n g(n)\varphi(2t-n) \\ \overline{\varphi(t)} = & \Sigma_n \overline{g(n)\varphi(2t-n)} \end{cases} \tag{4}$$

And the corresponding algorithm of decomposition and reconstruction of $g(n) = (-1)^{1-n}\bar{h}(1-n)$, $\overline{g(n)} = (-1)^{1-n}h(1-n)$ is:

$$\begin{cases} d_{j,k} = & \Sigma_{l\in z} c_{j+1,l}\, g(l-2n) \\ c_{j,k} = & \Sigma_{l\in z} c_{j+1,l}\, h(l-2n) \end{cases} \tag{5}$$

We can see that one of the dual filter groups $(h(n), g(n), \overline{h(n)}, \overline{g(n)})$ is used to decompose and the other is used to reconstruct in the double orthogonal decomposition of signals. According to fast decomposition algorithm of Mallat, we use biorthogonal wavelet filter banks to decompose the image, the function is:

$$F(x,y) = \sum_n C_{j-1}\varphi_{n,j-1}(x,y) + \sum_{j=0}^{L-1} D_n \varphi_{n,j}(x,y). \tag{6}$$

C_{j-1} is a low-frequency image, that is smoothness of the original image; different layers of decomposition D_{j-1}, D_j correspond to different solutions. The thesis puts an algorithm to enhance color image based on wavelet decomposition, and it transfers RGB image into HVS color space, then after the wavelet decomposition of the luminance component, it processes the frequency components and low frequency components respectively, meanwhile, stretch the index of the saturation components as figure1.

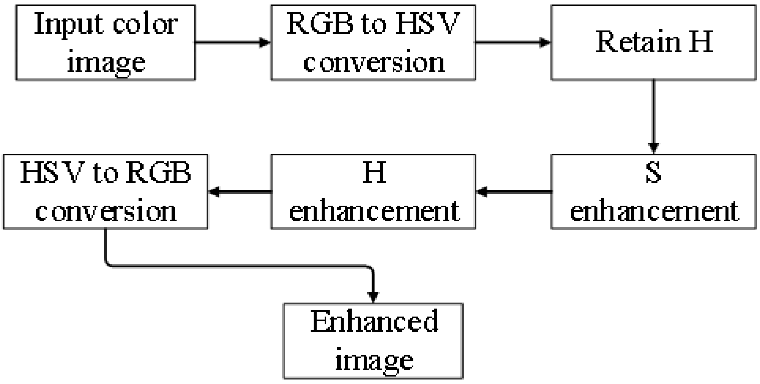

FIGURE 1. Flow chart of enhanced image.

2.1. **RGB to HSV Conversion.** Color vision can be processed using RGB color space or HSV color space. RGB color space describes colors in terms of the amount of red, green, and blue present. HSV color space describes colors in terms of the Hue, Saturation, and Value. In situations where color description plays an integral role, the HSV color model is often preferred over the RGB model. RGB defines color in terms of a combination of primary colors R, G and B but the HSV model describes colors similarly to how the human eye tends to perceive color. The followings are the color conversion equations:

$$H = cos^{-1}\frac{1/2[(R-g)+(R-b)]}{\sqrt{(R-g)^2+(R-b)(G-b)}}. \tag{7}$$

$$S = 1 - \frac{3}{R+G+B}[min(R,G,B)]. \tag{8}$$

$$V = \frac{1}{3(r+g+b)}. \tag{9}$$

3. **Improved wavelet transform adjustment method with enhancement of color Image.**

3.1. **The processing of the high frequency coefficients of the brightness component of images.** The thesis processes the high frequency details in a nonlinear unsharp masking, which makes the details more prominent and the visual effect better. Unsharp masking method is the realization of image edge enhancement algorithm, and the function is as equation (10):

$$\begin{cases} g(x,y) = & f(x,y) + K(f(x,y) - Q(x,y)) \\ Q(x,y) = & \frac{1}{M \times N} \sum\limits_{i=x-(M-1)/2}^{i=x+(M-1)/2} \sum\limits_{j=x-(M-1)/2}^{j=x+(M-1)/2} f(x,y) \end{cases} \tag{10}$$

Where $f(x, y)$ is the normalized value of the absolute value of wavelet coefficient. $M \times N$ represents the size of fuzzy template, usually $M = N$. In order to deal with the noise and overshoot phenomenon which is brought about by this method, this thesis put forward the nonlinear unsharp masking method based on region segmentation. The specific steps of nonlinear unsharp masking algorithm based on region segmentation are as follows,

$$K(x,y) = \frac{f(x,y)^{\alpha}}{f(x,y)^{\alpha} + (1 - f(x,y))^{\alpha}}. \tag{11}$$

The nonlinear unsharp masking method adopts sharpening function as function (11). Here α is a random real number which controls the form of $K(x,y)$, for the objective of Edge sharpening, the parameter $\alpha > 1$.

