An image fusion method based on wavelet transform

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Abstract. In some researches of image fusion, the wavelet transform (WT) often contribute more useful information. The objective of image fusion is to combine relevant information from two or more images of same scene into a single composite image, which is more informative. In this paper, an image fusion method based on wavelet transform (WT) is proposed. The different decomposition levels for image fusion based on WT are compared, by means of designing simulation experiments which can help us to find the most effective weighted factor of image fusion. The performance of the proposed method has been extensively tested, and simulation results show that the effectiveness of the fused image based on WT when the number of levels is available.

Keywords: image fusion; wavelet transform; multi-resolution analysis; evaluation of fusion.

1 Introduction

Image fusion techniques are extensively used in numerous applications, such as remote sensing, target detection, night vision, and medical imaging [1], [2], and different image fusion algorithms have been developed [3]-[5]. The purpose of image fusion is to integrate information from multiple input images to create a fused one which is more informative as compared to any of the input images, combining different images at different times to create a new image that will be more accurate and comprehensive[6]. Currently, image fusion technology has been widely used in digital imaging, such as remote sensing, multi-exposure multi-focus image integration, biomedical image, etc.[7], [8].

Compared with other multi-scale transforms, wavelet transform (WT) is more compact, which able to provide directional information, and contains unique information at different resolutions. So this paper mainly introduces the image fusion with WT, for successful tool for dealing with image signals. The WT is suitable for processing the non-steady signals and analyzing signals in time domain and frequency domain[9]. If the energy of signal is non-best accumulation in the frequency domain, WT analysis is not optimal. We research the meaning of image fusion is to overcome the limitations of single image. The possible of the defects in a single image effect judgment, which can make up for these shortcomings after fusion, needed to make the image information more intuitive [10]. Make the multi-source images at the same time.

Wavelet decomposition of the image is divided into two parts, including low frequency and high frequency. The approach can help us to find the most effective in the process of image fusion weighted factor, then to reconstruct complete process of wavelet coefficients, the experimental results for fusion image. One of the characteristics of WT fusion is flexible, because many factors influencing the image fusion, then introduce the more important points. There are two problems need to pay

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attention of wavelet decomposition of image fusion. The first is choice of wavelet basis function. The second is best level of wavelet decomposition. Ensure both are perfect fit, so the effect of image fusion is to achieve more perfect.

Different wavelet decompositions and reconstructions of the special features are different. The wavelet basis does not exist which is better than the other wavelet set when dealing with a particular image. The first of choose the most appropriate wavelet base is the series of church and state. The second category is Biro bi-orthogonal series. Wavelet base is one of the factors influencing fusion effect, because the choice of wavelet base in a certain extent, affecting the wavelet coefficients. If need the higher wavelet function, we can set the more number of the filter for WT. Filter can increase its ability to concentrate, with high local frequency characteristics. Under the same conditions of wavelet filter length, disappear moment will cause uneven distribution of wavelet coefficient fusion.

2 Image fusion based on WT

For each of the original image WT, respectively have its corresponding wavelet, and then construct wavelet image fusion according to the specific rules, again the complete fusion image is obtained by inverse transform. The basic process is as follows: A, B are two source images. F is fusion image. Step one is source image wavelet decomposition; Step two is set image information in different scales and do not move on image fusion at the same time in the wavelet domain decomposition of the sub image. began to fusion in accordance with the fusion rules and find out the wavelet coefficients; Step three is reconstruct wavelet inverse transformation for fusion image.

WT is the basic operation of the premise at different scales, then the items inner product for the before and after. Referred to the preceding paragraph is after displacement calculation of wavelet function, the consequent is a signal to be analyzed. In 1984, the French physicist earth Morlet data generated by the deep research to the earthquake, and concluding after repeated analysis and further calculation function:

$$\{ |a|^{-1/2} \varphi(\frac{x-b}{a}) | a,b \in R, a \neq 0 \} \tag{1}$$

The translation is put forward for the scientists had a sobering effect, so that the concept of continuous WT is proposed. Signals in the WT decomposition in different Yu Fu leaf transform, the former are broken down into a series of superposition of wavelet function. The latter is decomposed into superposition of trigonometric function. Acquiring method of the wavelet function is very simple, as long as the wavelet scaling and translation operation is right. We extract the effective information using wavelet multi-scale analysis. Multi-scale analysis is one of the most commonly used computing function translation, scaling. WT can observe the window changes with the change of frequency, which embodies with Fourier transform the thought of localization. So the WT has good performance in processing the non-stationary signal. The birth of multi-resolution analysis thought has created fast WT algorithm [11].

So how to determine the wavelet is important. Must satisfy the conditions as follows:

$$C_{\varphi} = \int_{0}^{+\infty} \frac{\left| \hat{\varphi}(w) \right|^{2}}{w} dw < +\infty \tag{2}$$

Where the Fourier transforms of $\varphi(t)$ is $\hat{\varphi}(\omega)$, and $\varphi(t)$ is the wavelet.

Conditions are C_{φ} <+∞, When $w = 0$, $\varphi(0)$ must be 0:

$$\hat{\varphi}(0)=\int_{t\in R}\varphi(t)e^{-jwt}dt\Big|_{w=0}$$
$$=\int_{t\in R}\varphi(t)dt=0 \tag{3}$$

$\varphi(t)$ must be some volatility. Continuous wavelet function is scaling through the basic wavelet function, translation and other manipulations of gens function:

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi(\frac{t-b}{a})\ a,b\in R,a>0 \tag{4}$$

The continuous WT of f (t) can be represented as:

$$W_f(a,b)=\langle f,\varphi_{a,b}\rangle=\frac{1}{\sqrt{|a|}}\int_{-\infty}^{+\infty}f(t)\overline{\varphi(\frac{t-b}{a})}dt \tag{5}$$

$$f(t)=\frac{1}{C_\varphi}\int_{+\infty}^{-\infty}\int_{+\infty}^{-\infty}W_f(a,b)\varphi_{a,b}(t)\frac{dadb}{a^2}\ (a\neq 0,f(t)\in L^2(R)) \tag{6}$$

Wavelet function of expansion from essentially describes the scope of the observation signals in image processing, namely scale. WT is also called resolution signal multi-resolution analysis. Multi-resolution analysis is to construct nested linear function space sequence $\{V_j\}$, j represent different resolution, in the resolution of 2^{-j}, $L^2(R)$ approximation, the higher the resolution, the greater the degree of approximation.

$$A_j f(t)=f_{A_j}(t),f(t)\in L^2(R),f_{A_j}\in V_j,j\in Z \tag{7}$$

$$\|A_j f(t)-f(t)\|\leq\|g(t)-f(t)\|,\forall g(t)\in V_j \tag{8}$$

Decomposition level of WT can affect the change of two parameters. When the layers are less, the smoothness of the wavelet function, the computational also will become worse. So the more layers of decomposition, the effect are better. As decomposition layers more cases will be the most important factor, prompting the smoothness of wavelet function, improving the quality of image compression ratio and compression. But fusion effect will decline when number of layers exceeds a certain value. At the same time, the amount of calculation is increase, as the fusion of image wavelet decomposition level increases. The best choice of the wavelet decomposition level is set according to the number of the wavelet filter. We need to the number of decomposition layers and filters unify, if want to make the fusion effect is best.

The characteristics of wavelet image fusion main train: the human eye is sensitive to local changes in apparent contrast situation. According to the characteristics of the human eye, according to the regulations the step by step is good fusion rules of operation. The first step in the source image is to extract the edge of the image features and segment. Then put these characteristics after WT. Finally, it is saved in the fusion image. Actually, find the most suitable fusion rules before image fusion experiments, according to the different types and characteristics.

There five methods of weighted average as follows. The first one is the measured value of a variable according to the chronological order, and calculates the weighted value of draw in a time sequence method. This method can eliminate noise in image fusion. Ensure that the original image information loss is smaller, which application is very wide. The second is mean method. Average method of operation is very simple, and then do average arithmetic. The arithmetic is in two pixels of

the image wavelet coefficients on the corresponding position. Get the mean as the wavelet coefficients. The fused image is obtained by inverse transformation after it. The third is take coefficient absolute value a solution. Apply to the original image must have the following characteristics to get the ideal fusion effect. Image fusion for the image may be a picture of the characteristics of the source image coverage, couldn't reflect the fusion effect. The larger wavelet coefficient of concentration the more energy, the greater the energy reconstruction images the better the results. The fourth is local variance rule. Singular value decomposition for local variance distribution matrix and the standard of the singular values of image feature vector matrix image size can be contained by the local variance of angle measuring. The structural similarity of images and the determination of image quality assessment are determined by the angle. The fifth is high frequency noise elimination method. Basic principle is to reconstitution again after high frequency component of the median filtering.

3 Evaluation and simulation results

A: Evaluation method

1. The subjective evaluation method, also known as the visual evaluation method. In simple terms are scientific research personnel directly to observation of the fused images, from the color, brightness, registration. This approach can change obviously before and after the fusion image. If the fusion image effect is not obvious, which cannot make accurate, we must judge objectively.

2. The objective evaluation method with the widely application of the image processing technology in computer and rapid development. The computer can be analysis of objective evaluation on the effect of image fusion, which according to certain index.

Computer discriminated image fusion indicators include the following:

(1) Information entropy

Image pixel is $M \times N$, the total for the image grayscale is L, image information entropy is defined as:

$$EN = -\sum_{i=0}^{L-1} p_i \, log \, p_i \tag{9}$$

$$p_i = \frac{N_i}{M \times N}, p = \{p_0, p_1, ..., p_{l-1}\} \tag{10}$$

Mainly reflects the image pixel contains different gray values of probability distribution. Information entropy can help us for the tremendous amount of image information. The relationship between the two is direct ratio, and the greater the amount of information fusion can ensure that the higher the quality.