1. Use local variance to segment the wavelet coefficients;
2. The absolute values of the three high frequency components in the second layer of the wavelet decomposition are normalized, and use function (11) to sharpen the medium contrast region;
3. Use simple enhancement to strengthen high contrast regions;
4. Reconstruct the strengthened wavelet coefficients.

3.2. **The processing of the low frequency coefficients of the luminance component of image.** After the wavelet decomposition, most of the energy gathers in the low frequency part. The thesis enhances the contrast according to frequency coefficients in the second layer of wavelet transformation in order to improve the contrast of overall image. The common method to enhance the contrast is to use nonlinear function to map the wavelet coefficient as (12)-(14), among them, ε is input coefficient, $g(x,y)$ is transformed coefficient, L is gain constant to strengthen the power of signals, M is the maximum modulus of wavelet coefficients in the value, normalized to the coefficients for processing.

$$g(x,y) = Hf(x,y) = L \times M \times K[\frac{\varepsilon}{M}]. \tag{12}$$

$$K(x) = \frac{sig(c(x-b)) - sig(-c(x+b))}{sig(c(1-b)) - sig(-c(1+b))}. \tag{13}$$

$$sig(x) = \frac{1}{1+e^{x}}. \tag{14}$$

b is the critical point parameters to control the enhancement curve, and its role is to ensure that the contrast between most coefficients can be enhanced; c is the parameter to control the curve shape of the function.

$$b = \frac{1}{m \times n \times M} \sum_{x=1}^{m} \sum_{y=1}^{n} |f(x,y)|. \tag{15}$$

The whole process of processing luminance component is shown in figure 2. From figure 2, we can know that the methods to deal with luminance component are divided into low frequency sub-band images (first class) and high frequency sub-band images (first class). In addition, the low frequency sub-band images has two level second: high frequency sub-band images (level second) and low frequency sub-band images (level second), which carries on nonlinear unsharp mask enhancement and nonlinear function enhancement respectively. Then the first level of image and second level image can be reconstructed with low frequency sub-band images (first class) and high frequency sub-band images (first class) severally. Therefore, processing of luminance component is finished.

Algorithm steps are as follows:

1. Read-in true color image;
2. Transform the true color image from RGB space into HSV space;
3. Enhance the true color brightness channel by Figure 2;
4. Saturation stays the same with blue, green and light red dominate; and adjust the image saturation by formula (15) if dark red dominates;

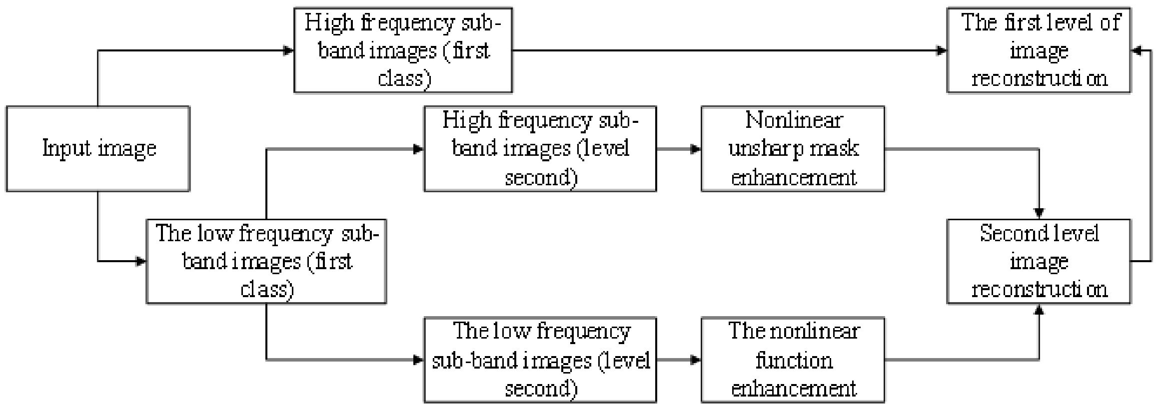

FIGURE 2. Flow chart of processing luminance component.

5. Enhanced true color image will transform from HSV space to RGB space.

4. Experimental results and analysis.

4.1. The processing of saturation component of image. In order to ensure the enhanced image color more clearly, we have carried out nonlinear index to adjust the saturation component, in order to expand the dynamic range of color change and to enhance the contrast. The mathematical model of exponential stretch is:

$$s = s^{\beta}. \tag{16}$$

In this model, β is the stretch factor which determines the saturation degree of saturation component.