(2)Mean image

The mean is the average of the image gray scale image, which is defined as:

$$\mu = \frac{\sum_{i=1}^{M} \sum_{j=1}^{N} I(i,j)}{M \times N} \tag{11}$$

If the mean for the human visual system is appropriate, then the image effect for human eye see is the best.

(3) Standard deviation

The second-order, third-order and fourth-order cumulates of zero-mean $x(n)$ are

$$\sigma = \sqrt{\frac{\sum_{i=1}^{M} \sum_{j=1}^{N} (I(i,j) - \mu)^2}{M \times N}} \tag{12}$$

Standard deviation is used to evaluate the size of the image contrast. The greater the standard deviation is the bigger, on behalf of the grayscale distribution is more dispersed, contains the amount of information.

(4) Root mean square error

$$RMSE = \sqrt{\frac{\sum_{i=1}^{M}\sum_{j=1}^{N}\left[R(i,j)-F(i,j)\right]^2}{M \times N}} \tag{13}$$

$R(i,j), F(i,j)$ are two images in (i,j) corresponding pixels. Judge the difference between source images and fusion image. Root mean square is error criterion. If we want to two image information content close to the same, then reduce root mean square error values.

(5) Signal-to-noise ratio (SNR)

$$SNR = 10\,log\frac{\sum_{i-1}^{M}\sum_{j-1}^{N}\left[F(I,J)\right]^2}{\sum_{i-1}^{M}\sum_{j-1}^{N}\left[R(i,j)-F(i,j)\right]^2} \tag{14}$$

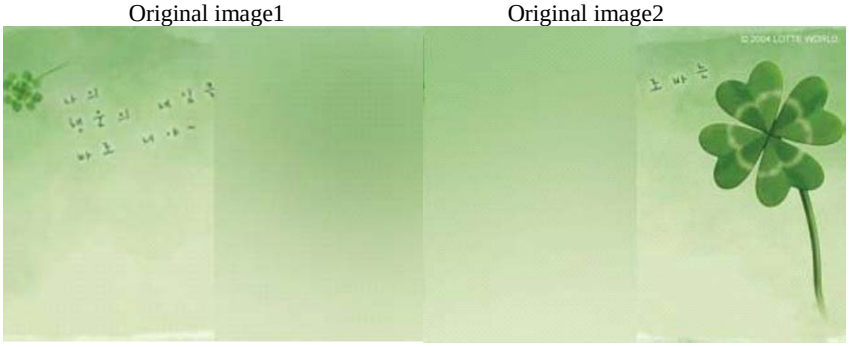
$R(i,j)$ isthe original image, $F(i,j)$ is the fused images.

To sum up, the image of the subjective evaluation and objective evaluations for judging from different angles and supplement each other, to ensure the comprehensive quality of image fusion after completed.

B:Simulation results

The two source images used in the experiment is on the left side of the very fuzzy, on the right side is clear. The source image two focuses is the reverse of the source Figure 1. First, layer of the WTfor the source image, then the low frequency selection of wavelet coefficients using the weighted average principle. Use absolute value for the selection of high frequency wavelet coefficients. From the results of observation, we successfully achieved the expected result. Fused image contains information of original Figure1(a) and Figure 1(b),the image quality is higher than the original image quality of the image, which fully reflects the significance of fusion.

Original image1 Original image2



(a) (b)

Figure 1. Original image. (a) Original image 1. (b) Original image 2.

Set several parameters, such as number wavelet decomposition layers and the number of channels of color image for of fused image. Color images into YIQ space first, to all color components of the image wavelet decomposition, and then selection in WT domain coefficient according to certain strategy, finally inverse discrete WT and YIQ inverse transform for quick result image. To convert color image from RGB to YIQ color space, we put the luminance and chrominance information of color image separately and independently.

Fusion image Fusion image

(a) (b)

Figure 2. Fusion image. (a) Fusion image for wavelet decomposition layers levels is10. (b) Fusion image for wavelet decomposition layers levels is1020.

Simulation with set the number of images is two, wavelet decomposition layers levels is 10 as Figure 2 (a), the number of channels color images to three. From simulation results, the quality of the fused images can be seen clearly higher than that of either the source image, which the effect is obvious, intuitive and clear. In Figure 2 (b), change the layer number of wavelet decomposition to levels is 1020, image fusion can still effect is better, but the speed of convergence can be slow.

Change the layer number of wavelet decomposition to 1030, merge the fusion image will display normal, but the fusion image is as follows, all is black as the Figure 3.To sum up, the choice of wavelet decomposition layers is important, not the more decomposition layers the better effect of image fusion.

Fusion image Fusion image

(a) (b)

Figure 3. Fusion image. (a) Fusion image for wavelet decomposition layers levels is1030. (b) Fusion image for wavelet decomposition layers levels is1050.

4 Conclusions

An image fusion method based on WT is described. The performance is measured on the basis of qualitative criteria. According to the results of fusion, the gradient of image is improved by using the different wavelet decomposition levels. As a result, the quality of fused images using the different set. Therefore, the image fusion method based on WT can be widely used in image fusion area to improve the quality of image effectively.

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