4.2. Parameter definition. Mean square error (MSE) is the quality measuring parameter which is used over a great extent, and is the simplest one among all other metrics. It is found by taking the average of the squared differences of the intensities of the original and estimated image. For an image of size $M \times N$ the mean square error (MSE) is defined as.

$$MSE = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f(x,y) - f'(x,y))^2. \tag{17}$$

Root mean square error (RMSE) is the other quality examining metric of the image. It is obtained by taking square root over mean square error (MSE).

$$RMSE = \sqrt{\frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} (f(x,y) - f'(x,y))^2}. \tag{18}$$

Peak signal to noise ratio (PSNR) is widely used in quality metric. It is measured in logarithmic scale in decibels (dB). By calculating the ratio of maximum signal power to the maximum noise power we can find the PSNR value of the corresponding image. If PSNR value of the image increases, the quality of the image also increases gradually

$$PSNR = 10log_{10}(\frac{255^2}{MSE}). \tag{19}$$

4.3. **Comparison experiments.** In order to avoid overshoot phenomenon, we take the value range of K_h as $[0.12, 0.2]$. Meanwhile, $\pi \in [0.8, +\infty]$, the parameters that this paper selects are: $a = 3$, $K_h = 0.15$ and $L = 6.2$, $b = 0.1$, $c = 3$, $\beta = 1.5$. It processes the luminance component and saturation component of the color image respectively in order to enhance the contrast and saturation. We select three images named A, B, C to conduct experiments. And we adopt state-of-the-art methods WTFA[13] and FWT algorithm[14] to compare with our new method. Figure 2 is the algorithm in the thesis and the effect drawing of FWT algorithm and histogram equalization method for image A. It turns out that though the brightness is improved in the WTFA method, the natural phenomenon in noise and color is very obvious, while the overall improvement of not obvious saturation component is not used in FWT algorithm. In the thesis, the details in the algorithm have been well improved, the noise has been suppressed, and the saturation component has also been processed with index, so the color image is clear and vivid, and the effect of enhancement is achieved. Similarly, the results are as figure4,5 for image B,C.

FIGURE 3. Different results of processing image A: WTFA method, FWT algorithm and New algorithm.

FIGURE 4. Different results of processing image B: WTFA method, FWT algorithm and New algorithm.

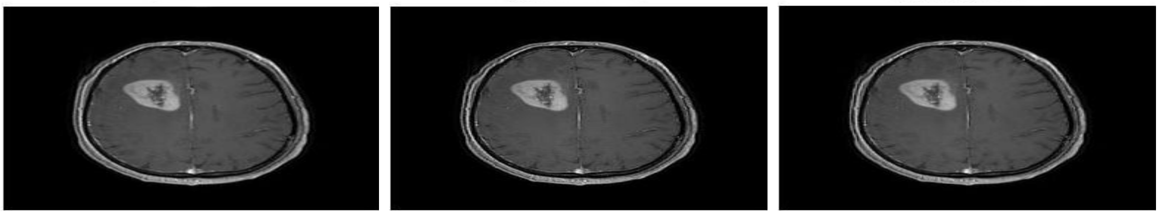

FIGURE 5. Different results of processing image C: WTFA method, FWT algorithm and New algorithm.

Table1 shows that PSNR of new method can reach to 45.24dB, 46.38dB and 45.94dB respectively for image A,B,C. The results are better than WTFA method and FWT method. In addition, visual effect of our method is very well.

TABLE 1. Comparison of MSE, RMSE, PSNR with the three methods.

Image	Criteria	WTFA method	FWT algorithm	Our new method
Image A	MSE	21.623	14.288	6.452
Image A	RMSE	4.65	3.78	2.54
Image A	PSNR	32.84dB	39.64dB	45.24dB
Image B	MSE	15.841	20.885	7.728
Image B	RMSE	3.98	4.57	2.78
Image B	PSNR	35.22dB	40.95dB	46.38dB
Image C	MSE	32.718	21.716	11.696
Image C	RMSE	5.72	4.66	3.42
Image C	PSNR	41.28dB	39.67dB	45.94dB

5. **Conclusions.** Because color image includes more visual information, it is more and more widely used, especially for the emerging technology of LCD display, color image processing is very important to improve the color expressive force. In this thesis, the color image is changed from RGB space to HSV space, then it decomposes the wavelet of the brightness component of color image; it uses human visual characteristics to enhance the images according to the different characteristics of high frequency and low frequency respectively; and the saturation component of color image is exponentially stretched to make colors more vivid, which gets good results. In the future, we will study more advanced wavelet transform adjustment methods based on this paper's method and apply them into practical engineering applications.

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